SUSTAINABLE VISION ACADEMIC JOURNAL

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Building Vision, Realizing Change

JOURNEY THROUGH THE JACQUELYN SANDERS FOUNDATION FELLOWSHIPS OF 2024

THE "ENGAGED SCHOLARSHIP" ACADEMIC COOPERATION MODEL PROFILED AND CRITIQUED

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Cover Photo Credit : Rice Research underway at the University of Antananarivo - Photographer: Finarch (Fellow)

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LETTER FROM THE **EDITOR**

"harnessing the potential of our most valuable resource: our next generation"

Dear Readers,

It is with great pride and excitement that we present to you the inaugural issue of the Sustainable Vision Academic Journal. This journal is more than just a collection of research papers; it is a testament to our commitment to fostering academic excellence and empowering the young minds of graduate students in developing nations.

At the Jacquelyn Jestine Sanders Foundation, we firmly believe that the key to addressing the myriad challenges faced by developing countries lies in harnessing the potential of their most valuable resource: the next generation. Graduate students, with their fresh perspectives, innovative ideas, and unbridled enthusiasm, are uniquely positioned to spearhead research that can lead to transformative solutions. Our mission is to support these bright minds by providing the resources, guidance, and platforms they need to succeed.

This journal is one of the many tools we are developing to advance our mission. Through the publication of high-quality, peer-reviewed research, we aim to facilitate the exchange of knowledge, promote interdisciplinary collaboration, and inspire a new generation of scholars and practitioners dedicated to making a positive impact on their communities and beyond.

In this inaugural issue, you will find a diverse array of articles that address critical issues ranging from sustainable development to off-grid technology. Each paper has been meticulously selected for its relevance, rigor, and potential to contribute meaningfully to developing nations in need of solutions. We are immensely proud of the work presented here and confident that it will spark valuable discussions, inspire further research, and ultimately contribute to the development of innovative solutions.

We extend our heartfelt gratitude to the authors, reviewers, and editorial board members who have worked tirelessly to bring this journal to life. Their dedication and expertise are the foundation upon which this publication stands. We also thank our readers for their interest and support. It is your engagement that drives us to continue striving for excellence.

As we embark on this new journey, we invite you to join us in our mission. Together, we can empower the next generation of scholars, tackle the challenges faced by developing nations, and build a brighter future for all.

Sincerely,

With gratitude and determination,
Ken Coman
Sustainable Vision Journal
JJSF

JACQUELYN JESTINE SANDERS FOUNDATION
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Foreword

Welcome to the 2024 edition of the **Jacquelyn Jestine Sanders Foundation Sustainable Vision Academic Journal**. This year's publication narrates the innovative concept the Foundation has been rigorously testing: engaging university students with real-world problems to illustrate their capability in addressing today's pressing challenges, especially when encouraged and supported.

In 2024, the Foundation partnered with the University of Antananarivo in Madagascar to tackle a critical issue: the chronic water infrastructure problems plaguing the university. The 35,000 students studying and residing there have long suffered from severe water shortages, leading to frequent demonstrations, some of which have escalated into fires and property destruction. This year saw a particularly poignant incident where frustrated students damaged empty water storage containers, highlighting the urgency for a sustainable and economical solution.

Recognizing the potential of young minds, the Foundation embarked on an ambitious project. We assembled 15 graduate student fellows from three local universities, granting them fellowships to analyze and address the water crisis with the hope of developing actionable plans that could attract NGO or government funding for implementation in the near future. These fellows, supported by external research from international correspondents across five countries, diligently explored technical and strategic solutions over the first six months of 2024.

Graduate Student Fellows from the University of Antananarivo

A significant achievement of this initiative has been the quarterly publication of the "Sustainable Vision Journal," a crucial communication tool for our fellowship participants. Through this journal, we share insights, progress, and learnings from the project, fostering a collaborative environment that bridges academic research and practical application.

The goals of the Foundation are multifaceted. We aim to demonstrate to global university communities that involving students in essential infrastructure planning is a powerful way to transition them from academia to impactful careers. The pride and sense of responsibility the fellows experience in contributing to national solutions are invaluable. Moreover, we believe that presenting these real-world problems to students and inviting their ideas can lead to innovative and viable solutions.

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For inquiries or to share feedback please write to: info@jacquelynsandersfoundation.org

Our vision extends beyond Madagascar. We aspire to see this program replicated in universities worldwide, promoting good practice without seeking ownership. Our initiatives in 2024 included also reforestation collaboration with schools in Kenya, involving younger students in planting and cloning trees. This is another testament to the Foundation's commitment to sustainable development and youth empowerment.

This journal profiles the experiences and outcomes of the 2024 Research Fellowships, serving as an invitation for other universities to follow and enhance this project model. We believe in the transformative power of student engagement and are excited to share our journey and insights with the global academic community.

Overview of the 2024 Academic Compilation

This year's Sustainable Vision Academic Journal weaves together a compelling narrative of research, innovation, and collaboration, all aimed at addressing the urgent water challenges at the University of Antananarivo. Rooted in the engaged scholarship model championed by the Jacquelyn Sanders Foundation, the compilation reflects the tireless efforts of Graduate Fellows from leading Malagasy universities, supported by international expertise.

The University of Antananarivo

The journal begins with **Fellowship-Led Research** in Antananarivo, where Graduate Fellows explore the chronic water shortages faced by the university. Each research document is introduced with reflective commentary, connecting the findings to a larger academic framework and underscoring the relevance of sustainable water solutions tailored to local needs.

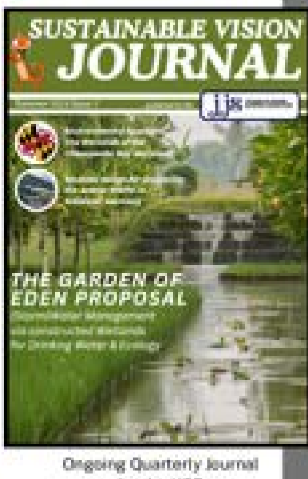
Following this, the journal delves into a **Comparative Analysis of Water Solutions in Africa**, providing an academic examination of similar initiatives across the continent. This section asks critical questions: How have wetlands, agroforestry, and permaculture systems succeeded in other regions of Africa? How might these solutions be adapted for Madagascar? The analysis underscores the potential for scalable, nature-based solutions.

Architectural Rendering
for planning pruposes

A pivotal section highlights **Supporting Research Documents** Sponsored by the Foundation, offering commissioned studies that emphasize the efficacy of natural solutions. These documents reinforce the argument for using wetlands and agroforestry systems as key components of water management in Antananarivo, presenting evidence from successful case studies worldwide.

Prototyping and Engineering Insights from Germany showcase hands-on experimentation with the proposed solution. Detailed accounts of the prototype construction process, including the challenges of selecting natural versus synthetic liners, offer valuable engineering insights. These practical findings serve as a blueprint for scaling the solution in Madagascar, providing crucial guidance for future implementation.

Throughout the introductory pages of each research report, **Reflections and Recommendations for Future Phases are woven in**, offering ongoing insights into the successes and challenges encountered. These reflections provide a roadmap for refining and replicating the program, ensuring that future efforts build on the lessons learned.



Ongoing Quarterly Journal
by the JJSF

The journal also features **several key appendices**, including:

- A Reprint of ARAFA's 2021 Work, which laid the groundwork for the current research.
- Initial Quality Testing of the Prototype Filter, offering early data on its efficacy.
- A Compelling **Letter of Intent from the University of Antananarivo** President, expressing the institution's commitment to implementing the Garden of Eden Model on campus.

Together, these sections tell a powerful story—not only of academic research and practical innovation—but of hope and commitment to building better infrastructure where it is most needed. The work presented in this volume is both a testament to the progress achieved and a beacon for future sustainable development.

JJSF SUSTAINABLE VISION

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Editorial notes on Mr. Finarch's Research of Intercropping with Rice / Rice Permaculture

Mr. Finarch undertook an essential study on the practicality of intercropping with rice, a topic that holds significant relevance for the water management challenges faced by the University of Antananarivo. Rice agriculture is notoriously water-intensive, and with the university dedicating approximately 10 to 15 acres to rice cultivation, understanding and optimizing water use is critical. Notably, this year, the university is also conducting research to test new rice strains from Japan, indicating its deep investment in this staple crop.

Madagascar, as a whole, is heavily reliant on rice agriculture, but this practice consumes an inordinate amount of water. The fellowship team found that all stormwater on the university grounds flows into the rice fields, where it either infiltrates the groundwater or exits the site entirely. This practice reflects the cultural norms in Madagascar, where the rainy season brings deluges of water that often lead to flooding and a desperate need for channels to carry the excess water away. In many instances, this water is directed to central areas used for rice production.

For the University of Antananarivo, which struggles with severe water shortages for much of the year, this traditional approach to water management is problematic. The fellowship team closely examined the potential for revising how water is managed in relation to the rice fields to maximize the use of available water. Mr. Finarch was specifically tasked with evaluating methods to reduce evaporation losses. This investigation led to the consideration of intercropping as a strategy to improve water management and potentially enhance agricultural outcomes economically.

Intercropping, along with related practices such as rice permaculture and agroforestry, emerged as promising areas for further research. Mr. Finarch's study underscores the connection between rice agriculture and permaculture at the university, linking the issue of water management to broader concerns of rain retention and water storage. By integrating these practices, the university could not only address its water shortages but also improve the sustainability and productivity of its rice agriculture.

The overarching need for improved water use at a national level in Madagascar, especially concerning rice agriculture, cannot be overstated. While rice remains a staple of the diet, there are growing opportunities to enhance its cultivation through better water management practices. The experience in Asia, where intercropping of rice has proven productive on many levels, provides a compelling model. Although rice permaculture has yet to gain widespread traction in Africa, its potential benefits suggest that its time has come. Adopting such innovative agricultural techniques could help Madagascar achieve better yields and more efficient water use, ensuring the long-term sustainability of both its agriculture and water resources.

The following article by Mr. Finarch delves deeper into these topics, exploring the relationship between rice agriculture and water management at the University of Antananarivo. His research offers valuable insights into how intercropping and other sustainable practices can be employed to enhance water use efficiency and support the university's agricultural and environmental goals.

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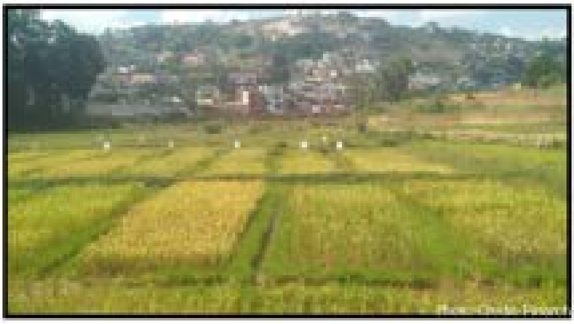

JJSF Fellow
FINARCH, Rafatro Tsiambanavalona
Graduate, Petroleum Engineering
Polytechnique D'Antananarivo
Written: May 2024

Abstract

The University of Antananarivo, initially known as the University of Madagascar, was established in 1961 in the Ankatso district, approximately 2 km from the city. This campus houses various plots of land that serve as experimental fields for students in tropical agriculture and sustainable development at Ecole Supérieure des Sciences Agronomiques (ESSA). Currently, these students are focusing on implementing innovative techniques such as PAPRiz and P-Dipping, originating from the Fy Vary project, funded by the Japanese government. These techniques are implemented in collaboration with the Ministry of Agriculture and Livestock.

In addition to educational activities, the surrounding agricultural lands are also utilized by local farmers. These lands are irrigated from two main sources: the region's groundwater reserves and runoff water, particularly during the summer season. Specially designed channels channel runoff water to the rice fields, significantly contributing to crop irrigation.

The surroundings also include ponds for aquaculture, green leaves and cassava fields. The layout and organization of all these agricultural areas are clearly depicted in a series of provided photos, providing a better understanding of the structure and management of farmland near the university.

Introduction

The University of Antananarivo stands at the forefront of agricultural innovation and sustainability in Madagascar. Beyond its academic pursuits, the university's campus serves as a dynamic hub where theory meets practice, particularly in the realm of agricultural cultivation. The integration of surrounding agricultural lands into its educational framework not only provides students with invaluable hands-on experience but also fosters collaboration with local farmers and government agencies. In this introduction, we delve into the rich tapestry of agricultural activities occurring within and around the university, exploring how these endeavors contribute to both academic excellence and community development.

I. Study Area

The University of Antananarivo was founded in 1961, originally known as the University of Madagascar. It is located approximately 2 km from the city, in a district called Ankatso. (RAZAFIMAHATRATRA, ANDRIANTSIFERANA, 2024) This is where there are plots of land divided into two sections: one is just south of the Higher School of Agronomic Sciences, and the other is near the Ankatso football field. If you want to see how to get there, take a look at Figure 1; it shows the map and the path to access these study areas.

I.1 Cultivation plot near Ecole Supérieure des Sciences Agronomiques

I.1.1 Existing studies

In the plots of land near the Ecole Supérieure des Sciences Agronomiques (ESSA), students specializing in Tropical Agriculture and Sustainable Development are engaged in experiments. They are currently testing a combination of techniques called PAPRiz and P-Dipping, derived from the Fy Vary project. This project, funded by the Japanese government through international cooperation agencies, is implemented in collaboration with the Ministry of Agriculture and Livestock. Students thus have the opportunity to put these techniques into practice on five varieties of rice, including FOFIFA 160, X265, and the new Fy Vary 32 and 85 varieties. (Navalona, 2024) Figure 2 illustrates the rice fields of these rice varieties.

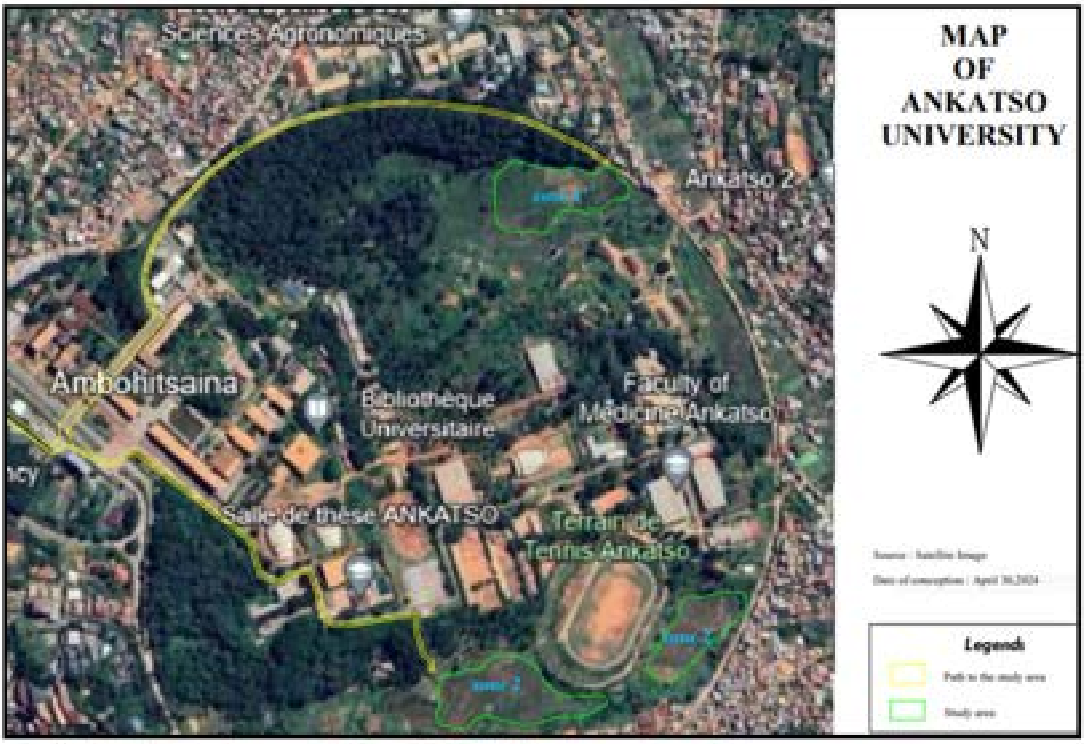

Figure 1: Map of the University of Antananarivo / Compiled Credit: FINARCH - assistance from Google Earth

Figure 2: Research Rice Laboratory Field at ESSA
Photo Credit: FINARCH, Rafatro Tsiambanavalona

I.1.2 Crop Plot near ESSA

The other rice fields and vegetable cultivation fields are operated by local farmers. All these fields are irrigated using groundwater reserves from the region. It only requires digging about a meter to access these reserves, as the ground level is quite low. An example of this type of digging can be seen in Figure 3, carried out by one of the farmers.

Figure 3: Readily available Water in the Rice Fields.
Photo Credit: FINARCH

During the summer, runoff water plays a significant role in irrigating the rice fields. Two canals have been specially constructed for this purpose. Rainwater, transformed into runoff water, is drained to a large area, from where it is directed into these two canals. You can see these canals in Figure 4.

Figure 4: Stormwater Runoff being routed to the Rice Fields (Zone 1)
Photo Credit: FINARCH

To the east of the rice fields, there are some ponds (see Figure 5) where other farmers practice aquaculture. Additionally, there are cassava fields next to the rice fields, which you can see in Figure 6.

Figure 5: Existing Lagoons in the Rice Fields
Photo Credit: FINARCH

Figure 6: Casava Production near the Rice Fields
Photo Credit: FINARCH

"Zone 1 - The Crop Plots near ESSA"

Absolutely, let's take a look at the plan in Figure 7 to get an overview of all the mentioned crops so far. This will help us better understand the layout of the area.

Figure 7: Zone 1 - Plan of cultivated plot near ESSA
Compiled Credit: FINARCH - assistance from Google Earth

I.2 Agricultural lands near the Ankatso football field (Zone 2)

There are two areas of agricultural land located southwest and east of the Ankatso football field. You can spot them in Figure 8.

Figure 8: Zone 2 - Cultivated plots near the Ankatso football field
Compiled Credit: FINARCH - assistance from Google Earth

I.3 Depth to Water in Zone 2

The cultivation plots to the southwest (Zone 2) are irrigated solely from water points to maintain the irrigation system in place. An example of these shallow water source is illustrated in Figure 9.

Figure 9: Zone 2 depth to water
Photo Credit: FINARCH

I.4 Zone 2B Stormwater Drainage into the Rice Field

On the other hand, the cultivation plots to the east of the field are supplied both by runoff water and water points. Stormwater Runoff water is drained through large underground drainpipes, which you can observe in Figure 10.

Figure 10: Stormwater drainage channel releasing into Zone 2
Photo Credit: FINARCH

Figure 12: Surface Water in Zone 1
Photo Credit: FINARCH,

II.1 Further Photodocumentary of the Lagoon Zone 1

The following photos provide further insight into the defined Rice Lagoon Zones.

Figure 11: Formal Rice Research in Zone 1 (Note the Field Markers)
Photo Credit: FINARCH

Figure 13: Zone 1 - Long Shot
Photo Credit: FINARCH

Figure 14: Zone 1 "Very Wet Farming"
Photo Credit: FINARCH

Figure 15: Zone 1 - A lone tree at the edge of the Wetland
Photo Credit: FINARCH

Figure 16: Constructed Water Channels in Zone 1
Photo Credit: FINARCH

II.2 Further Photodocumentary of Lagoon Zone 2 (near the Ankatso football field)

Figure 17: Tropical Wetlands of Zone 2
Photo Credit: FINARCH

Figure 18: Acres of Tropical Wetlands in the middle of the Capitol City's University
Photo Credit: FINARCH

Figure 19: Zone 2 - Wet, productive farmland with extensive, visible surface water
Photo Credit: FINARCH

Figure 20: Zone 2 - Surface water lagoons
Photo Credit: FINARCH

Figure 21: Zone 2 - Acres of surface water lagoons
Photo Credit: FINARCH

Figure 22: Zone 2 - Acres of surface water lagoons
Photo Credit: FINARCH

Figure 23: Zone 2 - Acres of surface water lagoons
Photo Credit: FINARCH

Figure 24: Zone 2 - Acres of surface water lagoons
Photo Credit: FINARCH

Figure 25: Zone 2 - Acres of surface water lagoons
Photo Credit: FINARCH

Figure 26: Zone 2 - Acres of surface water lagoons
Photo Credit: FINARCH

Figure 27: Zone 2 - Acres of surface water lagoons
Photo Credit: FINARCH

III. CONCLUSION

In conclusion, the University of Antananarivo emerges as a true living laboratory for tropical agriculture and sustainable development. By incorporating the surrounding agricultural lands into its campus and utilizing them as experimental grounds for agriculture students, it fosters hands-on and practical learning. Furthermore, collaboration with local farmers for crop maintenance and irrigation demonstrates a commitment to the local community and an integrated approach to agricultural development. The implementation of innovative techniques such as PAPRiz and P-Dipping, supported by government partnerships and research projects, strengthens the university's role as a driver of progress in the agricultural field. Lastly, the visual representation of the layout and management of agricultural lands provides enhanced transparency and understanding of these practices, paving the way for continued collaboration and future initiatives towards more sustainable and resilient agriculture.

IV. BIBLIOGRAPHY:

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Funding of the Academic Research

This Research Article was funded by the Jacquelyn Sanders Foundation as part of our efforts to assess the Water Management needs of the University of Antananarivo. The report highlights a valuable Asset which is available as part of the University landscape.

Sme editing of text, Figure numbers, and such has been done as part of preparation for publishing. Nevertheless, The findings of the Graduate Researcher remain independent.

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Concept Overview

The Jacquelyn Jestine Sanders Foundation is proud to introduce the concept of "Engaged Scholarship for Sustainable Solutions." This innovative approach seeks to transform higher education by integrating real-world problem-solving into academic curricula. The core idea is to leverage the intellectual potential of [university] students to address pressing local and global challenges, thus bridging the gap between theoretical study and practical application.

The Need for Engaged Scholarship

In traditional educational models, students often spend a significant amount of time studying theory without directly applying their knowledge to real-world issues. While theoretical understanding is crucial, the Foundation asserts that the most effective way to train the next generation is through hands-on engagement with actual problems. By working alongside students to solve local issues, we can cultivate a new breed of professionals who are not only academically proficient but also practically experienced and socially responsible.

The 2024 Initiative: University of Antananarivo

In 2024, the Foundation partnered with the University of Antananarivo in Madagascar to tackle the severe water infrastructure problems affecting the university. The chronic water shortages have led to frequent student demonstrations, highlighting the urgent need for a sustainable solution. Through the Engaged Scholarship model, 15 graduate student fellows from three local universities were selected to analyze and address these challenges. Their work included site evaluations, photovoltaic solution designs, and proposals for utilizing wetlands and rice permaculture as sustainable water management strategies.

Global Applicability and Invitation for Collaboration

The success of this initiative at the University of Antananarivo underscores the potential of Engaged Scholarship to be replicated and adapted by forward-thinking universities anywhere in the world. Whether addressing water management, food security, shelter, student health, or community development, this engaged scholarship model can be tailored to meet diverse engineering and societal needs.

Call to Action

The Jacquelyn Sanders Foundation actively invites responses to the articles within this journal. We believe that the concept of Engaged Scholarship needs to be considered, retested, refined, and improved through collaborative efforts. By sharing our experiences and insights, we hope to inspire other academic institutions to adopt and enhance this model, thereby fostering a global movement towards education that is deeply intertwined with real-world problem-solving.

Conclusion

The birth of Engaged Scholarship for Sustainable Solutions marks a significant step towards revolutionizing education. By engaging students in addressing critical challenges, we not only enhance their learning experience but also contribute to the betterment of our communities and the world at large. The Foundation is committed to advancing this model and looks forward to collaborating with universities and stakeholders globally to refine and expand this transformative approach.

Building Vision through Real-World Problem Solving with Students

In the Engaged Scholarship for Sustainable Solutions model, the publication of student research is a vital component. Under normal academic circumstances, it is crucial that the research conducted by students undergoes thorough peer review. This process ensures that the findings are robust, credible, and provide a solid foundation for subsequent research. We fully support the concept of peer review as it enhances the quality and reliability of academic work. However, the implementation of a rigorous peer review process comes with significant challenges, particularly in managing the associated costs.

Peer review is one of the most resource-intensive components of any academic program. It involves the time and expertise of qualified reviewers who critically evaluate, critique, and suggest improvements to the research documents. Given our commitment to maintaining a manageable budget for the program, we are faced with the dilemma of how to effectively execute peer review without compromising the quality of the students' work or the financial sustainability of the project.

To address this challenge, we propose an innovative approach: the book you hold in your hands serves as an open invitation for peer review. We are calling upon the global academic community to participate in the peer review process for the benefit of our student writers. Professors and researchers with relevant expertise in fields such as water management, filtration, biological filtration, photovoltaic design, hydrology, permaculture, agroforestry, and wetlands management are particularly encouraged to provide their feedback.

We welcome academic commentary and formal grading of the individual research documents included in this publication. This collaborative effort will not only enhance the quality of the current research but also assist the student writers in refining their reports. Our goal is to release a second edition of this book in 2025, which will include thoroughly peer-reviewed and revised reports.

For now, we acknowledge that much of the writing in this first edition is raw and could benefit from significant improvements. This is a natural part of the process, as you are gaining insight into both the research findings and the development of the students' academic skills.

We believe that this transparency is valuable and invites other universities to examine our process, improve upon it, and share their own versions of the project.

Continuous Process Improvement

Continuous Process Improvement (CPI) is a crucial aspect of our initiative. CPI involves the ongoing effort to enhance products, services, or processes through incremental improvements over time. By inviting the global academic community to engage with us, we aim to create a collaborative environment where best practices can be shared, refined, and implemented.

We urge universities and scholars worldwide to look at what we are doing, make improvements, and build upon our model. Your input on how the program can be better managed, made more efficient, or more successful on various levels is invaluable. By working together, we can continuously improve the process of engaging university students in real-world problem-solving.

Call to Action

We sincerely seek and invite the readers' responses and follow-up. Your feedback will play a pivotal role in helping us refine and enhance our approach. By participating in the peer review process, you contribute to the professional growth of the students and the overall success of the Engaged Scholarship model. Together, we can advance education by integrating practical study tasks that engage students in solving real-world problems.

We look forward to your contributions and thank you in advance for your support in making this initiative a success.

Introduction to Ms. Andriamaholy's Research on Photovoltaic-Powered Water Towers

Ms. Andriamaholy, an electrical engineering graduate student from Polytechnique University D'Antananarivo, has conducted extensive research on the infrastructure needed to power a water tower using photovoltaic systems and a simple pump. Her work addresses critical engineering questions related to the sizing of components necessary for such a system. Collaborating with fellow researcher Mr. Randrianarisolo, Ms. Andriamaholy evaluated an existing water tower in one of the student housing areas at the University of Antananarivo. This tower requires regular refilling to maintain water pressure for surrounding buildings.

Understanding the mathematics behind water storage and transport is mission-critical for water engineers in Madagascar. This study aims to develop a template for determining the typical components, energy loss factors, and the required sizing of each technical component. Using industry-standard software, PV Syst, the team conducted detailed component analysis to ensure accuracy and efficiency.

The primary intention of this study is not merely to supply water to the specific tower under examination but to design a "standard" system that can be used for similar water towers in the future. A nearly identical tower was recently constructed as part of the new vaccination research building at the university. This building was designed to collect rainwater and pump it up to an adjacent tower, making this study by the fellowship team crucial for background mathematics in designing water tower storage systems.

The research undertaken by Ms. Andriamaholy and Mr. Randrianarisolo delves into whether all loss factors have been adequately considered and if the sizing of the components is 100% correct. While there may be room for improvement, isolating this topic for detailed study is seen as an important technical step for managing water at the university. The ultimate goal is to develop a collection of standard-sized plans that can be used anywhere in Madagascar for building water towers where water pressure is needed and a technical solution is required.

Ms. Andriamaholy's research provides valuable insights and foundational knowledge for future water infrastructure projects, not only at the University of Antananarivo but also across Madagascar. Her work exemplifies the critical intersection of engineering and sustainable resource management, contributing to the development of practical, scalable solutions for water storage and distribution.

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TECHNICAL PLANNING FOR PHOTOVOLTAIC DRIVEN WATER TOWER STORAGE

JJSF-Jacquelyn Jestine Sanders Foundation

A STUDY PROJECTS

By Vahatra Fanantenana ANDRIAMAHOLY

Author Note

Bachelors in Electrical Engineering at Ecole Supérieure Polytechnique d'Antananarivo

JJSF Fellowship 2024, Rainwater Circulation and Aeration Team

Title:	RAINWATER CIRCULATION AND AERATION
Revision:	No 0
Issues:	- List of tables - More information about the system - Some adjustments for the Figure
Prepared by:	Vahatra Fanantenana ANDRIAMAHOLY
Reviewed by:	Tokiniaina Victoriot RANDRIANARISOLO
Date:	May 7, 2024

LISTS OF ABBRIVIATIONS

AC: Alternative Current
DC: Direct Current
GHI: Global Horizontal Irradiation
HP: Horsepower
JIRAMA: Jiro sy Rano Malagasy
JJSF: Jacquelyne Jestine Sanders Foundation
MPPT: Maximum Power Point Tracking
PV: Photovoltaic
PWM: Pulse Width Modulation

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Abstract

This Ankatso tower ensures the water supply for the university students. JIRAMA trucks regularly deliver the necessary water. This report takes an approach aimed at providing comprehensive details about this tower, highlighting its crucial importance in the residents' daily lives. Additionally, it offers detailed calculations to effectively size the components of a solar pumping system designed to continuously supply water to the storage reservoirs, thus ensuring a constant and sustainable water availability for the university community. We have also observed a tower where rainwater is pumped using energy from solar panels to fulfill the building's water requirements. We utilized both towers as inspiration for our design.

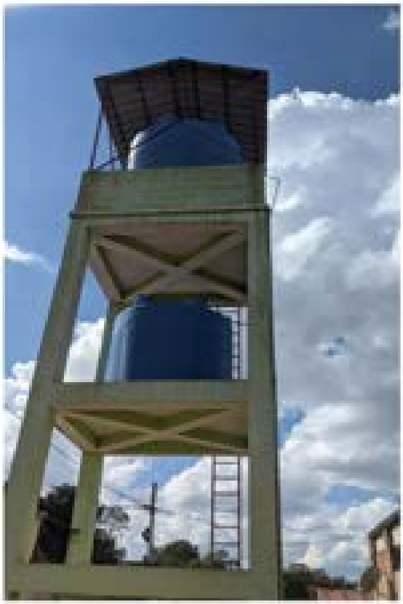


Figure 1: Real photo of the tower (Ankatso 1)

Figure 2 : Photo of the tower at the vaccination Ankatso

1 Design of the Tower:

The tower is a concrete structure that supports two storage tanks at different heights. Each storage tank is supplied independently and they have different volumes. In this image, it is even possible to install two more tanks on the lower levels. This means that the tower can simultaneously support four tanks, but the lower the tank is positioned, the lower the pressure will be.

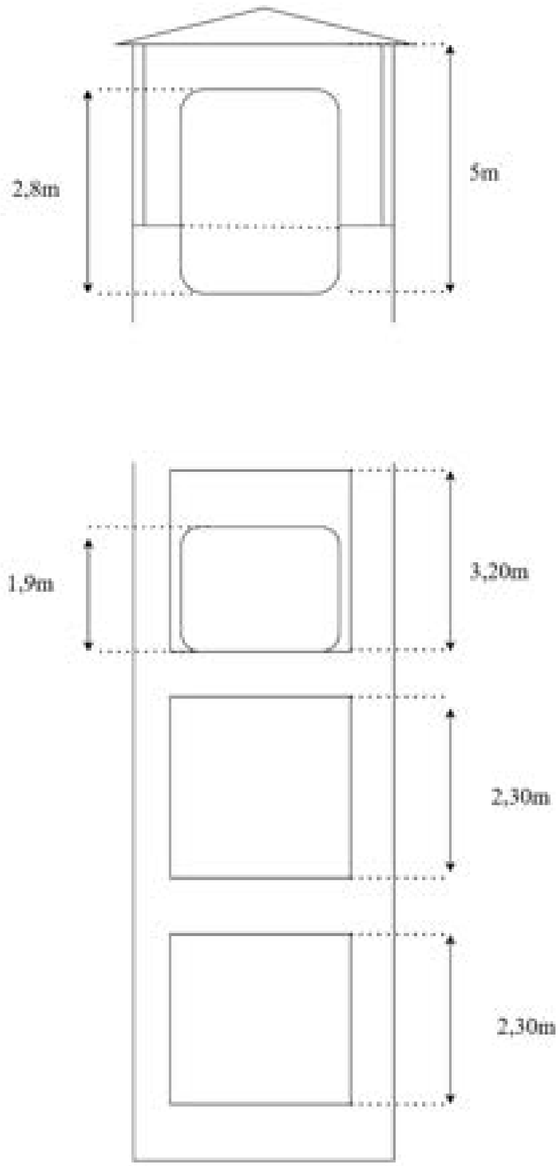


Diagram 1 : Design of the tower Ankatso 1

2 Volume of the tank:

These tanks are two categories of storage frequently used across the campus, with respective volumes of 1O and 5 cubic meters.

Tank 1: Diameter: 2m / Height: 3,18m / Volume: **~ 10 m3**

Tank 2: Diameter: 1,5m / Height: 2,83m / Volume: **~ 5 m3**

3 Design of the system:

3.1 Type of the pump :

Depending of the type of the pump, we should take those yield in consideration.

Table 1 : Benchmark Yield by Pump Type[2]

Pump type	Volumetric	Centrifugal (< 2 HP)	Centrifugal (> 2HP)
Benchmark yield	0,6	0,4	0,6

3.2 Topology of the system:

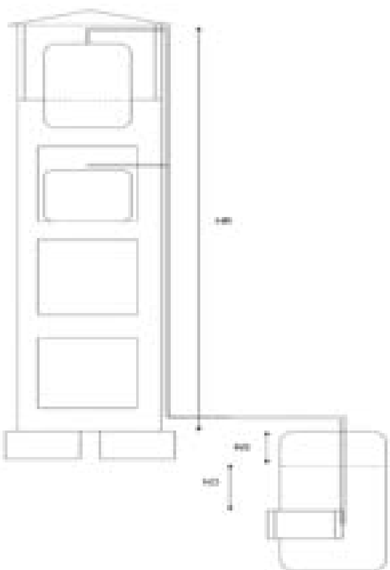


Diagram 2 : Pump System Schematic

Where

- H_R (Height of the water): It's the difference in height or altitude in meters (m) between the ground and the arrival at the highest point of the tank, tap, booster, etc.[2]
- N_S (Static level): It's the difference in height or altitude in meters (m) between the water level and the ground when the pump is stopped, so there are no variations in level.[2]

- N_D(Dynamic drilling level): It's a difference in height or altitude in meters (m) between the water level and the ground when the pump is running. The level can vary and even greatly in boreholes for example or depending on the seasons (evaporation). This information is obtained from the driller.[2]

Remark: For the tower at the Vaccination Research Building, we indeed have a tank for capturing rainwater, so both N_d and N_s are assumed to be references for the H_R.

Another point to consider is that we have the option to fill the tank from either the top or the bottom. Opting to pump from the top is advantageous for our design as it helps prevent sediment accumulation and ensures cleaner water quality.

The system in the vaccination building has been constructed to meet the general water requirements of the building.

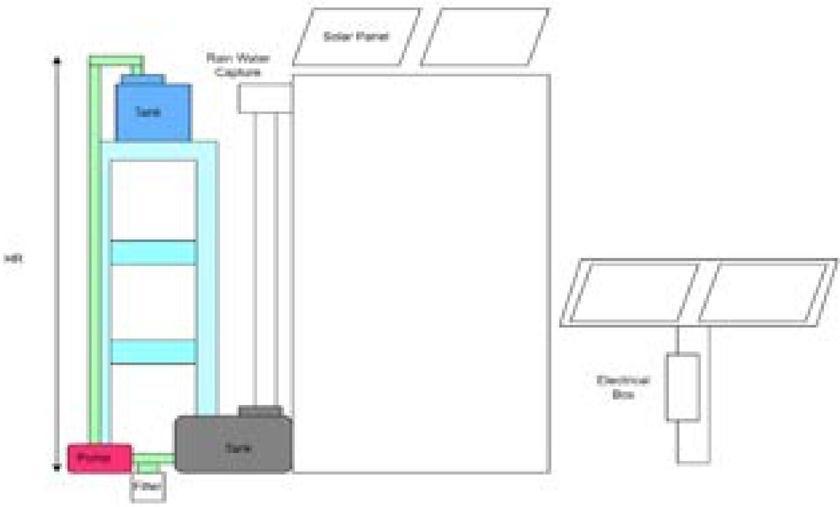


Diagram 3 : Solar Pumping system of the Vaccination Buildings

3.3 Role of the Component

Solar pump

A solar pump can be composed with several different technologies, volumetric (Shurflo), centrifugal or helical (Lorentz) and for varied uses such as surface pumping (pond, lake, river, tank) and submerged pumping (well, drilling).[2]

The advantage of this direct current supply is that we will able to adapt the rotation speed according to the energy available, which will allow pumping even with sunshine or low battery voltage. In addition, through technology or via a controller, we get rid of current peaks at start-up.[1]

⇒For the sizing of the system, the volume of the water that should be pumped and the height of the tank will be taken into consideration.

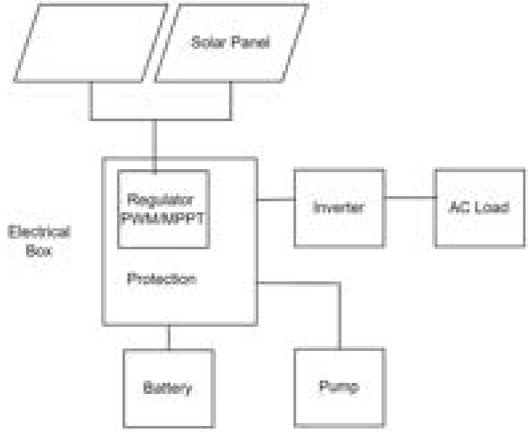


Diagram 4 : Components of a solar pumping system

In a solar pumping system, each component plays a critical role in ensuring efficient and reliable operation.

Solar Panel

The solar panel is the primary component that captures energy from the sun. Its role is to convert solar energy into electrical energy. This electricity is then used to power the water pump directly or stored in batteries for later use. The performance and size of the solar panel determine how much energy can be harvested and subsequently how much water can be pumped.

Battery

The battery in a solar pumping system stores electrical energy produced by the solar panels that is not immediately used. This storage allows the pump to continue operating during periods without sunlight, such as during the night or on cloudy days. Batteries ensure a consistent supply of electricity to the pump, thereby facilitating a stable operation regardless of varying solar conditions. However, the pump can work without using energy stockage if there are no other load that needs electricity that are connected to the system.

In other way, if we need to take into consideration the fact that there will be time that there won't be sunlight, instead of adding Batterie which should be expensive, we can build a bigger stockage of water.

Regulator (Charge Controller)

The regulator, or solar charge controller, manages the flow of electricity from the solar panels to the battery and the pump. Its main roles are:

- Preventing Overcharging: It ensures that the batteries do not overcharge, which can extend battery life and prevent safety issues.

- Regulating Voltage: It provides the correct voltage to the pump and prevents fluctuations that might damage the system.
- Maximizing Efficiency: Some advanced regulators include Maximum Power Point Tracking (MPPT) technology, which maximizes the efficiency of the solar panels by ensuring they operate at their optimal power output.

Protection

In a solar pumping system, protection plays a crucial role in ensuring the longevity and efficiency of the system. It safeguards against electrical faults, such as overcurrent and short circuits, which can damage components. Protection mechanisms also defend against environmental factors like lightning and power surges, ensuring the solar panels, pump, and controller operate safely and reliably.

Inverter

An inverter's role in a solar pumping system is to convert the DC (Direct Current) electricity generated by the solar panels and stored in the batteries into AC (Alternating Current). Most high-powered pumps, especially those used in large water systems, require AC to operate. Thus, the inverter is crucial for converting the stored DC into usable AC power for these pumps. Even if some smaller or specialized pumps operate on DC, systems designed for scalability or compatibility with existing infrastructure might still include an inverter.

3.4 Power needed calculation

To size the amount of energy that is needed we will break the problem for each of the tank.

To get the daily electrical energy we got the following formula:

$$E = \frac{V * mH * 0.2725}{np}$$

Where

- E represents the energy required in Watt-hours per day [Wh/d]
- V represents the volume in cubic meters per day [m^3/d]
- mH represents the manometric height (sum of the heights: N_S+ N_D+ Loss) in meters [m]
- 0.2725 represents the hydraulic coefficient
- n_p represents the efficiency of the pump

5- Choice of the pump:

The pump should then get the necessary power to pump during the day where the sun is available (~ 5 hours)

The power the pump should then be:

$$P = \frac{E}{nh}$$

Where:

P represents the power of the pump in Watt [W]

E represents the amount of needed energy in Watt-hours per day [Wh/d]

n_h represents the number of hour when there is sun

**It's important to emphasize that when choosing the pump, we must consider its flow rate, the maximum height to which it can pump water, and the pressure it can withstand.

3.5 PV sizing

To size the PV system, we should take into account the daily solar irradiation, which depends on the region, as well as the efficiency of the pump and the PV, which varies with the type of materials used.

$$Pp = \frac{E}{Dr \times K}$$

Where

P_p represents the total panel power to be installed in Watt-peak [Wp]

E represents the energy required in Watt-hour per day [Wh/d]

D_r represents the daily radiation in Kilowatt-hour per square meter per day [kWh/m²/d]

K represents the efficiency coefficient of the photovoltaic array (depending on the type of panel support and operating conditions)

3.6 Solar radiation map (GHI)

A solar radiation map is an image that shows how much sunlight reaches various locations on Earth. It helps to know where there is a lot or little sun, which is important when deciding where to install solar panels or studying the climate and environment.[3]

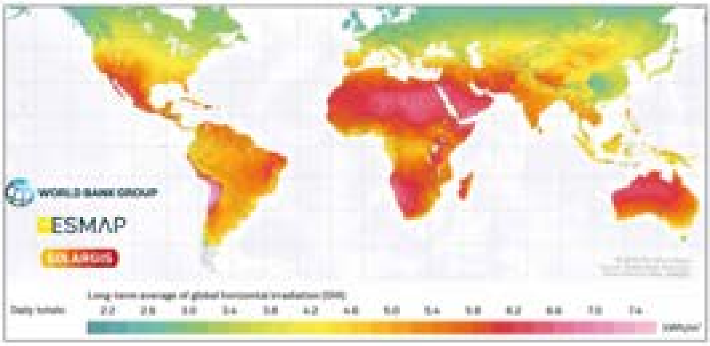


Figure 3 : Solar radiation map[3]

Our modular design approach for the solar water tower is intentionally designed to be adaptable to various geographic locations and usage contexts. Although our analysis focuses on the Antananarivo Campus tower, we have taken into account the need to adjust the sizing of solar panels and pump to meet the specific requirements of each site. Thus, our proposal can be implemented in various regions, providing a sustainable and scalable solution for water needs.

3.7 Solar irradiation for Madagascar

We obtained the following table, which displays the global irradiation data for Ankatso, sourced from the Meteonorm Dataset via PVSyst.

Site: Ankatso (Madagascar)
Data source: Meteonorm 8.0 (1991-2000), Sat=100 %

	Global horizontal irradiation	Horizontal diffuse irradiation	Temperature	Wind Velocity	Linke turbidity	Relative humidity
	kWh/m²/day	kWh/m²/day	°C	m/s	[-]	%
January	6.50	2.66	21.1	2.79	2.709	82.7
February	6.41	2.51	21.1	2.79	2.480	83.2
March	5.64	1.97	20.8	2.80	2.596	83.1
April	5.39	1.77	19.6	2.59	2.454	82.0
May	4.50	1.55	17.6	2.40	2.369	81.6
June	3.93	1.19	15.9	2.60	2.256	83.4
July	4.18	1.50	14.1	2.80	2.301	81.9
August	4.72	1.88	15.3	3.09	2.388	76.4
September	5.70	1.97	17.1	3.90	2.596	72.1
October	6.21	2.40	18.5	3.19	2.969	70.3
November	6.63	2.42	20.6	2.79	2.994	75.6
December	6.52	2.61	21.3	2.59	2.818	79.2
Year	**5.58**	**2.03**	**18.6**	**2.8**	**2.591**	**79.3**

Global horizontal irradiation year-to-year variability 3.5%

Figure 4 : Global irradiation at Ankatso

Table 2 : Solar panel efficiency by type and installation[1]

Choice of efficiency coefficient: depending on the type of panel support and operating conditions	Fixed installation of solar panels	Tracking the sun on the horizontal (modification of the inclination depending on the season)	Sun tracking with inclined or vertical axis (modification of the inclination according to the time of day)	Automatic sun tracking on 2 axes
Reference performance in a dusty environment or poor panel cleaning	0,5	0,6	0,7	0,8
Reference yield in a clean environment or regular cleaning of the panels	0,6	0,7	0,8	0,9

3.8 Result of the calculation :

The following constant were chosen for this calculation:

Pump efficiency = 40%

Solar efficiency = 80%

Irradiation = 5.9 kWh/m²/d (according solar radiation map)

Loss = 1/10m (Manometric height)

Table 3 : Result of the calculation with normal irradiation (tank 1 and tank 2)

Volume tank [m³]	Height of the tank [m]	well depth [m]	Loss [m]	Needed energy [Wh]	Power of the pump [W]	PV [W]
10	15	0	1,5	1124	191	238
10	15	10	2,5	1873	318	397
10	15	20	3,5	2623	445	556
10	15	30	4,5	3372	572	714
5	10	0	1,0	375	64	79
5	10	10	2,0	749	127	159
5	10	20	3,0	1124	191	238
5	10	30	4,0	1499	254	318

The irradiation is justified by the following figure from PV Syst while showing a 5.9 kWh/m²/d minimum while we got a clear Sky.

Meteo for Ankatso - Synthetically generated data from monthly values.

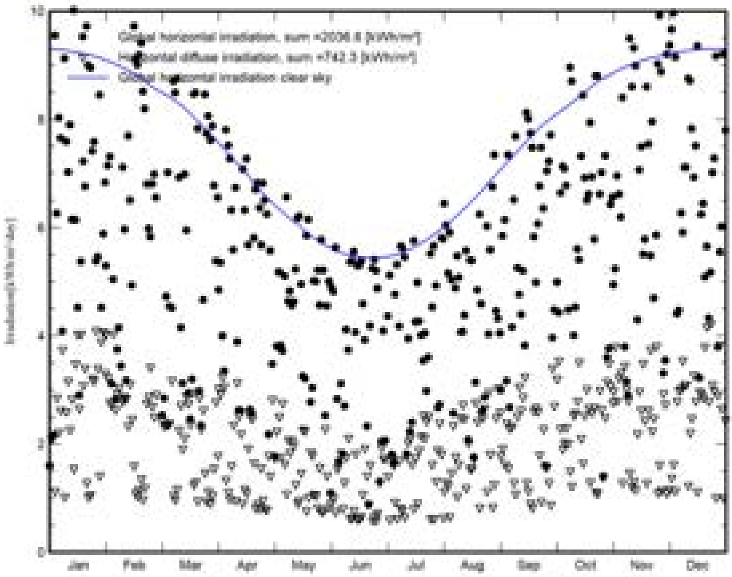


Figure 5 : Irradiation distribution at Ankatso

However, there are instances where we observe a minimal irradiation of 1.6 kWh/m2/d, which consequently yields the following result.

Table 4 : Result of the calculation with minimal irradiation (tank 1 and tank 2)

Volume tank [m3]	Height of the tank [m]	well depth [m]	Loss [m]	Needed energy [Wh]	Power of the pump [W]	PV [W]
10	15	0	1,5	1124	703	878
10	15	10	2,5	1873	1171	1464
10	15	20	3,5	2623	1639	2049
10	15	30	4,5	3372	2108	2635
5	10	0	1,0	375	234	293
5	10	10	2,0	749	468	585
5	10	20	3,0	1124	703	878
5	10	30	4,0	1499	937	1171

We can see in the result that we may need a total of 1171 W for the design up to the worst case.

We can also deduce that as the well depth increases, the power requirement for the pump also increases. In certain scenarios, a pump might meet the power criteria but fall short in delivering the required flow rate. Hence, it is crucial to thoroughly evaluate the characteristics of the pump.

⇒Then it's essential to size the component using software to simulate the scenario up to realistic data of the irradiation and the amount of water that is needed.

4 -Simulation with PV Syst

4.1 Overview of PV Syst

PVSyst is a widely used software tool for designing and simulating solar pumping systems. It enables precise system configuration by accurately sizing solar panels, pumps, and controllers based on specific water demand and solar irradiance data. PVSyst's simulation capabilities allow for detailed performance analysis, taking into account environmental factors such as solar radiation and temperature variations. The software also supports optimization of panel orientation and tilt angle to maximize energy capture.

4.2 Design roadmap

Table 5 : Steps in Designing a Solar Water Supply System

Step	Critical Point	Remark
Definition of the place where the system will be implemented	The annual irradiation will influence the system sizing	
Importation and analysis of the Meteorological data, especially the irradiation	The meteorological data will depend on the region, and this will influence the system configuration	
Analysis of the orientation of the panel	It's critical to choose the orientation up to the coordinate of the place to optimize the efficiency of the PV	• Variables: Tilt and azimuth of the panel • We should also consider shading effects
Definition of water needs	• Volume of water need • Volume of storage • Altitude of the Storage • Depth of the water sources	• The volume of water needed and the global irradiation will determine the required flow rate of the pump. • The altitude of the storage tank, the depth of the well, and the flow rate will determine the necessary power for the pump.
Choice of the Pump	We must choose a pump that meets the required flow rate and can lift water to the altitude of the storage tank's injection point.	
The PV panel Sizing	The PV panel will be sized to ensure it can provide the necessary power under typical conditions.	The number of panels that will be in series and parallel will be defined in order to satisfy the needed power and Voltage
The Regulator	The regulator should be slightly oversized to the PV for better security	

4.3 Orientation of PV Panel:

We first choose an orientation to the north by 25° to get the optimal inclination and Orientation of 0° Azimuth.

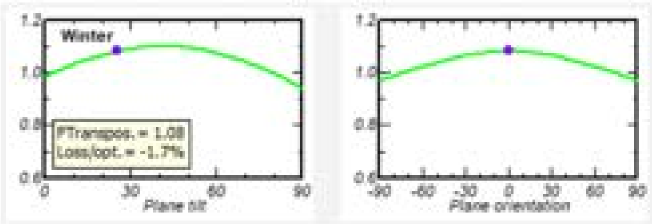


Figure 6 : PV orientation from PVSyst

Justification of the parameters

Orienting solar panels at a 25° angle to the north optimizes solar energy capture by aligning the panels with the sun's position in the sky, ensuring maximum exposure to direct sunlight throughout the day. Because Madagascar is located in the southern hemisphere, facing the panels northward directs them towards the equator, where the sun's path is most direct. The 25° tilt angle is selected to match Madagascar's latitude, maximizing the angle of incidence for sunlight year-round and thereby enhancing solar panel efficiency.

4.4 Configuration of the System

Here is the definition of the system and the needs

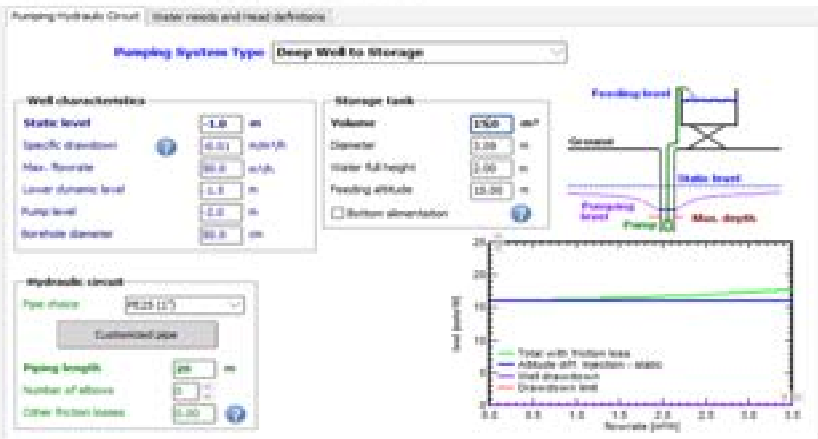


Figure 7 : Pumping Hydraulic Circuit from PVSyst

We have defined a $15m^3$/day need of water to fill both of the tank in the tower in Picture 1.

Here is the rationale behind these parameters:

- The static level is set at 1 meter as a standard reference, but it can be adjusted according to actual requirements.
- The daily demand is 15 m^3, meaning both tanks will be emptied by the end of the day.
- We used the height of the highest tank as the reference point for designing the system.

After adding the water need, we get the rough result from PVSyst:

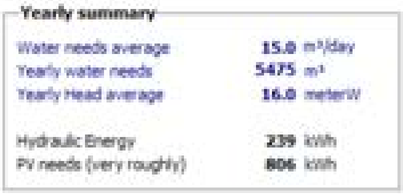


Figure 8 : Rough Estimation from PV Syst

Figure 9 : Pump definition from PVSyst

We choose a 300W 48V pump that has a $4.4m^3$/h to $1.6m^3$/h flow rate that potentially can fill the tank in 4 hours in an optimal use.

** We must emphasize the fact that all the materials that are cited during the simulation are just one choice many others they are neither recommended or preferred.*

Justification of the parameters:

The decision was influenced by both the flow rate and the maximum height, which spans from 2 to 20 meters. The specifications for power, voltage, and motor type may vary based on the materials at hand. In this scenario, opting for a pump that operates with lower power and voltage proves most compatible with the system, as it eliminates the necessity of adding extra panels to meet voltage requirements. This not only streamlines the design process but also cuts down on expenses and enhances the overall efficiency of the solar pumping system.

Here is the general configuration of the system*

General parameters

Pumping PV System

System Requirements

Basic Head	16 meterW

Water needs

Yearly constant	15.00 m³/day

Hydraulic circuit

Piping length	20 m
Pipes	PE25
Dint	29 mm

Deep Well to Storage

Well characteristics

Static level depth	-1.0 m
Specific drawdown	-0.01 m/m³/h
Diameter	50 cm
Pump level	-2.0 m
Lower dynamic level	-1.5 m

PV Field Orientation

Fixed plane	
Tilt/Azimuth	25 / 0 °

Storage tank

Volume	15.0 m³
Diameter	3.1 m
Feeding by top	
Feeding altitude	15.0 m
Height (full level)	2.0 m

PV Array and Pump

PV module

Manufacturer	Lightwaysolar
Model	Poly 300 Wp 72 cells
(Original PVsyst database)	
Unit Nom. Power	300 Wp
Number of PV modules	2 units
Nominal (STC)	600 Wp
Modules	2 Strings x 1 In series

At operating cond. (50°C)

Pmpp	539 Wp
U mpp	33 V
I mpp	16 A

Total PV power

Nominal (STC)	1 kWp
Total	2 modules

Pump

Manufacturer	Lorentz
Model	PS2-150 C-SJ5-8
Pump Technology	Centrifugal
	Deep well pump
Motor	DC motor, brushless

Associated or integrated converter

Type	MPPT
Voltage range	20 - 52 V

Operating conditions

	Head min.	Head Nom.	Head max.	
	2.0	11.0	20.0	m
Corresp. Flowrate	4.38	2.92	1.57	m³/h
Req. power	278	270	278	W

Control device

Manufacturer	Solarjack
Model	PCB-120
System Configuration	MPPT-DC converter

Pumping system controller

System Operating Control

Power Conditioning Unit

Type	MPPT-DC converter

Operating conditions

Nominal power	300 W
Power Threshold	3 W
Max. efficiency	96.0 %
EURO efficiency	94.0 %
Minimum MPP Voltage	20 V
Maximum MPP Voltage	52 V
Maximum Array Voltage	60 V
Maximum Input Current	15.0 A

Figure 10 : Summary of the System from PVSyst

** We must emphasize the fact that all the materials that are cited during the simulation are just one choice many others they are neither recommended or preferred.*

We can see the distribution of the amount of water stored in the tank up to the daily solar irradiation.

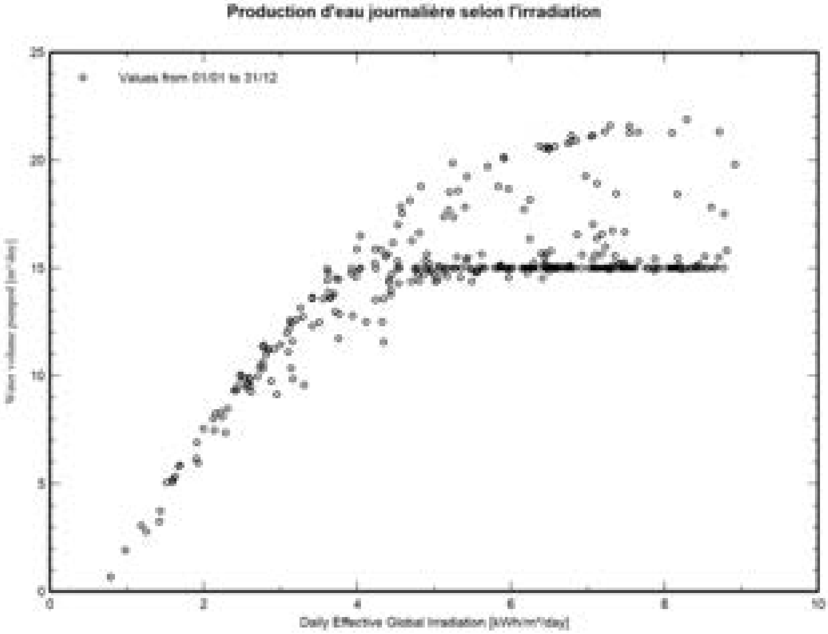


Figure 11 : Water volume pumped related to daily Global irradiation

We can see that most of the time, the tank of 15m³ is full. This graph illustrates that the water pump, when paired with the solar panel, exhibits a threshold of irradiation that must be surpassed for optimal efficiency (3.5 kWh/m2/day in our case for a daily output of 10m3, and 4 kWh/m2/day for a full 15m3). In our scenario, we engineered the system based on recommendations from the software and the materials accessible to us.

Here is the PV characteristic that shows the needed area of 4 m2

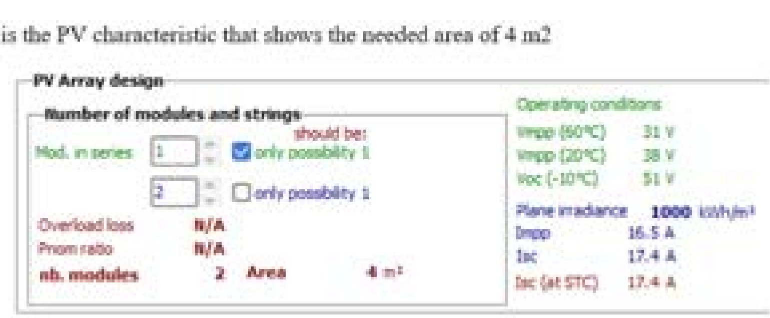


Figure 12 : PV system configuration from PVSyst

The graph below illustrates the pumped water volume and the deficit for each month. It is evident that the most critical scenario occurs in June, with a shortfall of 50m³. This lack of water is also justified by the table in the Figure 4.

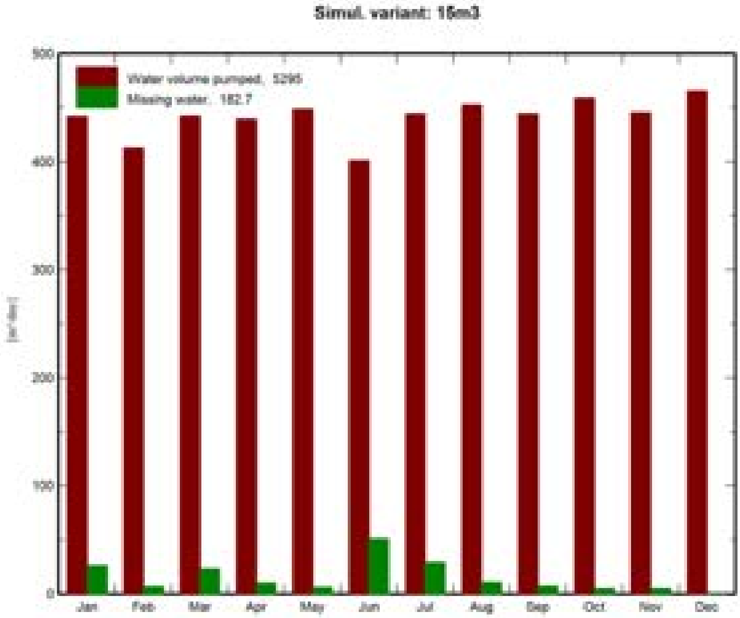


Figure 13 : Total of pumped and missing water

Conclusion:

A PV system with two 300kW, 30V solar panels, an MPPT controller of 500W, and a 300W water pump capable delivering 4.4m³ per hour can operate with only a 3.3% water shortage. This demonstrates the resilience and adaptability of solar-powered systems in managing resources effectively.

Results summary

Water		Energy		Efficiencies	
Water Pumped	5295 m³	Energy At Pump	680 kWh	System efficiency	63.6 %
Specific	5423 m³/kWp/bar	Specific	0.13 kWh/m³	Pump efficiency	35.0 %
Water needs	5475 m³	**Unused (tank full)**			
Missing Water	3.3 %	Unused PV energy	153 kWh		
		Unused Fraction	14.1 %		

Figure 14 : Result Summary from PVSyst

The main result shows here that for the 5475 m³ of water that is needed, the system is capable of delivering 5295 m³ and with a 14,1% of electricity that is unused that mean 153 kWh of energy that can be used for other needs.

⇒ According to figure 12, the roof will not provide enough space for installing solar panels.

Open Discussion for Other Design

The simulations conducted using PVSyst enable us to construct a system based on realistic data rather than overestimating it for worst-case scenarios, which offers distinct advantages. This approach facilitates accurate sizing of system components, such as solar panels and pumps, in accordance with actual water demand and solar irradiance conditions. By avoiding unnecessary overestimation, we can reduce initial costs and construct a more efficient system that functions optimally under typical operating conditions. This ensures that the solar pumping system is both cost-effective and dependable. It's worth noting that all results presented in this report pertain to the baseline system configuration. Adjustments in the well depth and water tower height can be made to accommodate specific requirements. This adaptability permits customization of the system to various site conditions, ensuring optimal performance and cost-effectiveness tailored to the local context.

PVSYST
PHOTOVOLTAIC SOFTWARE

Version 7.2.4

PVsyst - Simulation report

Pumping PV System

Project: PV Driven Water Storage Tower

Variant: Baseine simulation
Project: PV Driven Water Storage Tower
System power: 600 Wp
Ankatso - Madagascar

PVsyst V7.2.4
VC0, Simulation date:
19/05/24 12:44
with v7.2.4

Project: PV Driven Water Storage Tower

Variant: 15m3

Project summary

Geographical Site
Ankatso
Madagascar

Situation

Latitude	-18.70 °S
Longitude	47.72 °E
Altitude	1433 m
Time zone	UTC+3

Project settings

Albedo	0.20

Meteo data
ankatso
Meteonorm 8.0 (1981-2000), Sat=100 % - Synthétique

System summary

Pumping PV System

Deep Well to Storage

PV Field Orientation
Fixed plane
Tilt/Azimuth 25 / 0 °

Water needs
Yearly constant 15.00 m³/day

System information
PV Array

Nb. of modules	2 units
Pnom total	600 Wp

Results summary

Water

Water Pumped	5296 m³
Specific	5423 m³/kWp/bar
Water needs	5475 m³
Missing Water	3.3 %

Energy

Energy At Pump	689 kWh
Specific	0.13 kWh/m³

Unused (tank full)

Unused PV energy	153 kWh
Unused Fraction	14.1 %

Efficiencies

System efficiency	63.6 %
Pump efficiency	35.0 %

Table of contents

Project: PV Driven Water Storage Tower

Variant: 15m3

PVsyst V7.2.4
VC0, Simulation date:
19/05/24 12:44
with v7.2.4

General parameters

Pumping PV System

System Requirements

Basic Head	16 meter/W

Water needs

Yearly constant	15.00 m³/day

Hydraulic circuit

Piping length	20 m
Pipes	PE25
Dint	29 mm

Deep Well to Storage

Well characteristics

Static level depth	-1.0 m
Specific drawdown	-0.01 m/m³/h
Diameter	50 cm
Pump level	-2.0 m
Lower dynamic level	-1.5 m

PV Field Orientation

Fixed plane	
Tilt/Azimuth	25 / 0 °

Storage tank

Volume	15.0 m³
Diameter	3.1 m
Feeding by top	
Feeding altitude	15.0 m
Height (full level)	2.0 m

PV Array and Pump

PV module

Manufacturer	Lightwaysolar
Model	Poly 300 Wp 72 cells
(Original PVsyst database)	
Unit Nom. Power	300 Wp
Number of PV modules	2 units
Nominal (STC)	600 Wp
Modules	2 Strings x 1 In series

At operating cond. (50°C)

Pmpp	539 Wp
U mpp	33 V
I mpp	16 A

Total PV power

Nominal (STC)	1 kWp
Total	2 modules

Pump

Manufacturer	Lorentz
Model	PS2-150 C-SJ5-8
Pump Technology	Centrifugal
	Deep well pump
Motor	DC motor, brushless

Associated or integrated converter

Type	MPPT
Voltage range	20 - 52 V

Operating conditions

	Head min.	Head Nom.	Head max.	
	2.0	11.0	20.0	m
Corresp. Flowrate	4.38	2.92	1.57	m³
Req. power	278	270	278	W

Control device

Manufacturer	Solarjack
Model	PCB-120
System Configuration	MPPT-DC converter

Pumping system controller

System Operating Control

Power Conditioning Unit

Type	MPPT-DC converter

Operating conditions

Nominal power	500 W
Power Threshold	5 W
Max. efficiency	97.0 %
EURO efficiency	95.0 %
Minimum MPP Voltage	75 V
Maximum MPP Voltage	120 V
Maximum Array Voltage	250 V
Maximum Input Current	0.0 A

Project: PV Driven Water Storage Tower

Variant: 15m3

PVsyst V7.2.4
VC0, Simulation date:
19/05/24 12:44
with v7.2.4

System losses

Thermal Loss factor
Module temperature according to irradiance

Uc (const)	20.0 W/m²K
Uv (wind)	0.0 W/m²K/m/s

DC wiring losses

Global array res.	34 mΩ
Loss Fraction	1.5 % at STC

Module Quality Loss

Loss Fraction	-1.3 %

Module mismatch losses

Loss Fraction	2.0 % at MPP

Strings Mismatch loss

Loss Fraction	0.1 %

IAM loss factor
ASHRAE Param: IAM = 1 - bo(1/cosi -1)

bo Param.	0.05

Project: PV Driven Water Storage Tower

Variant: 15m3

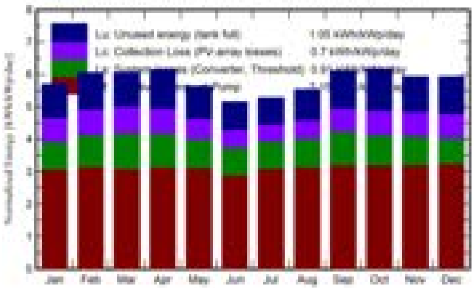
PVsyst V7.2.4
VC0, Simulation date:
19/05/24 12:44
with v7.2.4

Main results

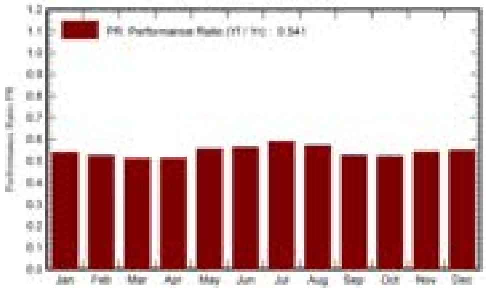
System Production

Water		Energy		Efficiencies	
Water Pumped	5295 m³	Energy At Pump	689 kWh	System efficiency	63.6 %
Specific	5423 m³/kWp/bar	Specific	0.13 kWh/m³	Pump efficiency	35.0 %
Water needs	5475 m³	**Unused (tank full)**			
Missing Water	3.3 %	Unused PV energy	153 kWh		
		Unused Fraction	14.1 %		

Normalized productions (per installed kWp)



Performance Ratio PR



Balances and main results

	GlobEff kWh/m²	EArrMPP kWh	E_PmpOp kWh	ETkFull kWh	H_Pump meterW	WPumped m³	W_Used m³	W_Miss m³
January	170.1	89.28	57.32	13.64	16.59	441.6	438.5	26.50
February	164.0	85.16	53.35	12.44	16.61	412.5	412.5	7.46
March	182.9	93.79	57.74	11.75	16.57	442.0	442.0	23.05
April	180.8	93.29	56.75	13.61	16.62	439.4	440.0	10.04
May	170.7	90.34	58.26	12.32	16.61	448.4	458.4	6.56
June	151.3	80.98	52.26	10.33	16.61	401.2	399.0	51.02
July	160.0	86.43	57.84	10.41	16.58	444.1	435.7	29.26
August	168.0	89.89	58.67	11.86	16.59	452.5	454.3	10.68
September	179.0	93.91	57.93	13.56	16.59	444.1	442.3	7.67
October	186.2	96.94	59.87	15.74	16.59	459.0	459.6	5.38
November	172.6	89.80	58.04	12.89	16.57	445.2	444.9	5.09
December	177.6	92.95	60.80	14.42	16.56	465.3	465.0	0.00
Year	2063.2	1082.76	688.84	152.97	16.59	5295.4	5292.3	182.71

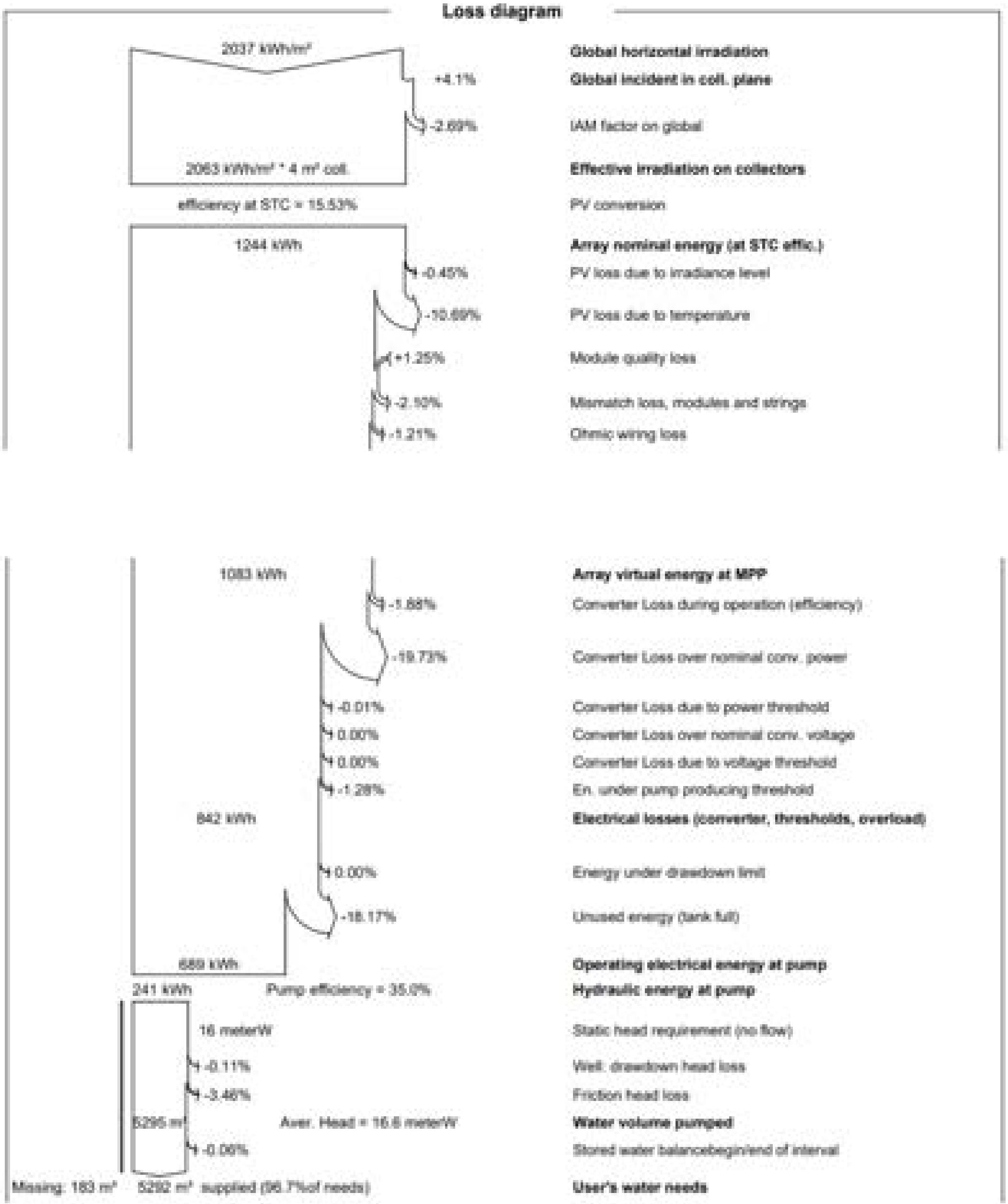
Legends

GlobEff	Effective Global, corr. for IAM and shadings	WPumped	Water volume pumped
EArrMPP	Array virtual energy at MPP	W_Used	Water drawn by the user
E_PmpOp	Pump operating energy	W_Miss	Missing water
ETkFull	Unused energy (tank full)		
H_Pump	Average total Head at pump		

PVsyst V7.2.4
VC0, Simulation date:
19/05/24 12:44
with v7.2.4

Project: PV Driven Water Storage Tower

Variant: 15m3



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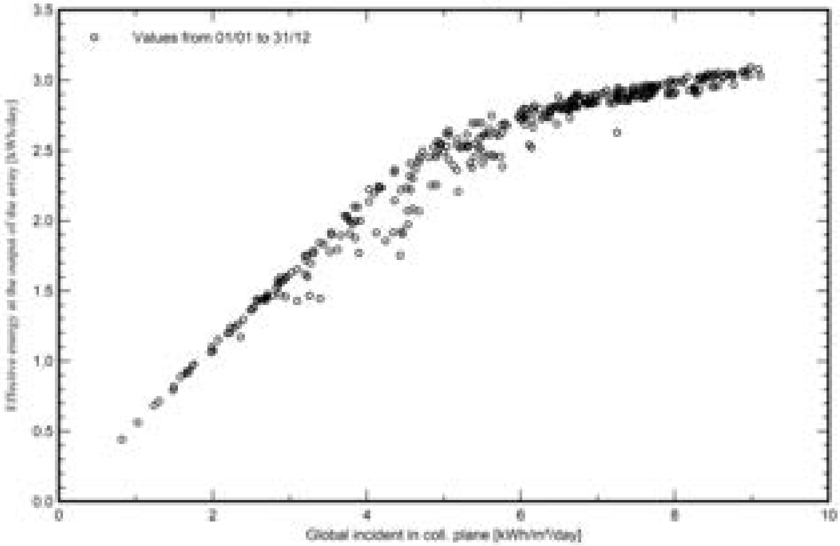
with v7.2.4

Project: PV Driven Water Storage Tower

Variant: 15m3

Special graphs

Diagramme d'entrée/sortie journalier



Project: PV Driven Water Storage Tower

Variant: 15m3

PVsyst V7.2.4
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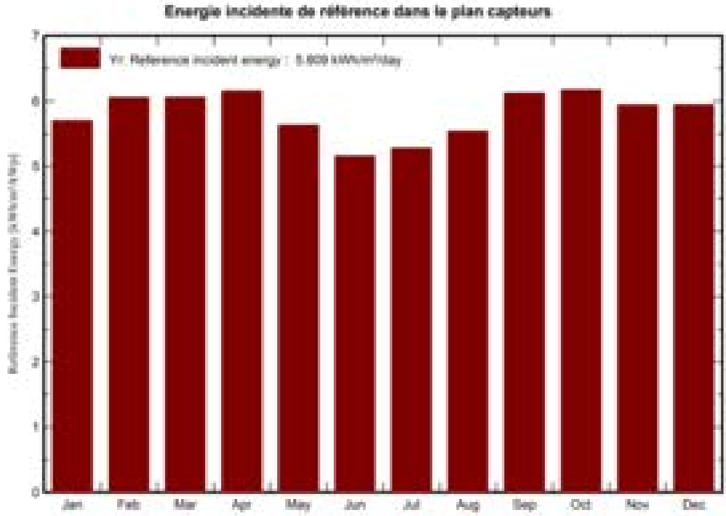
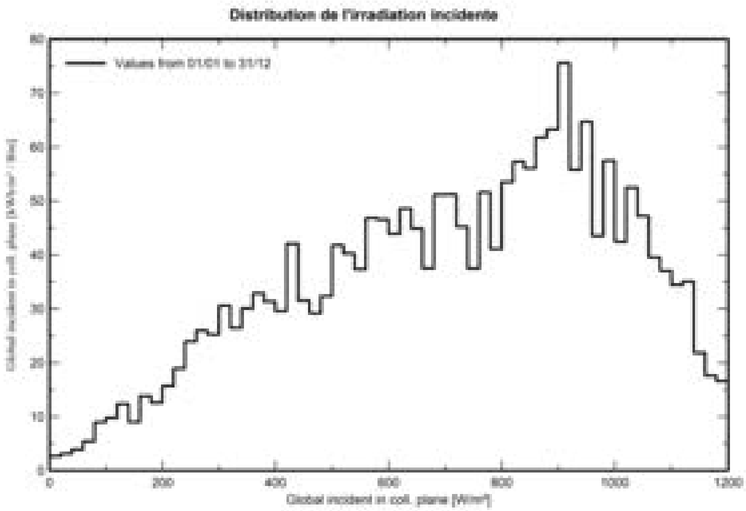
with v7.2.4

Predef. graphs





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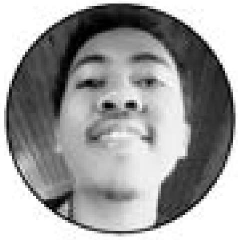

Introduction to Mr. Randrianarisolo's Research on Rainwater Capture from University Buildings

Mr. Randrianarisolo, a dedicated researcher, focused his efforts on assessing the viability of capturing rainwater from the rooftops of the University of Antananarivo's buildings. His study aimed to determine how the largest structures on the university property could contribute to alleviating the severe water shortages faced by the institution. By conducting extensive calculations, Mr. Randrianarisolo evaluated the volume of water currently being captured temporarily on the rooftops before it is either infiltrated into the groundwater or directed into larger channels leading to the university's rice fields.

Understanding the potential for rainwater capture is crucial for improving water management at the university. Mr. Randrianarisolo's work involved a meticulous analysis of the largest buildings, providing a detailed assessment of the water they collect during rainfall. His findings set the stage for identifying which buildings are the primary targets for the installation of rainwater capture mechanisms, ensuring that the university can optimize its water resources effectively.

This research is a foundational step toward developing a comprehensive rainwater harvesting strategy for the University of Antananarivo. By pinpointing the buildings with the highest potential for rainwater capture, Mr. Randrianarisolo's study lays the groundwork for future installations of rainwater harvesting systems. These systems could significantly reduce the university's reliance on external water sources, improve water availability for students and staff, and contribute to more sustainable water management practices.

Mr. Randrianarisolo's work highlights the importance of innovative solutions in addressing Madagascar's pressing water issues. His research provides a critical perspective on how existing infrastructure can be leveraged to meet the university's water needs, offering a practical approach to enhancing water sustainability on campus. This study not only supports the immediate goal of improving water capture and utilization but also aligns with broader efforts to promote environmental stewardship and resource efficiency within the university community.

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RAINWATER CAPTURE PROJECTIONS FOR THE UNIVERSITY OF ANTANANARIVO ROOFTOPS

A STUDY PROJECTS

RANDRIANARISOLO Tokiniaina Victoriot

Author Note

RANDRIANARISOLO Tokiniaina Victoriot holds the following degree:

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Title :	RAINWATER CAPTURE PROJECTIONS FOR UNIVERSITY ROOFTOPS
Revision :	No 3
Issues:	- Unity of the graph in figure 11-12-13 - Rainfall unity on table 1 and the table after figure 16 - Total rainfall capture in table in chap-8 - Revision with Mr Tafita Ralijaona
Prepared by :	RANDRIANARISOLO Tokiniaina Victoriot
Reviewed by :	Professor Tafita Ralijaona
Date :	21/04/2024

Abstract

The analysis of rainfall estimation is crucial when aiming to optimize rainwater capture methods. This projection facilitates the sizing of the equipment that will be deployed. Merely assuming the quantity of rainfall or relying on unfounded estimates could lead to either an over or underestimation of the capture system's capacity. The analyzed data also provides an insight into the efficiency of the system. Within our Rainwater Management Study, estimation stands as a pivotal element, serving as a solid foundation for project initiation. It is imperative to ensure accurate estimation methodologies to drive the success of rainwater harvesting initiatives.

For data analysis, we will leverage multiple sources to establish a robust foundation for our estimation. Primarily, we will utilize official data from the APIPA (The Authority for Flood Protection of the Antananarivo Plain) spanning 20 years across various zones in Antananarivo. Our estimation will not solely focus on the total annual rainfall quantity but will encompass an analysis of the water quantity supplied throughout the year, considering different scenarios (wet and dry years) to provide insight into all possible eventualities. This approach ensures a comprehensive understanding of rainfall dynamics and water availability, thereby enhancing the effectiveness of our assessment.

1- Presentation of the climate in Madagascar and description of the case of Antananarivo:

Madagascar experiences two main seasons : a hot and humid season (summer) from November to April, and a dry and cool season (winter) from May to October. Two short inter-seasons separate these main seasons, each lasting approximately one month. For the central highlands, the climate is rather cool, with average annual temperatures ranging between 15°C and 22°C. This region experiences the lowest average temperatures in Madagascar, dipping below 14°C. It receives significant rainfall, with annual precipitation ranging from 1 000 to 2 000 mm. Approximately 90 to 95% of the total annual precipitation occurs from November to April. Precipitation is relatively low during the months of September and October. [1] [2] [3]

2- Estimation of precipitation in Antananarivo:

The data collected from various sources [1] [6] [7] appear to converge towards an estimation of rainfall in Antananarivo averaging 1000 mm per year. According to the estimation provided by our specialist in the journal, this value is approximately valid for the Antananarivo region. However, the sources did not specify how they collected their data or arrived at the result of this estimation. Furthermore, we also need to investigate the daily rainfall history to provide more specific and useful data for the rainwater harvesting project, as storage and other elements will be sized according to the amount of water that will be available daily to make them more efficient. The data provided in [4] by APIPA and in [5] dataset seems to suggest a high resolution of precipitation for two decades (2000-2022), which is highly relevant for our study.

3- Data Analysis According to Various Sources

Two types of data collected from websites providing access to meteorological data for Antananarivo provide precipitation statistics for the region. One, sourced from [7], appears to provide approximately the same values as those sourced from [6].

Antananarivo -Précipitation moyennes		
Mois	Quantité(mm)	Jour de pluie
Janvier	270	18
Février	255	17
Mars	185	17
Avril	50	9
Mai	20	6
Juin	7	6
Juillet	10	8
Août	15	9
Septembre	10	4
Octobre	65	8
Novembre	170	14
Décembre	305	20
An	1365	136

Figure 1 : Antananarivo precipitation, source : [7]

Actually, both of them indicated that their data had been analyzed for the period from 1991 to 2021, but their analysis appear to not converge into one result. However, they gave an estimation around 1000 mm of precipitation per year. The table emphasize also the fact that there are two seasons in Antananarivo and it is confirmed by the number of rainy days.

Antananarivo -Précipitation moyennes		
Mois	Quantité(mm)	Jour de pluie
Janvier	289	17
Février	256	15
Mars	147	12
Avril	40	6
Mai	16	2
Juin	7	1
Juillet	8	1
Août	6	1
Septembre	8	1
Octobre	31	4
Novembre	87	8
Décembre	189	13
An	1084	81

Figure 2 : Antananarivo precipitation, source : [6]

Some data from [9] provide a history of rainfall for the past four years that we can also take into consideration for our analysis. They also reflect the current situation due to recent climate change and the trend of rainfall reduction even the 2019 is not complete.

mm	2019	2020	2021	2022	2023	2024
Jan	-	414,8	86,4	338,8	235, 2	194
Fev	-	182, 2	174	132,4	118	239, 8
Mar	-	149, 6	123, 2	139,8	205, 6	48
Avr	-	29,2	19,2	2,6	61,2	-
Mai	-	0	5,4	0,8	24,2	-
Jun	-	6,4	8	1	1	-
Jul	-	1,8	0,8	3,2	0 , 8	-
Aou	-	0	2,8	0,6	1 7 , 2	-
Sep	-	1	1,4	1,8	0 , 8	-
Oct	-	64	23,2	17,2	124,6	-
Nov	2,2	21,2	113, 2	67,8	60	-
Dec	129	94,4	97	181,8	129,2	-
AN	131, 2	964, 6	654, 6	887,8	977, 8	481,8

Figure 3: Antananarivo Precipitation 2019-2024 in millimeters, source [9]

On the other hand, we can also observe a decrease in the number of rainy days over the past few years, as depicted in the following figure, where an average of 70 rainy days is shown.

Days	2019	2020	2021	2022	2023	2024
Jan	-	17	8	18	18	17
Fev	-	10	13	11	10	15
Mar	-	7	12	11	18	5
Avr	-	6	6	1	8 -	
Mai	-	0	2	0	-	
Jun	-	3	2	0	3 -	
Jul	-	1	0	0	-	
Aou	-	0	1	0	0 -	
Sep	-	0	0	1	-	
Oct	-	6	2	3	0 -	
Nov	1	6	8	8	-	
Dec	9	10	7	13	12	
An	10	66	61	66	87	37

Figure 4 number of rainy days in Antananarivo 2019-2024 [9]

0
-
8
-
7
-

In addition to those data, we have this Rainfall map of Antananarivo from [1] that indicate the amount of rain during each month of the year, it also shows that there is not a really significant variation of the amount of precipitation in the region of Antananarivo. It also shows the two season of year that reflect the amount of precipitation.

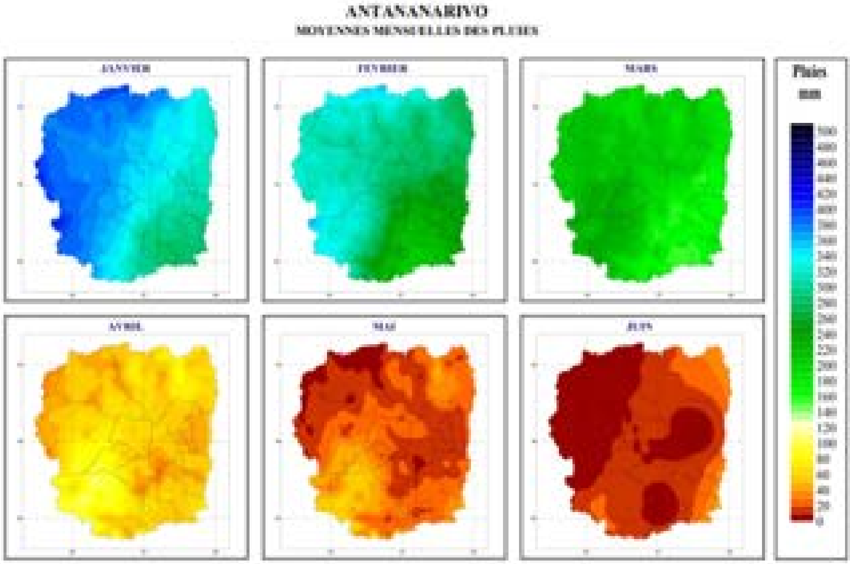


Figure 5 Average Rainfall of Antananarivo

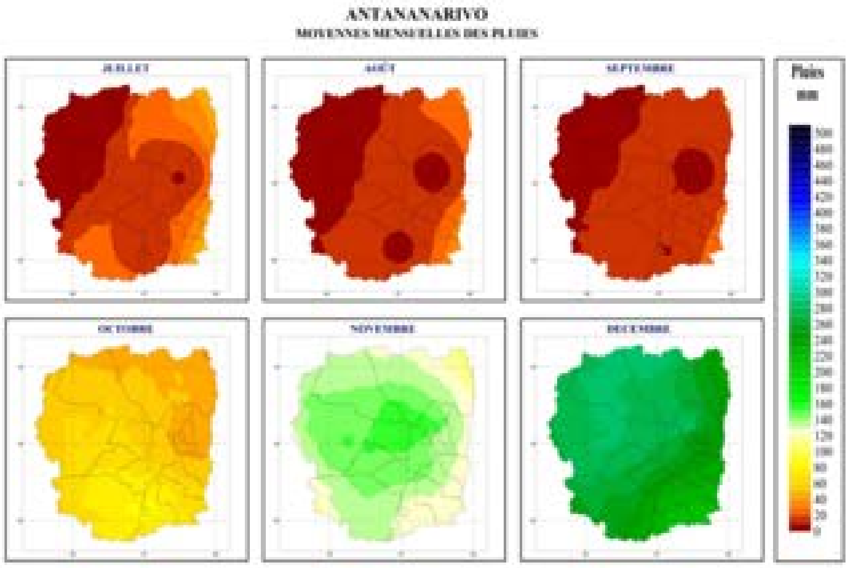


Figure 6 Average Rainfall of Antananarivo

4- Data Analysis According to APIPA station data

Those previous data can be used to validate the result of our Analysis based on the measurement made in the APIPA Station. Actually, the APIPA provide a large dataset of hourly measurement from 2000 to 2022 from its nine (9) stations around Antananarivo. The localisation of these Station will be detailed in later section of this document. We had to fill the missing data which we can not always know if it is a null value or should take a special value. By converting the daily data to a monthly data for a better visualisation, we get the next result that show the rainfall data of each station. Given the necessity of capturing both short and long-term relationships within the dataset, we have opted to examine three distinct time periods (2000-2022 / 2010-2022 / 2019-2022). These are actualy derivated by monthly average.

	Alarobia	Anosibe	Anosizatom	bohimanam	Mbanjakandria	Ambatofotsy	Antalomita	Behenjy	Anjeva	Moyenne
Jan	293, 1	321.7	302, 5	343, 2	299, 4	295, 0	337, 8	304.5	323, 7	314.1
Feb	217, 8	264.9	201, 4	230, 4	236, 4	215, 5	245, 3	220.4	229, 0	228.9
Mar	161.0	180.9	164.7	203.6	221.1	186.0	153.9	170.1	182.9	180.3
Apr	42.5	82.0	61.4	68.2	61.1	60.7	48.1	54.1	50.0	58.7
May	24.4	32.5	19.7	17.7	35.5	38.8	14.8	19.6	17.9	24.5
Jun	14.9	18.3	12.8	8.9	37.8	7.1	12.6	10.0	6.2	14.3
Jul	12.5	43.8	1.7	5.5	33.3	11.9	10.3	4.6	5.1	14.3
Aug	11.3	27.5	4.1	10.7	27.3	1.8	8.6	6.1	6.8	11.6
Sep	12.5	19.3	5.1	9.2	21.2	29.3	10.4	9.6	12.8	14.4
Oct	36.1	45.9	26.8	39.2	47.5	47.9	71.5	53.7	42.2	45.7
Nov	102.8	132.0	115.6	118.7	112.1	158.6	134.8	171.0	125.0	124.1
Dec	221.6	273.5	234.6	235.8	249.5	222.7	250.0	232.8	246.4	234.1
Total	1353.7	1444.4	1132.1	1291.1	1380.3	1271.3	1356.2	1306.6	1244.1	1264.9

Figure 7 APIPA monthly average rainfall for 2000-2022

	Alarobia	Anosibe	Anosizatom	bohimanam	Mbanjakandria	Ambatofotsy	Antalomita	Behenjy	Anjeva	Moyenne
Jan	232.8	255.8	294, 3	329.4	250, 5	261, 1	280, 3	273.9	258, 3	269.8
Feb	191.6	265.8	193, 1	256.2	202, 5	203, 9	226, 5	191.7	173, 1	207.8
Mar	129.4	162.7	177.5	258.6	186.2	192.2	128.0	168.9	162.7	170.7
Apr	36.2	71.9	58.2	53.7	43.1	55.1	36.9	43.2	30.9	47.2
May	13.0	29.2	13.9	14.5	30.2	50.7	10.2	16.5	13.2	21.3
Jun	9.9	11.4	20.4	10.5	30.1	8.5	11.9	12.0	2.9	13.1
Jul	7.3	95.2	1.3	3.1	27.5	13.2	9.1	1.3	0.6	17.7
Aug	4.6	38.6	1.2	15.1	23.6	0.8	6.1	2.2	0.5	10.0
Sep	3.9	7.7	0.2	4.3	12.8	38.2	9.9	0.9	7.9	9.5
Oct	42.1	40.7	35.8	81.9	51.5	40.1	89.2	56.7	37.3	53.3
Nov	77.8	80.2	106.3	92.6	94.2	121, 8	106.2	78.7	98.8	96.3
Dec	129, 7	208.2	200.8	181.0	196.7	165.4	172.9	210.5	179, 1	187.0
Total	895.3	1325.8	1103.6	1564.8	1137.6	1182.8	1083.2	1054.3	985.7	1103.6

Figure 8 APIPA monthly average rainfall for 2010-2022

	Alarobia	Anosizatom	bohimanam	Mbanjakandria	Ambatofotsy	Antalomita	Behenjy	Anjeva	moyenne
Jan	130, 5	385, 9	294, 4	246, 6	300, 4	272, 2	316, 5	264, 5	299, 8
Feb	172, 4	172, 6	178, 4	189, 7	174, 7	155, 6	151, 1	178, 4	171, 5
Mar	116.2	163.0	204.1	176.5	169.0	138.8	150.0	144.4	160.0
Apr	13.2	32.5	32.6	36.4	23.1	30.7	35.9	4.6	27.9
May	13.7	9.0	17.3	23.2	22.8	6.6	0.1	5.0	12.0
Jun	17.1	68.7	22.5	42.8	18.5	16.3	6.2	7.5	26.1
Jul	5.1	0.0	7.9	34.2	29.4	7.7	2.1	1.9	11.9
Aug	4.1	0.0	37.3	12.1	1.4	4.7	6.9	0.0	8.9
Sep	3.4	0.1	21.0	12.3	118.4	18.5	0.0	20.2	27.2
Oct	43.7	34.1	83.3	44.2	73.8	132.8	43.8	75.5	69.6
Nov	64.2	181, 1	126, 0	52.7	87.2	114.2	66.3	91.4	102, 7
Dec	107, 0	132, 6	86.0	167.4	131.8	122.3	163, 5	80.8	126, 5
Total	690.5	1179.4	1110.7	1038.1	1150.2	1000.4	948.4	874.2	1045.9

Figure 9 APIPA monthly average rainfall for 2019-2022

Remark: The Alarobia data was biased by missing values, so we did not include it in the calculation of the mean value in the table for 2019-2022.

We have the following illustration for different range of data that we have analyzed from the dataset where we used the average min and max value of total yearly precipitation per station:

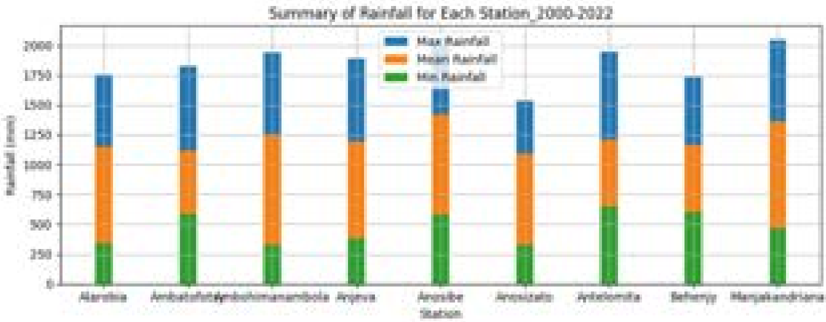


Figure 10 Min/Max/Average rainfall Data 2000-2022

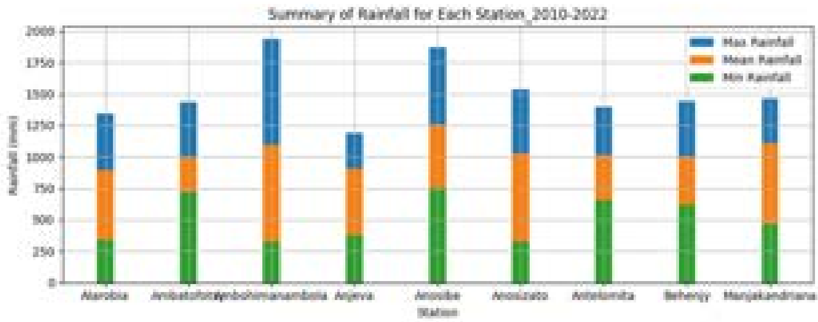


Figure 11 Min/Max/Average rainfall Data 2010-2022

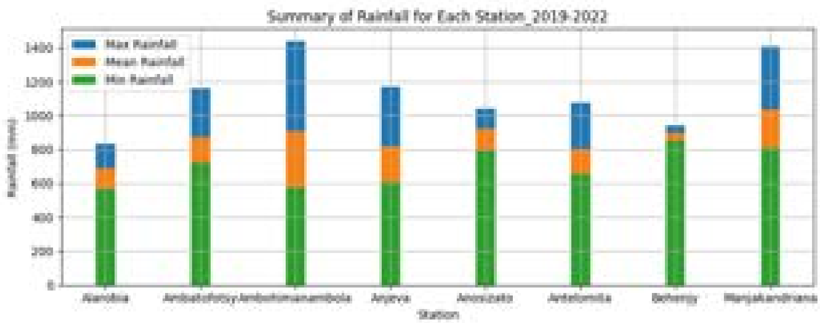


Figure 12 Min/Max/Average rainfall Data 2019-2022

We can observe that the rainfall measured at the station tends to decrease over the year. The more recent the data we analyze, the lower the values are. However, we can still rely on the fact that over the past 10 years, the average rainfall was estimated to fluctuate around 1000 mm per year.

The repartition of the average precipitation during the year is illustrate in the figure bellow for the periode between 2019 to 2022 and 2010-2022.

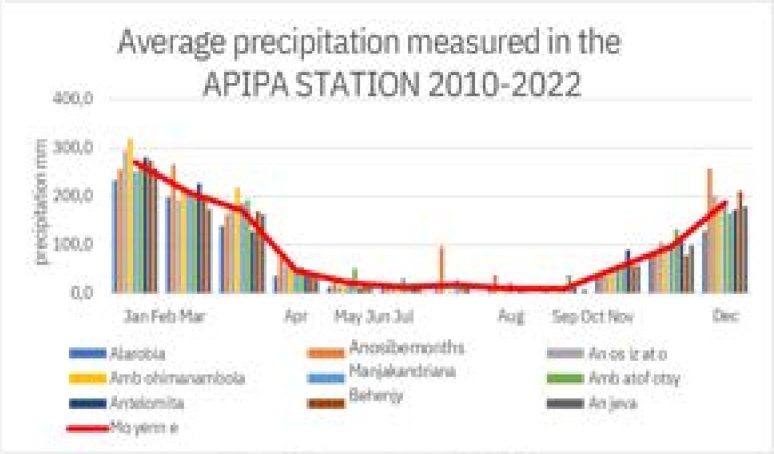


Figure 13 Average precipitation 2010-2022

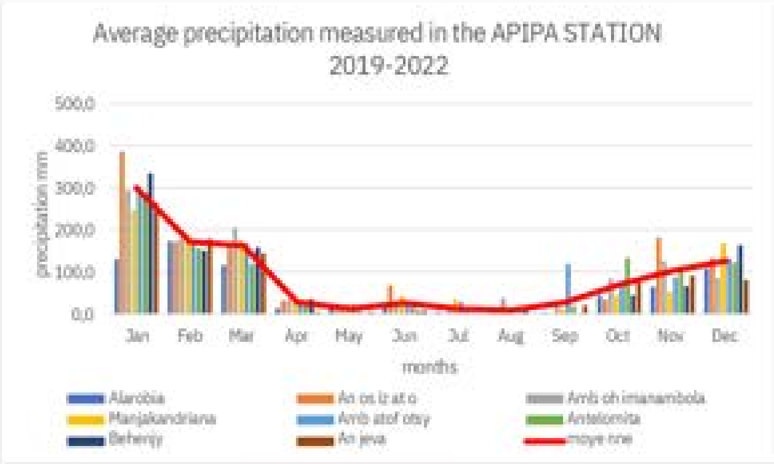


Figure 14 Average precipitation 2019-2022

The assertions posited in [1] and [2] are readily affirmed by the visual representation, wherein the two distinct seasons of Madagascar are discernible. Antananarivo is not exempt from this validation.

5- Analys of the past Scenario from APIPA data

The following table will show the number of rainy days as the amount of precipitation during these days for the 2019-2022 period:

Table 1 rainfall Scénario 2019-2022 Source APIPA

	Average Annual Rain mm	Max Rain mm	Average Number of Rainy day [mm]	Rainy day > 1mm	Rainy day > 5mm	Rainy day > 10mm	Rainy day > 25mm	Rainy day > 50mm	daily max rain
Anosizato	921,6	1044,0	58	51	36	26	12	4	119
Ambohimanambola	909,8	1440,1	69	52	35	24	8	3	142
Manjakandriana	1038,1	1408,0	133	101	53	29	10	2	120
Ambatolotsy	871,6	1161,3	72	57	36	27	10	3	131
Antelomita	804,9	1078,5	114	70	36	23	9	2	135
Behenjy	896,2	943,8	73	58	39	28	13	3	83
Anjeva	820,4	1169,4	52	51	37	25	10	2	113
Antananarivo	894,6	1178	82	63	39	26	10	3	120

This table demonstrates the following key findings:

- The average number of rainy days varies considerably, ranging from 52 to 133 days across the stations with an average of 82
- Precipitation events exceeding 25 mm occur within a range of 8 to 13 days.
- The highest recorded daily rainfall spans from 83 mm to 142 mm.
- Notably, there are instances of significant rainfall, with some days experiencing precipitation of up to 10 mm, and a few days even reaching 50 mm.

This indicates that occasionally, there are instances of minimal precipitation (1 mm), where the losses during capture may outweigh the volume collected. For instance, each system requires a minimum threshold of precipitation to effectively collect and store water. Additionally, it is noteworthy that during periods of heavy precipitation, undersized storage facilities may result in a significant portion of the rainfall being lost. These are important parameters to consider in the analysis.

The following illustration depicts a duration curve, a graphical representation illustrating the cumulative distribution of rainfall intensity throughout the year. This curve offers valuable insights into the distribution of rainfall intensity over time. Through analysis of the curve, patterns such as periods of heavy rainfall, dry spells, and overall variability in rainfall intensity become evident. The duration curve serves as a crucial tool for rainwater harvesting endeavors. It guides the sizing and design of rainwater harvesting systems by indicating the necessary storage capacity required to efficiently capture rainfall. For the 2021 data, we can easily see how the precipitation is distributed for Antananarivo. It gives a continuous curve of the discrete description on the table 1.

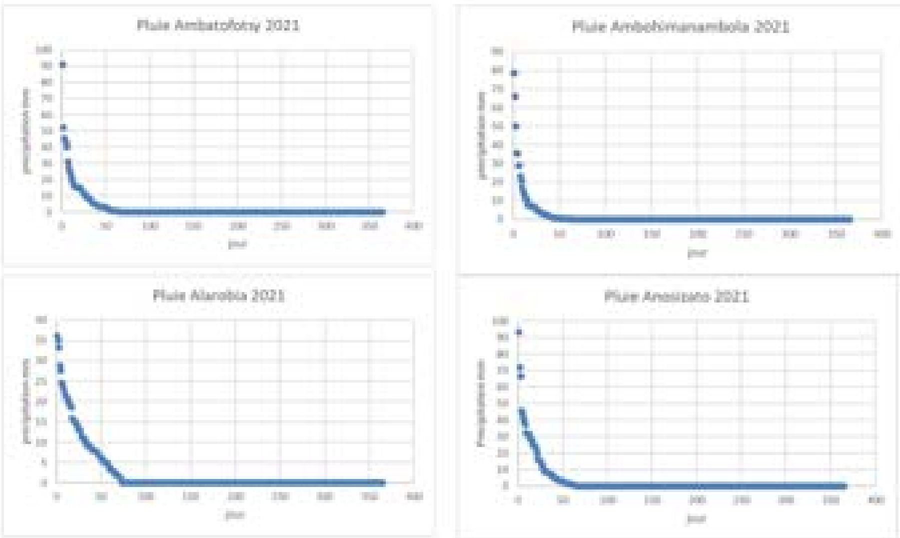


Figure 15 duration curve of precipitation in APIPA STATION 2021

The processed data from APIPA will be appended to this document to verify the basis of all analyses conducted for rainfall estimation.

6- RAINFALL MAP

Based on the rainfall data collected from the APIPA Station Measurement, we have developed a rainfall map of the Antananarivo City region, where the university is located. The Inverse Distance Weighting (IDW) method was employed in creating this map, a widely utilized technique for constructing rainfall maps based on weighted data. The map was generated using QGIS software. The data utilized for this purpose were derived from the average rainfall records spanning the period from 2000 to 2022 and the 2019-2022.

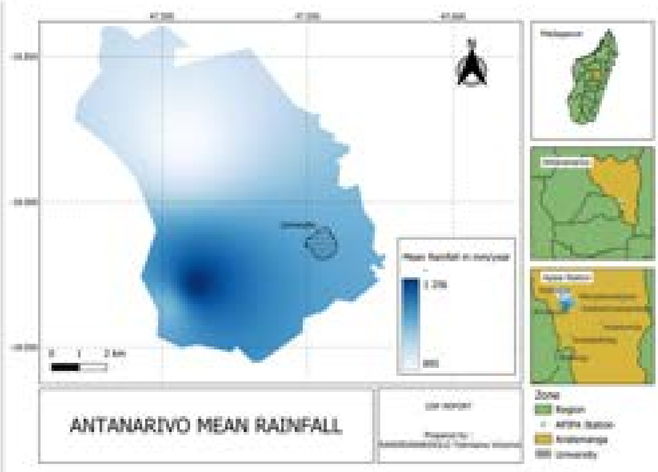


Figure 16 : Rainfall map based on APIPA data 2000-2022

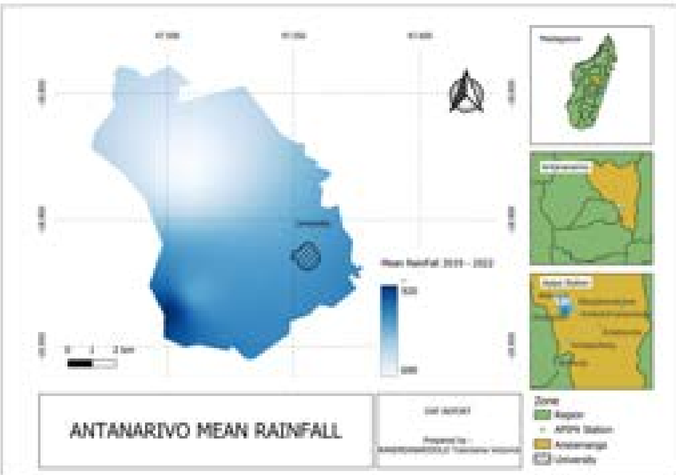


Figure 17: Rainfall map based on APIPA data 2019-2022

Based on Figures 9 and 10, we can infer that the estimated precipitation at the University of Antananarivo fluctuates around 800 mm/year from 2012 to 2022. However, considering the average data from the period 2000-2022 leads to an estimated value of 1000 mm/year for precipitation at the University of Antananarivo.

7- BUILDING ROOFTOP AREA

For the subsequent calculations, it will be necessary to ascertain the surface area of the buildings within the University of Antananarivo. The surface area of each building will subsequently allow us to deduce the volume of water that can be captured, as the captured rainfall volume is expressed as follows:

$$V = A * p * c$$

Where:

- V is the Volume of rain harvested [m3]
- A is the Area of the Roof [m2]
- p is precipitation [m]
- c is the coefficient related to the type of the roof

Table 2 type of catchement

Type of Catchement	Tyles	Corrugated metal sheet	Concrete	Brick pavement	Soil on slopes less than 10%	Rocky natural catchements
Coefficient	0.8-0.9	0.7-0.9	0.6-0.8	0.5-0.6	0.0-0.3	0.2-0.5

From the Volume harvested, we can evaluate the type of stockage we will need. The roof area will be determined utilizing GIS software QGIS, which applies spatial analysis techniques to compute the surface area of rooftops within the designated region. This software facilitates precise measurements of geographical features, including building footprints, thereby enabling the extraction of accurate roof area data for further analysis.

Each building is subsequently assigned a unique ID and labeled with corresponding attributes, such as the roof area, department affiliation, and building name. Following this, buildings will be categorized based on their roof area dimensions. This classification will offer initial insights into which buildings may yield the highest volume of captured rainfall. It is noteworthy, however, that roof area alone does not exclusively inform our selection process, as the needs of occupants also warrant consideration. The findings indicate that there are 168 structures within the university, with surface areas ranging from 36 to 2726 m^2.

We actually got:

- 2 structures that have an area exceeding 2188 m^2
- 7 structures with an area from 1650 to 2188 m^2
- 2 structures with an area from 1381 to 1650 m^2
- 12 structures with an area from 843 to 1381 m^2

Those Building are actually the Conaco DEGS, Conaco Medecine, Conaco Lettre, Primature, Conaco Science, NAS, Library, Gymnase, DT_DEGS, DT_Medecine, Bloc

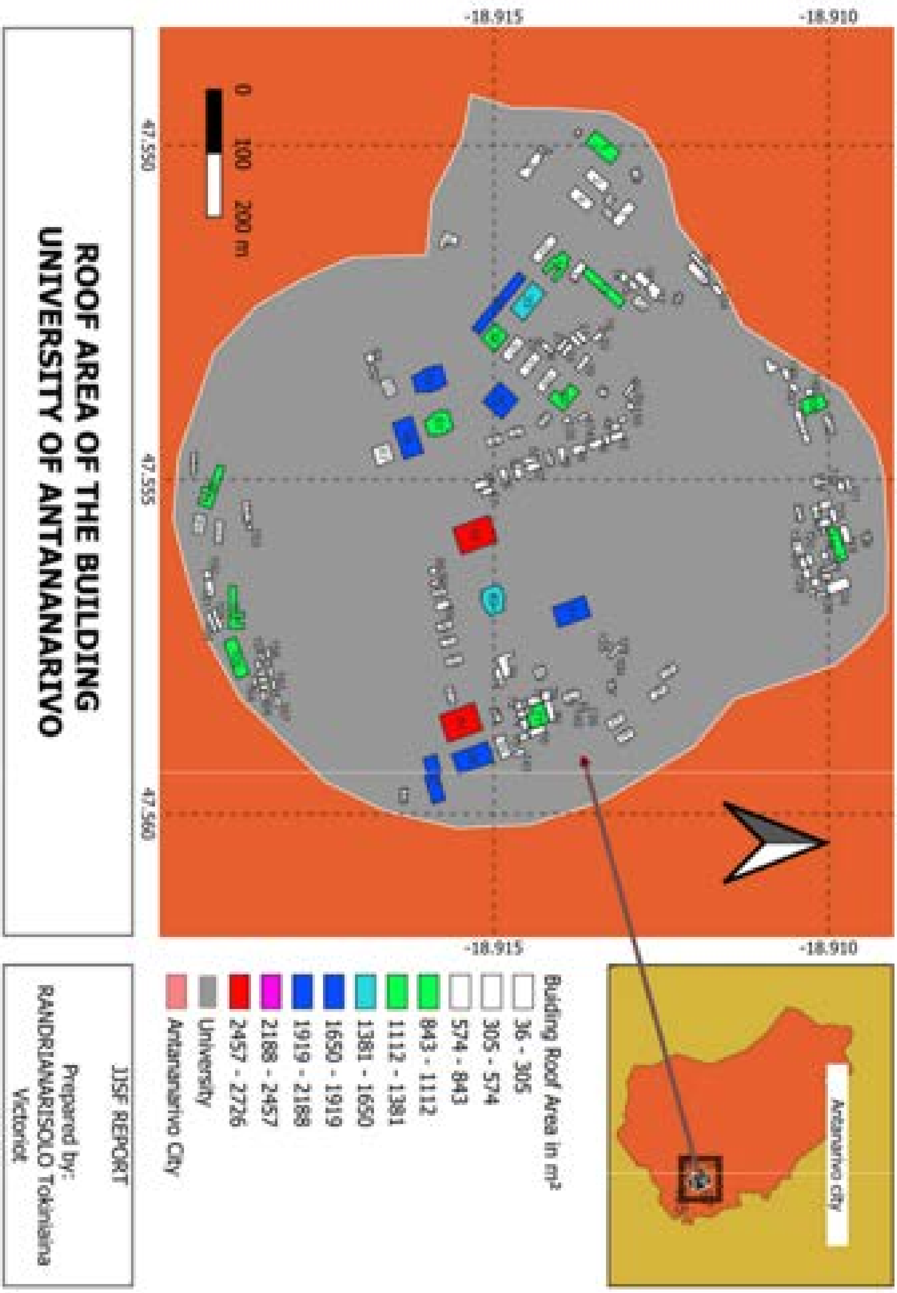
Tech Polytechnique, Departement Mathematique, Departement lettre, Science Q1, Présidence …

Table 3 List of the building in the university of Antananarivo

ID	Building name	Departement	Roof Area (m²)
68	CONACO	FLSH	2726
94	CONACO	DEGS	2679
66		Gymnase	2033
96	CONACO	Medecine	2029
34	Département	Science	1907
81	Conaco3	Science	1873
60		Library	1751
62	DT	DEGS	1731
97		Primature	1653
69	NAS	Science	1385
1	AEDECOUA	DEGS	1347
105		AdminUA	1337
61	DT	Medecine	1336
13	Département	FLSH	1196
98		AdminUA	1059
30		Science	1024
102		AdminUA	1010
32	Q1Q2	Science	997
106	Atelier	Agro	925
117		Agro	921
77	Bloc tech	POLY	913
11		Présidence	901
67	Département	Sport	843
10	Département	Médecine	774
4	DSC	DEGS	758
2	DSC	DEGS	751
7	Amphi DEGS	DEGS	724
9		Labo CM	700

The table above presents the key buildings with roof areas exceeding 700 m². To provide a visual representation of their placement within the university premises, a map displaying these buildings alongside their respective IDs is included below. Despite the relatively modest roof areas of many structures, their central positioning within the campus facilitates effective rainwater harvesting. The close proximity of these buildings allows for the consolidation of collected rainfall, potentially mitigating the limitations posed by individual roof areas. Consequently, while the roof areas may be individually small, their combined contribution to rainwater harvesting remains significant due to their strategic positioning within the campus. Moreover, the relevance of these structures is underscored by their central location, which aligns with the pertinent needs of the university community.

de


ROOF AREA OF THE BUILDING
UNIVERSITY OF ANTANANARIVO
-18.915
-18.910
47.550
47.555
47.560
0
100
200 m
Antananarivo city
Building Roof Area in m²
36 - 305
305 - 574
574 - 843
843 - 1112
1112 - 1381
1381 - 1650
1650 - 1919
1919 - 2188
2188 - 2457
2457 - 2726
University
Antananarivo City
JJSF REPORT
Prepared by:
RANDRIANARISOLO Tokiniaina
Victoriot

8- Analysis of Scenario from APIPA data based on the roof Area

The following table based on the formula $V=A \cdot p \cdot c$ and an average rainfall of 894.6 mm from the APIPA data (2019-2022) is stored on the excel file that gives all the foundation of our study. We choosed a max daily rainfall as 120 from the table 1.

Table 4 Aversted Rainfall from the building

id	Buisling name	Departement	Roof Area [m²]	Type of roof	Volume from Total RainFall [m3/year]	Volume for daily max rainfall	Volume for 25 mm of precipitation [m3/day]	Volume for 10 mm of precipitation [m3/day]	Volume for 5 mm of precipitation [m3/day]
68	CONACO	FLSH	2726	0,8	1 951,0	262,6	54,5	21,8	10,9
94	CONACO	DEGS	2679	0,8	1 917,4	258,1	53,6	21,4	10,7
66		Gymnase	2033	0,8	1 455,0	195,9	40,7	16,3	8,1
96	CONACO	Médecine	2029	0,8	1 452,2	195,5	40,6	16,2	8,1
34	Département	Science	1907	0,7	1 194,2	160,8	33,4	13,3	6,7
81	Conaco3	Science	1873	0,8	1 340,5	180,5	37,5	15,0	7,5
60		Library	1751	0,7	1 096,6	147,6	30,6	12,3	6,1
62	DT	DEGS	1731	0,8	1 238,9	166,8	34,6	13,8	6,9
97		Primature	1653	0,7	1 035,2	139,3	28,9	11,6	5,8
69	NAS	Science	1385	0,8	991,3	133,4	27,7	11,1	5,5
1	AEDECOUA	DEGS	1347	0,7	843,6	113,6	23,6	9,4	4,7
105		AdminUA	1337	0,7	837,3	112,7	23,4	9,4	4,7
61	DT	Médecine	1336	0,8	956,2	128,7	26,7	10,7	5,3
13	Départementt FLSH		1196	0,7	749,0	100,8	20,9	8,4	4,2
98		AdminUA	1059	0,7	663,2	89,3	18,5	7,4	3,7
30		Science	1024	0,7	641,3	86,3	17,9	7,2	3,6
102		AdminUA	1010	0,7	632,5	85,1	17,7	7,1	3,5
32	Q1Q2	Science	997	0,7	624,4	84,0	17,4	7,0	3,5
106	Atelier	Agro	925	0,7	579,3	78,0	16,2	6,5	3,2
117		Agro	921	0,7	576,8	77,6	16,1	6,4	3,2

id	Busding name	Departement	Roof Area [m²]	Type of roof	Volume from Total RainFall [m3/year]	Volume for daily max rainfall	Volume for 25 mm of precipitation [m3/day]	Volume for 10 mm of precipitation [m3/day]	Volume for 5 mm of precipitation [m3/day]
77	Bloc tech	POLY	913	0,7	571,8	77,0	16,0	6,4	3,2
11		Présidence	901	0,8	644,9	86,8	18,0	7,2	3,6
67	Département	Sport	843	0,7	527,9	71,1	14,8	5,9	3,0
10	Département	Médecine	774	0,7	484,7	65,2	13,5	5,4	2,7
4	DSC	DEGS	758	0,7	474,7	63,9	13,3	5,3	2,7
2	DSC	DEGS	751	0,7	470,3	63,3	13,1	5,3	2,6
7	Amphi DEGS	DEGS	724	0,7	453,4	61,0	12,7	5,1	2,5
9		Labo CM	700	0,8	501,0	67,4	14,0	5,6	2,8
	TOTAL	29 building	38870		24 904	3 352	695	278	139

9- Estimation of the rainwater drained to the pipe to the rice field:

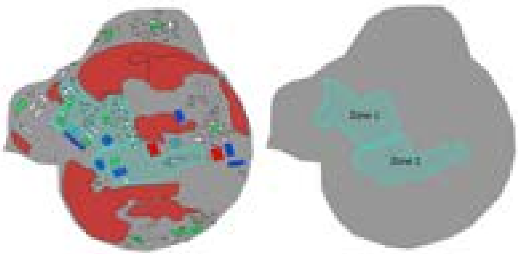


Figure 18 Zone existing infrastructure channes rainwater

Through investigations conducted during the fellowship workshop, it has come to our attention that certain existing infrastructure channels rainwater towards the adjacent rice fields.

Table 5 Rain Cachement from the two specifoid area

id	Area	Coefficient	Total rain capture [m3/year]	Volume for Daily MAX Précipitation [m3/day]	Volume for Daily 25mm précipitation [m3/day]	Volume for Daily 10mm précipitation [m3/day]	Volume for Daily 5mm précipitation [m3/day]
1	72674	0,3	19513	2616	545	218	109
2	64625	0,3	17352	2327	485	194	97

These estimations are derived from the analysis of Zones 1 and 2, which feature rainwater drainage systems leading to the rice fields. Utilizing coefficients of rainwater catchment and previous rainfall data scenario, we have arrived at the aforementioned results.

10- Key Results:

From the previous study, we came to some considerable results:

- Wet Season: the graph from figure 11-12 and the table on the figure 5-6-7 has shown that there is a rainy season of 5 - 6 months from October to April where the precipitation is significant for Antananarivo. It confirms what is said on many literature
- Total Rainfall: the amount of precipitation for Antananarivo average 1000 mm/year from 1991-2022 but as we move to the recent year, it tend to fluctuate around 900 to 800 mm/year (table 1)

Number of rainy days: The average number of rainy days exhibits significant variation, ranging from 52 to 133 days across the stations, with an overall average of 82 days.

Table 6 Key result of the analysis

	Average Total Rain [mm/year]	Max rain mm	Average number of rainy day mm	Rainy day > 1mm	Rainy day > 5mm	Rainy day > 10mm	Rainy day > 25mm	Rainy day > 50mm	daily max rain
Antananarivo	894,6	1178	82	63	39	26	10	3	120

- Area of the building: Building area breakdown:

4 structures with an area exceeding 2000 m^2

13 structures with an area ranging from 1000 m^2 to 2000 m^2

11 structures with an area ranging from 700 m^2 to 1000 m^2

- Amount of Rainwater harvested: The extreme value of rainfall harvested are between this table for roof Area from 2726 to 700 m^2

Table 7 Rainfall Arvested Range

Roof Area [m²]	Type of roof	Volume from Total RainFall [m3/year]	Volume for daily max Rainfall [m3/day]	Volume for daily precipitation of 25 mm	Volume for daily precipitation of 10 mm	Volume for daily precipitation of 5 mm
2726	0,8	1 951,0	262,6	54,5	21,8	10,9
700	0,8	501,0	67,4	14,0	5,6	2,8

11- Discussion:

- On the method:

calculating the average of data without considering missing values, one common approach is to simply exclude the missing values from the calculation and then divide the sum of the remaining values by the number of non-missing values. This method provides a straightforward way to compute the average based only on available data points.

However, it will lead to a nonconvergent estimation of the total rainfall in yearly average and total monthly average like we can see on the table 1 and figure 7. But they gave an estimated value that fluctuate between 900 to 1000 mm/year.

- Relevant result: Although, based on the similarity of the results we have observed from many other sources, we can conclude that the analysis of rainfall from the APIPA station measurements provides robust and relevant data that we can rely on to draw firm conclusions.
- Suggestion: It is advisable to consider the lower range of precipitation values from the total rainfall dataset, reflecting the observed trend of annual precipitation. However, when sizing equipment, it's crucial to also account for daily rainfall data. Both the analysis of monthly and yearly average totals should be factored in when making decisions based on the dataset.

Conclusion:

This document presents a comprehensive analysis of a substantial dataset aimed at corroborating information obtained from diverse sources regarding precipitation in Antananarivo. Specifically, it delves into an examination of the wet season in Antananarivo and provides estimations of the total annual rainfall for the University of Antananarivo. These data were subsequently utilized to gauge the potential harvestable rainwater for a year based on the roof area of existing buildings. Furthermore, various scenarios for rainwater collection were analyzed in detail. Indeed, these results and analyses serve as a foundational framework for future studies, particularly for the JJSF Water Management Project. They provide valuable insights into precipitation patterns, rainfall estimation, and potential rainwater harvesting opportunities, laying a solid groundwork for further exploration and implementation within the project's scope.

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Some editing of text, Figure numbers, and such may have been done as part of preparation for publishing. Nevertheless, The findings of the Graduate Researcher remain independent.

JACQUELYN JESTINE SANDERS FOUNDATION
BUILDING VISION, REALIZING CHANGE

"This Fellowship will give me the experience and above all the assets I need to contribute to the development of my country, to improve the management, treatment, use and consumption of water in Madagascar."

JJSF Fellow
RAMIANDRISOA, Rebeca Tatiana
Masters Graduate, Water & Environmental Engineering
University of Antananarivo
2024

Introduction to the Fellowship of RAMIANDRISOA Rebeca Tatiana

We are proud to introduce the contributions of Rebeca Tatiana RAMIANDRISOA, a distinguished student specializing in Water Engineering and Environmental Engineering. Throughout her fellowship, Rebeca has demonstrated exceptional dedication to understanding and addressing critical environmental challenges in her community. Her comprehensive report on Boreholes / Wells reflects her commitment to sustainable practices and innovative solutions in the field.

Recognizing the diverse linguistic backgrounds of our fellowship participants, we discovered that not all students felt entirely comfortable using English as a medium for their reports. In our pursuit of consistency, we initially requested that all reports be submitted in English. However, we believe it is vital to honor the work of our French-speaking students, who bring unique perspectives and insights to our collective mission. Therefore, we have chosen to present Rebeca's report in French, her native language, to ensure her voice and ideas are conveyed authentically.

We are pleased to provide this report for the benefit of our French-speaking readers, fostering an inclusive environment that values linguistic diversity and cultural heritage. For those who prefer English, an English-language version of Rebeca's report is also available on the foundation's website, ensuring accessibility to a wider audience.

We invite you to engage with Rebeca's important work, which not only highlights the significance of effective borehole management but also underscores the role of education and community involvement in promoting sustainable development. Her findings and recommendations serve as a valuable resource for policymakers, practitioners, and scholars alike, contributing to our collective efforts to create a cleaner and healthier environment.

JACQUELYN JESTINE SANDERS FOUNDATION
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RAINWATER CAPTURE PROJECTIONS FOR UNIVERSITY ROOFTOPS

LA QUALITE D'EAU ET LES DONNEES SUR LES FORAGES DE L'UNIVERSITE D'ANTANANARIVO

UN PROJET D'ETUDE AVEC JACQUELYN JESTINE SANDERS FOUNDATION

Note de l'auteur:

RAMIANDRISOA Rebeca Tatiana Masteur en Génie de l'Eau et en Génie de l'environnement

Table des matières

INTRODUCTION

L'Université d'Antananarivo, en tant qu'institution académique de premier plan à Madagascar, joue un rôle essentiel dans la vie intellectuelle et sociale de la Région. Au cœur de ses activités se trouve la question cruciale de l'accès à l'eau potable, une ressource indispensable à la fois pour les besoins quotidiens de la communauté universitaire et pour la réalisation de ses missions de recherche et d'enseignement. En examinant de près ces données, nous pourrons mieux comprendre les défis auxquels l'Université est confrontée en matière d'eau et identifier les opportunités pour améliorer la gestion de cette ressource vitale. Dans cette présentation, nous commencerons par explorer les caractéristiques des forages de l'université, mettant en lumière leur nombre, leur emplacement géographique et leur profondeur. Ensuite, nous examinerons de près la qualité de l'eau dans ces forages, en analysant les paramètres clés tels que le pH, la turbidité et la présence éventuelle de contaminants. Enfin, nous discuterons des implications de ces données pour la communauté universitaire et proposerons des recommandations pour une gestion plus efficace de l'eau sur le campus. Cette représentation des données est non seulement essentielle pour évaluer la situation actuelle de l'approvisionnement en eau à l'université d'Antananarivo, mais elle offre également une base solide pour orienter les politiques et les actions visant à assurer un accès sûr et durable à cette ressource vitale pour les années à venir.

I -PRESENTATION DES FORAGES DE L'UNIVERSITED'ANTANANARIVO

I -1. Nombre total de forages:

L'Université d'Antananarivo dispose actuellement de six(06) forages opérationnels répartis sur le campus principal. Ces forages sont stratégiquement positionnés pour fournir un accès à l'eau à l'ensemble de la communauté universitaire.

I -2. Localisation des forages:

Carte géographique illustrant l'emplacement précis de chaque forage sur le campus. Cette carte permet de visualiser la répartition géographique des points d'accès à l'eau et facilite la planification de la maintenance et des futurs projets d'expansion.

N°	Latitude	Longitude
F01	18°54'41.45"S	47°33'28.86"E
F02	18°54'42.59"S	47°33'22.12"E
F03	18°55'03.41"S	47°33'17.64"E
F04	18°54'45.12"S	47°33'20.97"E
F05	18°55'03.18"S	47°33'18.10"E
F06	18°55'01.42"S	47°33'17.79"E

Tableau 1: Localisation des forages

Figure1: Forages d'Ankatso **source:** Google Earth

I -3. Profondeur des forages:

Le tableau 2 présente la profondeur de chaque forage, allant de 15 mètres à 50 mètres en fonction des caractéristiques géologiques locales. Ces informations sont cruciales pour comprendre la structure des aquifères et la capacité des forages à fournir un approvisionnement en eau suffisant.

Numéro	F01	F02	F03	F04	F05	F06
Profondeurs (mètres)	15	15	14	17	30	50

Tableau 2: Profondeurs des forages

I -4. Capacité de production d'eau : Débit (m3/h)

Données sur la capacité de production d'eau de chaque forage, mesurée en mètre cube par heure. Ces chiffres permettent d'évaluer la disponibilité d'eau des forages et leur capacité à répondre aux besoins de la communauté universitaire, notamment en période de pointe.

Numéro	F01	F02	F03	F04	F05	F06
Débit(m3/h)	1,5	1,5	1,25	1,5	3	2,5

Tableau 3: Débits des forages

I -5. État de fonctionnement:

L'évaluation de l'état de fonctionnement de chaque forage est donnée dans le tableau 4 ci- dessous, y compris les informations sur les pannes récentes, les réparations effectuées et les prévisions de maintenance préventive.

Numéro	Etat actuel
F01	Besoin de réhabilitation et achat + installation pompe
F02	Besoin de rehabilitation et achat + installation pompe
F03	Besoin d'approfondissement et achat + installation pompe
F04	Abandoné pour raison de sécurité
F05	Fonctionnel mais par l'adduction d'eau de CITE Ankatso 1
F06	Fonctionnel et pour l'adduction d'eau du Gymnase couvert Ankatso

Tableau 4: Etat de fonctionnement des forages

II -QUALITE DE L'EAU DANS LES FORAGES

Sur les six forages que l'université a mis en place, trois ont été soumis à des controles de qualité approfondis pour évaluer la qualité de l'eau. L'étude a recueilli des données exhaustives concernant ces trois forages,permettant une comprehension détaillée de la qualité de l'eau dans ces zones spécifiques. Ces etudes ont été réalisées en 2020.

Voici les localisations des trois forages étudiés:

Figures 2: figures des trois forages étudiés

II -1-Valeurs des turbidités:

Forage	F1	F2	F3	Norme
Turbidité (NTU)	12	19	38,7	< 5NTU

Tableau 5: Turbidités dans les forages

II -2-Valeurs des pH:

Forage	F1	F2	F3	Norme
Ph	7,35	8,61	7,75	6,50-9

Tableau 6: pH dans les forages

II -3-Valeurs des conductivités électriques:

Forage	F1	F2	F3	Norme
Conductivité (µS/cm)	150	537	127	<3000

Tableau 7: Conductivités électriques dans les forages

II -4-Valeurs de l'analyse des matières en suspension :

Forage	F1	F2	F3	Norm
MES(mg/L)	80	124	180	e <30

Tableau 8: matières en suspension des forages

II -5-Analyse de DBO5:

Forage	F1	F2	F3	Norm
DBO5 (mg O2/L)	5,25	6,20	6,80	e ≤5

Tableau 9: DBO5 dans les forages

II -6-Analyse de DCO:

Forage DCO	F1	F2	F3	Norm
(mg O2/L)	22,3	23,22	28,50	e ≤20

Tableau 10: DCO dans les forages

II -7-Analyse de coliformes totaux:

Forage	F1	F2	F3	Norme
CT en UFC/100mL	3,9.102	1,36.102	2,52.103	0 UFC/100mL

Tableau 11: Coliformes totaux dans les forages

II -8-Analyse des coliformes fécaux:

Forage	F1	F2	F3	Norme 0
CF en UFC/100mL	102	6,8.101	2,50.102	UFC/mL

Tableau 12: Coliformes fécaux dans les forages

II -9-Analyse de stréptocoque fécaux:

Forage	F1	F2	F3	Norme O
SF en UFC/100mL	<1	6	<1	UFC/100Ml

Tableau 13: Stréptocoque fécaux dans les forages

II -10-Analyse de spores des bactéries Anaérobie sulfite-réductrice :

Forage	F1	F2	F3	Norme
ASR en UFC/20mL	<1	2	<1	

Tableau 14: Spores des bactéries ASR dans les forage

CONCLUSION

Les données sur les forages de l'Université d'Antananarivo et la qualité de l'eau dans ces forages nous offrent un aperçu de l'état actuel de l'approvisionnement en eau sur le campus. En examinant de près ces données, nous pouvons tirer plusieurs conclusions importantes qui orienteront les efforts futurs pour assurer un accès sûr et durable à cette ressource vitale. La présentation des forages a mis en lumière l'importance de ces infrastructures pour la communauté universitaire, en soulignant leur nombre, leur localisation et leur capacité de production d'eau. Ces informations sont essentielles pour planifier la maintenance et l'expansion futures des forages afin de répondre aux besoins croissants en eau sur le campus. La qualité de l'eau a révélé des variations importantes dans certains paramètres de qualité de l'eau d'un forage à l'autre. Bien que la plupart des forages respectent les normes de qualité de l'eau, certains présentent des problèmes potentiels de contamination ou de fluctuations dans les niveaux de certains contaminants. Cela fournit une base solide pour guider les décisions futures en matière de gestion de l'eau à l'université d'Antananarivo. Elle souligne l'importance de la collaboration entre les parties prenantes et de l'adoption de pratiques durables pour garantir un accès équitable et sécurisé à cette ressource vitale pour toute la communauté universitaire.

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Some editing of text, Figure numbers, and such may have been done as part of preparation for publishing. Nevertheless, The findings of the Graduate Researcher remain independent.

JACQUELYN JESTINE SANDERS FOUNDATION
BUILDING VISION, REALIZING CHANGE

"I am attending university because I feel that I still need solid knowledge for a bright future and I know that my country needs me."

JJSF Fellow
RAKOTOMALALA, Ny Ando Erica
Masters Graduate, Chemical Engineering
University of Antananarivo

Introduction to the Wastewater Analysis of Ms. JoJo Rakotomalala

We are pleased to present the wastewater analysis conducted by Ms. JoJo Rakotomalala, a dedicated researcher who has undertaken the crucial task of assessing the wastewater treatment projections established by ARAFA. In the field of environmental engineering, accurate projections are essential for effective planning and implementation of wastewater management systems. JoJo's work plays a pivotal role in evaluating these projections, ensuring they are grounded in rigorous analysis and align with current best practices.

By critically examining the existing data and methodologies used in ARAFA's projections, Ms. Rakotomalala provides invaluable insights into the effectiveness and reliability of these assessments. Her analysis focuses on determining whether the current team concurs with ARAFA's findings or if there is a basis for modifying the projections to better reflect the realities of wastewater treatment needs.

Through a thorough evaluation of the assumptions and calculations underpinning the projections, JoJo's work contributes to a more nuanced understanding of wastewater management in the region. This analysis not only aids in refining treatment strategies but also ensures that future projects are informed by accurate and relevant data.

As we delve into JoJo's findings, we invite readers to engage with her critical assessments and insights, which are instrumental in enhancing the field of wastewater treatment and contributing to the sustainability of our environmental resources.

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University Wastewater – Volume Projections Report

RAKOTOMALALA Ny Ando Erica

Author note

RAKOTOMALALA Ny Ando Erica holds the following degree:

Premier Partenaire des Professionnels

Bachelor of chemical and industrial process engineering

Abstract

Nowadays, Antananarivo, the capital of Madagascar is classified among the most polluted city in the world. Apart from air pollution and the wastes that fill the streets, wastewater are also a big part of the problem, especially the ones from the university campus of Antananarivo. This report contains assessment of the volume of wastewater produced daily and annually on Tanà campus with some details and its situation of everyday.

Divers students are living in the campus during their five years of study. That means, current students are using water for their meals, bath, laundry, dishes... Wastewater from those daily routines must be well treated before they get dumped. Today, infrastructures in the university campus are old, do not work as well as expected so that ARAFA made a study about the maintenance of water network and an efficient wastewater treatment system. Emergency repair work and some wastewater treatment through lagoons are mentioned in the document.

Nonetheless, a global analysis explored the extent of the amount of wastewater that could be produced and filtrated per day, with such benefits for the campus, economy and environmental protection.

Through a synthesis of that research exertion, this paper comments the solutions suggested by working on the daily volume of wastewater and evaluating where it goes. These points extend beyond wastewater treatment efficiency for a more wonderful way of environment protecting.

Keywords: wastewater, treatment, volume

Introduction

As universities strive for sustainability, wastewater management emerges as a critical aspect of campus operations. With diverse sources ranging from laboratories to dormitories, opportunities for treatment. Implementing advanced solutions and the wastewater generated presents unique challenges and innovative strategies, this project aims to minimize their environmental footprint while ensuring compliance with regulatory standards. To achieve this, an initial step involves assessing the volume of wastewater generated daily, mapping where it goes and evaluating if the solutions suggested by ARFA is accurate. Furthermore, understanding the current wastewater management practices, whether through onsite treatment facilities, municipal systems, or other means, provides insights into areas for improvement and optimization. Let's explore the tailored solutions and sustainable practices employed in treating wastewater from the diverse ecosystem university campus of Antananarivo.

Independent assessment of the volume of wastewater produced daily and annually on Tanà campus

Every year, 35 000 students frequent Ankatso University of Antananarivo including bachelors. It is to highlight that not all them are living in the campus because most of them reside in town and around the university. Those who come from province are those who really hold the campus and they are around 5 000 students per year.

Those who do not live in the campus just use water for laboratories and toilets but those in the campus use water for their cooking, bath, laundry and dishes, that generate a large amount of wastewater produced per day.

Let us put an average quantity of used water for those who do not live in the campus and for those who do.

<u>Students who do not leave in the campus</u>: around 30 000 students just frequent university for studying. They do not really use water apart from going to the toilets and some of them use water during their experiments in the laboratory.

If all 200 students use toilets in one day, with 0,75 L of water and around 20 students use water in laboratory with 2L of water per day:

(0,5*200) + (2*20) = 140 L per day

<u>Students who live in the campus</u>: around 5 000 students are staying in the campus to live during their five years of study.

Their daily use of water can be divided in 4 parts: meal, bath, dishes and laundry that is not that very frequent as the three main uses. If we put 0,5 L for meal, 1 L for dishes and 0,5 L for bath:

(0,5*5000) + (1*5000) + (0,5*5000) = 10 000 L per day

In addition, they can make their laundry sometimes so if they make it once a week with 35 L per week, it gives:

35/7 = 5 L per day

There is also a fact that teachers and employees of the university use water during their days at the campus. Around 2 000 teachers and employees frequent the university every day. If all of them use 0,25 L per day:

0,25*2000 = 500 L per day

After summing all this, we get:

140 + 10 000 + 5 + 500 = 10 645 or 10,645 m3 per day

A very larger flow rate compared to the ARAFA report that gives 6 m3 per day.

To sum up, the amount of water produced every year in the campus is:

10,645 * 365 = 3885,425 m3 per year

<u>Where does the water go today?</u>

Five principal exhaust nozzles of wastewater in Ankatso University.

- One in the field of agronomy department
- Two next to the football field of Ankatso University
- - One at the east of 119
- - One at the east CONACO Médecine
-

<u>Wastewater that get out from the exhaust nozzle in the field of agronomy department</u>

The wastewater from all laboratories situated on the hill, including Chemistry, Geology, BEC/ADD, BA/ECES, and Pharmacology, is channeled into a common system along with the wastewater from the PPC laboratory, as well as those from the Biochemistry department and the Department of Plant Biology in Building I. Similarly, wastewater from facilities such as the FLSH department (restrooms, refreshment area) and all the offices of the presidency, including toilet wastewater, is also directed into this system, ultimately flowing towards the Agronomy field.

Wastewater that get out from the exhaust nozzls next to the football field of Ankatso University

The wastewater from the Physics, Chemical Thermodynamics, and restroom facilities in Building R is channeled through PVC pipes and converges into a common junction with the two laboratories in Buildings Q (Chemistry Laboratory, Environmental Chemistry Laboratory). Similarly, wastewater from the 28 laboratories, restrooms, and cafeteria in departments P and O is directed into another junction, linking back to the aforementioned laboratories and restrooms.
The wastewater from the hill laboratories and PPC is bifurcated: one stream heads towards the Agronomy field, while the others merge into a junction with wastewater from laboratories in Buildings P, O, and I, subsequently flowing towards two outlets. Wastewater from the surroundings of the gymnasium, DEGS Cathedral, Medicine, and the Baccalaureate Office is interconnected, funneling towards two outlets situated on the Ankatso football field.

Wastewater that get out from the east of the bus stop 119

The wastewater originating from the laboratories and restroom facilities at the Madagascar Institute for Vaccine Research, along with those from the medical-social service, are directed towards a drainage system. From there, they continue their flow towards a drainage outlet situated east of bus stop 119. Additionally, wastewater from Buildings A and B of the DEGS faculties is combined with wastewater from the building west of the DEGS parking lot. Subsequently, this amalgamated wastewater flows towards the same drainage outlet located east of bus stop 119.

Wastewater that get out from the exhaust nozzle at the east of CONACO Medecine

The wastewater generated by the Water Engineering, Environmental Engineering, and Geology laboratories is directed through two drainage systems, both linked to a central manhole. This manhole serves as a junction point for all wastewater from the Polytechnic Higher School of Antananarivo's laboratories, as well as wastewater from nearby buildings and the Conaco facility near Stichom. Subsequently, this collective wastewater is conveyed through pipelines and discharged eastward of the Medicine Conaco.

Does the ARAFA solution address the larger water challenges of the university?

Through this report, the ARAFA solution addresses partly the larger water challenges of the university because the amount of water produced every day is 10,645 m3 per day. So that the wastewater treatment system could be larger than ARAFA suggested in their report.

Anyway, the methods that ARAFA have suggested is efficient because they have studied all about the steps of treatment necessary and the rehabilitation of the infrastructures as well.

All the parameters that need to be verified were done such as COD or Chemical Oxygen Demand, BOD5 or Biochemical Oxygen Demand, suspended solids, volatile suspended solids, and organic matter. And we can see that wastewater from the University Campus is still easy to treat because, most of the parameters are under the standards effluent discharge.

The materials and the design suggested are also efficient because it shows innovation for the system.

To conclude, the ARAFA report is a good document to start a wastewater treatment for the Campus of Ankatso University, but it is also possible to think about extending the sizing of the design already suggested.

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JACQUELYN JESTINE SANDERS FOUNDATION
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"By harnessing collective expertise and resources, this initiative can facilitate the implementation of sustainable solutions to improve water access and conservation, to the benefit of Madagascar's communities and ecosystems."

JJSF Fellow
SAFIDINOMENA Lala Zo Harifetra Onjavalisoa
Masters Graduate, Water & Environmental Engineering
University of Antananarivo
2024

Introduction to the Fellowship of SAFIDINOMENA Lala Zo Harifetra Onjavalisoa

We are excited to showcase the contributions of SAFIDINOMENA Lala Zo Harifetra Onjavalisoa, an accomplished student specializing in Water Engineering and Environmental Engineering. Throughout her fellowship, Zo has exhibited remarkable dedication to understanding and tackling critical environmental issues in her community. Her detailed report on Wastewater Management exemplifies her commitment to sustainable practices and innovative solutions in this important field.

In recognizing the diverse linguistic backgrounds of our fellowship participants, we found that not all students were entirely comfortable submitting their reports in English. While we initially requested that all reports be presented in English for consistency, we feel it is essential to honor the contributions of our French-speaking students, who offer valuable perspectives and insights to our shared mission. Consequently, we have decided to present Zo's report in French, her native language, to ensure her thoughts and ideas are communicated authentically.

We are delighted to share this report for the benefit of our French-speaking audience, promoting an inclusive environment that values linguistic diversity and cultural heritage. For those who prefer English, an English-language version of Zo's report is also available on the foundation's website, ensuring broader accessibility.

We encourage you to explore Zo's significant work, which not only emphasizes the importance of effective wastewater management but also highlights the vital roles of education and community engagement in fostering sustainable development. Her findings and recommendations serve as a valuable resource for policymakers, practitioners, and scholars, contributing to our collective efforts to create a cleaner, healthier environment.

JACQUELYN JESTINE SANDERS FOUNDATION
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UNIVERSITE D'ANTANANARIVO
FACULTE DES SCIENCES
MENTION PROCEDES ET ECOLOGIE INDUSTRIELLE

EAUX USEES UNIVERSITAIRES –RAPPORT DE PROJECTIONS DE VOLUME

SAFIDINOMENA Lala Zo Harifetra Onjavalisoa

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PAT : Personnels Administratifs Techniques

CNRE : Centre National Pour le Recherche de l'Environnement

ARAFA : Angovo Rano Fandrosoana

EU : Eau Usée

EI : Evaluation Indépendant

BEC : Bassins sédimentaires, Evolution, Conservation

PPC : Physiologie – Animale Pharmacologie et Cosmétologie

BA : Biologie Animale

ECES : Entomologie Culture Elevage Santé

FLSH : Facultés des Lettres et Sciences humaines

Q = débit

.m3/j = mètre cube par jour

.m3/an =mètre cube par an

L = Litre

INTRODUCTION

Etudier les eaux usées des campus universitaire est crucial pour une gestion durable de l'eau et de l'environnement, nécessitant des rapports détaillés sur les volumes produits, les méthodes de traitement existantes et des suggestions pour renforcer l'efficacité et la conformité des systèmes de gestion. **[0]**

L'Université d'Antananarivo, comme de nombreuses institutions d'enseignement supérieur, est confrontée à des défis majeurs liés à la gestion de ses eaux usées. Dans le cadre de cet examen, nous entreprenons une évaluation indépendante du volume d'eaux usées produit quotidiennement et annuellement sur le campus. Cette analyse vise à comprendre l'ampleur du problème et à identifier les meilleurs pour sa résolution.

Dans un premier temps, nous examinerons où vont actuellement les eaux usées générées par l'Université de Tana. Comprendre le flux actuel des eaux usées est essentiel pour évoluer l'efficacité des systèmes existants et identifier les lacunes potentielles.

Enfin nous évaluerons la solution ARAFA, proposée pour répondre aux grands défis de l'eau de l'Université. Nous analyserons en détail son adéquation par rapport aux besoins spécifique de l'Université de Tana, en tenant compte de facteurs tels que la capacité, la durabilité environnementale et les couts associés.

Cette étude vise à fournir une base solide pour la prise de décision informée en matière de gestion des eaux usées sur le campus universitaire, en mettant en lumière les défis existants et en proposant des solutions viables pour l'avenir.

I. Evaluation indépendante du volume d'eaux usées produits quotidiennement et annuellement sur le campus de Tana

- Le nombre d'étudiants à l'université d'Antananarivo est de plus de35000 par ans **[1]**. En moyenne, un étudiant utilise 0,25 L d'eau par jour pour se laver et utiliser les toilettes.

Les eaux usées produites par les étudiants sont :
Q= 35000 * 0,25 = 8981,5L par jours et Q = 8981.5*365 =3278247 ,5 L par ans. Les débuts en m 3 /j et en m 3/an sont : Q= 8,381 m3 /jour et Q =3278,247 m3 /an

- Le nombre d'enseignants à l'Université d'Antanarivo est de 773**[2]**. En moyenne, un enseignant utilise 0,25 L d'eau pour se laver et pour utiliser les toilettes.

Les eaux usées produites par les enseignants sont :
Q = 773 * 0,25 = 193,25 L par jours et Q = 193.5 * 365 = 70536,25 L /an. Les débuts en m3/j et en m3 /an sont : Q = 0,193 m3 /jours et 70,536 m3/an.

- Les nombres des PAT à l'Université d'Antananarivo sont 1128**[3]**. En moyenne, un PAT utilise 0,25 L d'eau par jour pour se laver et pour utiliser les toilettes.

Les eaux Usées produites par les PAT sont :
Q = 1128 * 0,25 = 282 L par jours et 282 * 365 =102930 L / an. Les débuts en m3/j et en m3/an sont : Q =0,282 m3/j et 102,930 m3/an

-Il y a 168 laboratoires de recherche à l'Université d'Antanarivo [4].

La quantité d'eau utilisée par un laboratoire est en moyenne de 40 Litres par jour.

Les eaux usées produites par les laboratoires de recherche de l'Université d'Antananarivo sont :
Q = 168*40= 6720 m3/j. Les débuts en m3/j et en m3/an sont : Q = 6,720 m3/J et 2452,8 m3/an.

-A l'Université d'Antananarivo il y a 8 Buvettes **[5]**. En moyenne, une buvette consomme 20 L D'eau par jours.

Les eaux usées produites par les buvettes sont :
Q = 20 * 8 = 160 L /j et 160 *365 = 58400 L/an. Les débuts en m3/j et en m3/an sont : Q = 0,16 m3/j et 58,4 m3/an.

Le tableau ci-dessous présente l'évaluation indépendante du volume d'eaux usées produites quotidiennement et annuellement sur le campus de Tana

Tableau 1 : ***Evaluation indépendante du volume d'eaux usées***

	Volume d'eaux usées produit quotidiennement en m3/j	**Volume d'eaux usées produit annuellement en m3/an**
Etudiants	8,831	3278,247
Enseignants	0,193	70,536
PAT	0 ,282	102,930
Buvettes	0,16	58,4
Laboratoires	6,720	2452,8
Totaux	15,736	5962,913

Source :[1] ,[2],[3],[4],[5]

Le tableau suivant montre le volume d'eaux usées dans le rapport ARAFA

Tableau 2 :***Volume d'eaux usées dans le rapport ARAFA***

	Volume d'eaux usées produit quotidiennement en m3/j	**Volume d'eaux usées produit annuellement en m3/an**
Après curages des canaux Dans	3,25	1186,25
laboratoires	06	2190

Source : Rapport ARAFA

Figure 1 : ***volume d'eaux usées d'après évaluation indépendante et dans le rapport ARAFA***

I.1 Discussion du rapport ARAFA

D'après lit le rapport ARAFA, le débit d'eaux usées après curage des canaux est de 5 à 7 L/mn ;312,5 à 437,5 L/h et 3,25 m3/j mais le débit des eaux usées dans tous les laboratoires de recherche de l'Université d'Antananarivo est de 6000 L/j ou 6 m3/j donc il reste encore de l'eau usée qui n'est pas incluse là-dedans.

Par ailleurs, le puisard qui a été bouché pour obtenir les eaux usées à analyser au CNRE n'est pas clairement défini dans le rapport de l'ARAFA.

Bref, il y a encore de l'eau sale qui coule par certaines buses, et cela n'est pas mentionné dans le rapport de l'ARAFA.

I.2 Discussion entre le volume dans le rapport ARAFA et l'évaluation indépendante du volume d'eaux usées produites quotidiennement et annuellement sur le campus Tana

Le volume total des eaux usées dans le rapport ARAFA est de 9,25 m3/j et de 3373 ,25 m3/an parce que le volume des eaux usées après curage des canaux est de 3,25 m3/j et le volume des eaux usées dans les laboratoires des recherches est de 6 m3/j.

Le volume des eaux usées produites quotidiennement et annuellement sur le campus de Tana après l'évaluation indépendante est de 15, 736 m3/j et de 5962,93 m3/an.

Si on regarde la valeur et l'histogramme dans le photo 1 ci- dessus, le volume des eaux usées produites quotidiennement et annuellement sur le campus de Tana après l'évaluation indépendante est plus grand que le volume d'eaux usées dans le rapport ARAFA.

Le débit des eaux usées sortant de chaque buse n'est pas indiqué dans le rapport de l'ARAFA.C'est pourquoi les valeurs sont très éloignés.

II. Les eaux usées aujourd'hui

Actuellement, les eaux usées du campus sont rejetées directement dans l'environnement sans aucun traitement, ce qui peut avoir des conséquences néfastes sur l'environnement et la santé publique. **[6]**

Il y a 5 principaux points d'évacuation des eaux usées sur le Campus Universitaire :

- Une buse d'évacuation des eaux usées se trouve sur le champ d'Agronomie.
- Une buse d'évacuation des eaux usées se trouve à l'Est du CONACO Médecine.
- Deux buses d'évacuation des eaux usées se trouvent en bas du terrain de Foot Ball d'Ankatso.
- Une buse d'évacuation des eaux usées se trouve à l'Est de l'arrêt de Bus 119.

II.1. Evacuation des eaux usées dans le champ d'agronomie

Les eaux usées de tous les laboratoires de la colline (Laboratoire Chimie, géologie, BEC /ADD, BA/ECES, pharmacologie) sont connectées dans un regard avec les eaux usées du laboratoire PPC, ainsi que ceux des laboratoires du département biochimie et du département biologie végétale dans le bâtiment I

Les eaux usées du département FLSH (les toilettes, la buvette) et les eaux usées dans tous les bureaux de la présidence, comme les eaux usées des toilettes, sont connectées dans un canal avec les eaux usées des laboratoires mentionné ci-dessus et qui s'écoulent vers le champ d'Agronomie.

*Figure 2 :**Evacuation des eaux dans le champ d'Agronomie***

II.2. Evacuation des eaux usées à l'Est du Conaco Médecine

Les eaux usées des laboratoires Génie de l'eau et Génie de l'environnement et géologie sont évacuées via deux puisards et qui sont connectées à un regard commun avec tous les eaux usées des laboratoires du l'Ecole Supérieur Polytechnique d'Antananarivo ainsi qu'aux eaux usées des bâtiments et des Conaco situé à proximité du Stichom.

La somme de toutes ces eaux usées passe par les conduites et est évacuée à l'est du conaco Médecine.

Figure 3 ***: Puisard***

Figure 4 ***: Buse d'évacuation des eaux usées à l'Est du conaco médecine***

II.3. Eaux usées s'évacuent par les deux buses dans le terrain du Foot Ball

Les eaux usées des laboratoires de physique, de thermodynamique chimique et des toilettes du bâtiment R s'écoulent à travers des tuyaux PVC et qui se connectent à un regard avec les deux laboratoires dans les bâtiments Q (Laboratoire Chimie, Laboratoire chimie de l'environnement). Les eaux usées des 28 Laboratoires, des toilettes et de la buvette des départements P et O s'évacuent dans un regard et qui sont connectées aux laboratoires et aux toilettes mentionné ci- dessus et qui sont coulées vers les deux buses sur le terrain de foot Ball Ankatso.

Les eaux usées des laboratoires colline, PPC séparent en deux voies, les uns s'évacuent vers le champ d'agronomie et les autres sont connectées dans un regard avec les eaux usées des laboratoires dans le bâtiment P, O, I et qui sont coulées vers les deux buses sur le terrain de Foot Ball Ankatso.

Les eaux usées du gymnase, des toilettes de la cathédrale DEGS, de Médecine et de l'Office du baccalauréat sont toutes connectées et s'écoulent vers les deux buses sur le terrain de foot Ball Ankatso.

Figure 5 : ***Buse d'évacuation 1***

Figure 6 : ***Buse d'évacuation 2***

II.4. Evacuation des eaux usées à l'Est de l'arrêt de Bus 119

Les eaux usées des laboratoires, des toilettes de Madagascar Institute for vaccine research et celles du service médico-social s'écoulent vers une conduite puis elles se dirigent vers la buse située l'Est de l'arrêt de bus 119.

Les eaux usées du bâtiment A et bâtiment B des facultés DEGS se connectent à un regard commun avec les eaux usées du bâtiment à l'ouest du parking DEGS puis elles s'écoulent vers la buse à l'Est de l'arrêt de bus 119.

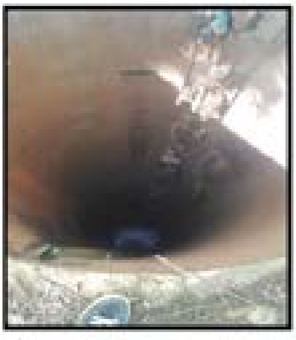

Figure 7 : ***Evacuation des eaux usées à l'Est de l'arrêt de bus 119***

III. Oui, La solution ARAFA répond aux grands défis de l'eau à l'université

La solution ARAFA vise à traiter les eaux usées du campus avant leur rejet, ce qui pourrait contribuer à résoudre les principaux défis liés à l'eau tels que la protection de l'environnement et de la santé publique. Cependant, sa mise en œuvre nécessiterait des investissements significatifs en infrastructures et en fonctionnement. **[7]**

La gestion efficace de l'eau constitue un défi majeur pour les institutions universitaires à travers le monde. L'introduction de la solution ARAFA a suscité un intérêt croissant en tant que moyen innovant de relever ces défis. Cette étude vise à évaluer dans quelle mesure la solution ARAFA répond aux grands défis de l'eau à l'Université.

III.1. Analyse des défis de l'eau à l'Université : [8]

III.1.1. Gestion de la demande en eau:

Les campus universitaires nécessitent d'importantes quantités d'eau pour répondre aux besoins des étudiants, du personnel et des infrastructures.

III.1.2. Conservation de l'eau

La réduction de la consommation d'eau et la préservation des ressources sont essentielles pour assurer la durabilité environnementale.

III.1.3. Gestion des eaux usées

Le traitement efficace des eaux usées est crucial pour éviter la pollution et préserver la qualité de l'eau.

III.1.4. Adaptation au changement climatique

Les effets du changement climatique, tels que les sécheresses et les précipitations irrégulières, impactent la disponibilité et la gestion de l'eau.

III.2. Evaluation de la solution ARAFA

III.2.1. Gestion intelligente de la demande en eau

ARAFA utilise des capteurs et des algorithmes avancés pour surveiller et optimiser la consommation d'eau, permettant une utilisation plus efficace des ressources.

III.2.2. Technologies de conservation de l'eau:

Des fonctionnalités que la détection des fuites et la régulation de la pression contribuent à minimiser les pertes.

III.2.3. Traitements des eaux usées :

ARAFA intègre des systèmes de traitement des eaux usées qui réduisent la pollution et permettent une réutilisation sure des eaux traitées. La solution proposée, le système DEWATS, semble être bien adaptée au contexte de l'Université. Ce système comprend un filtre à sable et un filtre à planté, qui permettent un traitement efficace des eaux usées avant leur rejet. Le dimensionnement détaillé de ce système indique que la solution a été étudiée de manière approfondie.

III.2.4. Adaptabilité aux conditions climatiques

Les algorithmes de prévision de pointe d'ARAFA prévoient les variations météorologiques, permettant une gestion proactive de l'eau pour atténuer les effets du changement climatique.

L'ARAFA présente un potentiel prometteur pour relever les grands défis de l'eau de l'université. En intégrant des technologies avancées de surveillance, de conservation et de traitement de l'eau, ARAFA offre une approche holistique et efficace pour garantir une gestion durable de l'eau sur les campus Universitaires. Cependant, des efforts continus de recherche, de développement et de mise en œuvre seront nécessaires pour optimiser l'efficacité et maximiser les avantages de cette solution dans les environnements Universitaires.

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JACQUELYN JESTINE SANDERS FOUNDATION
BUILDING VISION, REALIZING CHANGE

Well-known scholarships like the Rhodes, Gates Cambridge, and Fulbright offer significant financial support and prestigious credentials, but they are highly competitive and benefit a limited number of students. These scholarships often focus on addressing large-scale, global challenges and nurturing leaders to work on broad societal issues. Scholars gain access to vast networks, mentorship, and resources, facilitating their ability to tackle major problems.

In contrast, the JJSF Model is inclusive, aiming to involve a larger number of students in meaningful projects. It emphasizes solving local problems, directly benefiting the community in which the university is situated. Students gain hands-on experience in real-world problem-solving, enhancing their education and practical skills. The model is designed to be replicable and adaptable by any university, allowing for widespread implementation and continuous improvement.

The value of universities tackling local problems is manifold. For students, working on actual issues allows them to apply their academic knowledge to practical situations, preparing them for their future careers. Actively participating in problem-solving increases student engagement and motivation, fostering a deeper connection to their studies. Additionally, students develop a wide range of skills, including research, critical thinking, project management, and collaboration.

Communities benefit from having local issues receive focused attention from bright, motivated students who can bring fresh perspectives and innovative solutions. Collaboration between universities and local governments or organizations can lead to better-integrated community efforts and stronger partnerships. Leveraging the resources of a university, such as labs, libraries, and expertise, can make a significant difference in addressing community challenges.

For universities, engaging in solving local problems enhances their reputation and demonstrates their commitment to social responsibility. Successful projects can attract funding from donors, government agencies, and businesses interested in supporting community-focused initiatives. Offering students the chance to work on real problems can also make the university more attractive to prospective students seeking a comprehensive and practical education.

An example project, such as tree multiplication and care, illustrates the benefits well. Agricultural students can learn the entire process of tree multiplication and nursery management, gaining valuable skills in horticulture. Producing thousands of trees in one school year can contribute significantly to local reforestation efforts and environmental sustainability. Such projects can involve local communities, raising awareness and fostering a sense of collective responsibility for environmental stewardship.

The JJSF Model's key idea is scalability and replicability. The model is not intended to expand solely under the JJSF Foundation's direction. Instead, it serves as a blueprint that other institutions can adopt, adapt, and improve upon. By engaging the next generation of students as active participants in their education, focusing on real-world problems and contributing to solutions, the model promotes continuous improvement. Encouraging universities to take ownership of the model and tailor it to their specific contexts allows the approach to evolve and improve over time, driven by the collective efforts of students, faculty, and communities.

In conclusion, the JJSF Model presents a compelling approach to education that integrates academic learning with real-world problem-solving. By involving students in tackling local issues, universities can provide valuable experiences, benefit their communities, and foster a culture of innovation and responsibility. This model complements the impact of exclusive scholarships by offering a scalable, inclusive, and practical framework for educational and societal advancement.

JACQUELYN JESTINE SANDERS FOUNDATION

The Jacquelyn Jestine Sanders Foundation supports the Sustainable Development Goals:

SUSTAINABLE DEVELOPMENT GOALS

The Jacquelyn Jestine Sanders Foundation's Engaged Scholarship for Sustainable Solutions program aligns closely with several of the United Nations Sustainable Development Goals (SDGs). These goals are designed to address global challenges and promote sustainable development in various sectors. Our program's emphasis on involving university students in real-world problem-solving contributes to achieving these goals in meaningful ways. Here is an overview of how our program supports specific SDGs:

Goal 4: Quality Education

The Engaged Scholarship program enhances the quality of education by integrating practical, real-world problems into the academic curriculum. By engaging students in addressing critical issues such as water management, we provide hands-on learning opportunities that go beyond theoretical studies. This approach equips students with the skills, knowledge, and experience needed to tackle complex challenges, fostering a more robust and practical education.

Goal 6: Clean Water and Sanitation

Our focus on water infrastructure and management directly contributes to Goal 6, which aims to ensure availability and sustainable management of water and sanitation for all. By addressing the water issues faced by the University of Antananarivo, the program works towards improving access to clean water and efficient sanitation systems. Student research on topics like water filtration, rainwater harvesting, and wastewater management helps develop sustainable solutions that can be implemented locally and potentially scaled globally.

Goal 11: Sustainable Cities and Communities

The program's efforts to improve water infrastructure in Antananarivo support the creation of more sustainable and resilient urban environments. As the city struggles to provide basic services to its growing population, our students' innovative solutions can help address these urban challenges. Enhancing the university's water management system also contributes to making the campus a model of sustainability that can inspire broader community efforts.

Goal 13: Climate Action

By promoting sustainable water management practices and addressing the impacts of deforestation and desertification, the program supports climate action initiatives. Research on wetlands, permaculture, and agroforestry helps mitigate the effects of climate change by promoting practices that enhance carbon sequestration, reduce soil erosion, and improve water retention. These efforts align with Goal 13, which focuses on taking urgent action to combat climate change and its impacts.

Goal 15: Life on Land

The program's involvement in reforestation and tree propagation efforts supports Goal 15, which aims to protect, restore, and promote sustainable use of terrestrial ecosystems. By producing at-risk tree species and researching sustainable land management practices, our students contribute to the preservation and restoration of Madagascar's unique biodiversity. This work helps combat deforestation, promote reforestation, and maintain healthy ecosystems.

Goal 17: Partnerships for the Goals

The Engaged Scholarship program embodies the spirit of Goal 17 by fostering partnerships between the Foundation, universities, and the global academic community. By inviting international scholars to participate in peer review and collaboration, we strengthen the means of implementation and revitalize the global partnership for sustainable development. This collaborative approach ensures that our efforts are informed by diverse perspectives and expertise, enhancing the overall impact of the program.

The Jacquelyn Jestine Sanders Foundation's Engaged Scholarship for Sustainable Solutions program is a powerful example of how education, research, and practical application can come together to address critical global challenges. By aligning our efforts with the United Nations Sustainable Development Goals, we not only improve local conditions but also contribute to broader, global sustainability efforts. We invite the academic community and other stakeholders to join us in this endeavor, helping to refine and expand the program to maximize its impact on sustainable development.

Constructed [illegible] UV treatment
Photo Credit: AI Visualization (OpenAI)

JACQUELYN JESTINE SANDERS FOUNDATION

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Abstract

This article explores the integration of permaculture principles, specifically focusing on techniques like System of Rice Intensification (SRI) and agroforestry, into traditional rice cultivation practices. Through a case study analysis of successful implementation in various regions, including Madagascar, India, and Vietnam, the benefits of sustainable rice farming methods are highlighted. By emphasizing practices such as polyculture, integrated pest management, composting, and mulching, farmers have reported increased yields, reduced input costs, and improved soil health. The article discusses the importance of agroforestry in providing shading within rice lagoon systems and its role in enhancing biodiversity and climate resilience. Overall, the findings suggest that incorporating permaculture principles in rice cultivation can lead to more sustainable and productive agricultural systems. Let us refer to this combination of wet rice field agriculture mixed with [fruit] trees ... as "Wetlands Agroforestry"

Wetlands Agroforestry

Constructed Wetlands
Photo Credit: AI Visualization (OpenAI)

Introduction

As environmental concerns and the need for sustainable agricultural practices grow, integrating permaculture principles into conventional farming is gaining attention. Permaculture, derived from "permanent agriculture," is a holistic approach to farming that emphasizes sustainability, biodiversity, and natural systems. In the context of rice production, permaculture can offer invaluable benefits, enhancing both environmental health and agricultural productivity. This document compares the research efforts in Asia and Africa, highlighting key areas of focus, challenges, and opportunities, with a particular emphasis on innovative water management techniques and notable lagoon-based permaculture projects.

What is Permaculture?

Permaculture is a design philosophy that works with natural processes to create self-sustaining ecosystems. It involves principles such as observing and interacting with natural systems, capturing and storing energy, and integrating rather than segregating different components of the ecosystem (Mollison, 1988). In agriculture, these principles aim to create food systems that are resilient, efficient, and environmentally friendly.

Benefits of Permaculture in Rice Production

Soil Health and Fertility

One of the core principles of permaculture is maintaining soil health. Conventional rice farming often relies on synthetic fertilizers, which can degrade soil quality over time. Permaculture encourages the use of natural fertilizers and organic matter, such as compost and green manure, which enrich the soil. This approach maintains the soil structure and promotes the presence of beneficial microorganisms (Altieri & Nicholls, 2005).

For instance, incorporating nitrogen-fixing plants like legumes in paddy fields can naturally replenish soil nutrients, reducing the need for chemical fertilizers.

Water Management

Rice production is fundamentally water-intensive, with traditional methods requiring large amounts of irrigation. Permaculture advocates for efficient water use through techniques like swales, ponds, and mulch, which are aimed at optimizing water retention and conservation, especially critical in regions prone to both drought and heavy rains (Fukuoka, 1978).

Slowing Down Rainwater

Implementing swales—shallow, broad ditches on contour lines—helps to capture and slow down rainwater. This technique reduces soil erosion and allows water to percolate into the ground, recharging groundwater supplies and increasing soil moisture. Swales prevent the rapid runoff that typically occurs during heavy rains, instead allowing water to be absorbed gradually into the soil, creating a more consistent and prolonged water supply for crops.

Storing Water for Dry Periods

Creating ponds and reservoirs within rice paddies is another permaculture strategy that stores rainwater for use during dry periods. These water bodies not only serve as a water source during times of scarcity but also play a role in supporting biodiversity, as they can be integrated with fish habitat.

Filterable Water Benefits

By capturing and storing water through these methods, permaculture systems often produce cleaner, filterable water. As water moves through the soil and plant roots, it undergoes natural filtration, which can significantly improve water quality, making it suitable for agricultural and even household use after further purification.

Biodiversity

Permaculture promotes biodiversity, which can lead to healthier ecosystems and more resilient crops (Holmgren, 2002). In rice production, integrating different plant species and livestock creates a balanced and diverse system. This diversity helps control pests and diseases naturally, reducing the reliance on chemical pesticides.

Agroforestry, for example, involves planting trees alongside rice fields, providing shade, habitat for beneficial insects, and additional income through timber or fruit. Such systems enhance the overall resilience of the farm.

Economic and Social Benefits

Implementing permaculture strategies can lead to economic benefits for farmers. Reduced reliance on chemical inputs lowers production costs, while diverse crop systems can provide multiple income streams. Additionally, permaculture practices often require less labor-intensive methods, making farming more accessible for small-scale and marginalized farmers (Mollison, 1988).

Case Studies

System of Rice Intensification (SRI)

The SRI method, which incorporates several permaculture principles, has shown significant benefits in various regions. By planting younger seedlings, reducing planting density, and improving water management, SRI methods enhance root growth and increase yields with fewer inputs (Uphoff, 2003).

Integrated Rice-Duck Farming

In countries like Japan and the Philippines, farmers have successfully integrated ducks into rice paddies. Ducks help control pests and weeds while providing natural fertilizer through their droppings. This method has improved yields and reduced the need for chemical inputs (Gopalakrishnan et al., 2013).

Agroforestry

The practice of integrating trees into rice lagoon systems for shading is often referred to as "agroforestry." Agroforestry involves the intentional combination of trees and shrubs with crops or livestock to create a more sustainable and productive agricultural system.

In the context of rice cultivation, incorporating trees around or within the rice fields can provide several benefits, such as shading the rice plants, reducing water evaporation, improving soil health through root systems, attracting beneficial insects, and providing additional sources of income or nutrition.

Agroforestry practices in rice cultivation can help enhance biodiversity, improve resilience to climate change, and promote more sustainable and holistic land management. The integration of trees in rice lagoon systems is one of the ways farmers can implement agroforestry principles to create more diverse and resilient agricultural landscapes.

Notable Wetland Permaculture Project

Koh Rong Island, Cambodia

Project Name: **Song Saa Reserve**

Overview: The Song Saa Reserve on Koh Rong Island is an impressive large-scale permaculture project that integrates rice paddies with water lagoons and diverse agroforestry systems. This project forms part of Song Saa's effort to create a sustainable community and ecosystem while focusing on responsible tourism and agriculture.

Figure 1: Song Saa Master Plan
Photo Credit: https://songsaareserve.com/

Key Features:

- Integration of rice paddies with naturally-occurring water lagoons.
- Planting of native trees and fruit-bearing species within the lagoon system.
- Utilization of nutrient-rich water from the lagoons to irrigate rice fields.
- Cultivation of edible aquatic plants and fish to enhance productivity and biodiversity.

Figure 2: Tree Conservancy in Cambodia
Photo Credit: https://songsaareserve.com/

Benefits:

- Improved water retention and soil health.
- Enhanced biodiversity and resilience of the agro-ecosystem.
- Provision of multiple income streams from rice, fruit, and fish.

Quote from the Song Saa Project Website:

"Considerable work has been devoted to the development of an effective strategy for the restoration of rainforest at the Song Saa Reserve. Key to this has been an appreciation that rainforest restoration is about more than just 'planting trees' and requires an understanding of a range of disciplines. This entails uniting biology, soil and social science, hydrology and biodiversity conservation in a strategy that ensures the greatest opportunities for restoration success."

Figure 3: Lagoons of Song Saa
Photo Credit: https:://songsaareserve.com/

Song Saa Reserve Website. (2024, 16 May). One-Million Trees Programme. https://songsaareserve.com/beyond-sustainability/1-million-trees-programme/

Notable Wetland Permaculture Method

Mekong Delta, Vietnam
Project Name:
VAC Farming System (Vuon-Ao-Chuong)
Overview: The VAC farming system in the Mekong Delta is a traditional Vietnamese farming method that epitomizes the principles of permaculture. 'VAC' stands for garden (Vuon), pond (Ao), and livestock pen (Chuong), representing the integration of diverse agricultural practices including rice and tree cultivation combined with aquaculture.

Key Features:

- Rice fields are constructed around water lagoons (ponds) that are stocked with fish.
- Trees, such as coconut, banana, and fruit trees, are planted around and within the rice fields.
- Duck and other livestock are integrated into the system, contributing to pest control and soil fertility.

Benefits:

- Efficient use of land and water resources.
- Natural pest control and reduction of chemical use.

Diversified and stable sources of food and income for local farmers.

Quote from Permaculture News on VAC:

"The typical VAC garden-farm in a coastal area is from 2000-5000 square metres. It is bordered by a row of Casuarina equisetifolia which acts as a windbreak, hinders drifting sand and filters salt. Other timber trees and rattans are densely planted on mounds built up around the garden as protection. Within the garden a variety of fruit trees is grown, such as bananas, mulberries, figs, papaya and citrus, plus tuber crops such as sweet potato, arrowroot and jicama. Fish and prawns are raised in brackish ponds and canals. The most common forms of livestock raised are buffalo, cattle, pigs and poultry, especially ducks."

Permaculture News Website. (2008, October). Vuon – Ao – Chuong – The Traditional Vietnamese Farm.https://songsaareserve.com/beyond-sustainability/1-million-trees-programme/

Figure 4: VAC Style "Lagoon Farming" in Vietnam
Photo Credit: https://vnexpress.net/

Notable Lagoon-Based Permaculture Style of Farming

Sundarbans, India and Bangladesh

Project Name:

Integrated Mangrove-Aquaculture Farming System

Overview: The Sundarbans, a vast mangrove forest area in India and Bangladesh, features innovative permaculture projects where rice fields are integrated with mangrove lagoons. These ecosystems harness the natural benefits of mangroves, such as water filtration and storm protection, alongside sustainable rice and tree cultivation.

Figure 5: Mangrove Aquaculture, India
Photo Credit: Tamil Nadhu, India © MSSRF. (http://www.mangrovesforthefuture.org/news-and-media/news)

Key Features:

- Utilization of brackish water from mangrove forests in rice cultivation.
- Planting of mangrove trees and other salt-tolerant species around rice paddies and lagoons.
- Integration of aquaculture, including fish and shrimp farming, within lagoon systems.

Figure 6: Integrated Mangrove Aquaculture, India
Photo Credit: Aquaculture Journal Issue 209, p. 43-59

Benefits:

- Enhanced resilience to climate change and storm surges.
- Improved water quality and soil health through natural filtration.
- Sustainable livelihoods through diversified agriculture and aquaculture.

Notable African Permaculture Project

Abukassims Oasis, Egypt

Project Name: ***Sekem Project***

Overview: The Sekem Project in Egypt's desert region is a pioneering example of large-scale sustainable agriculture. It integrates water-efficient permaculture practices with rice and tree cultivation within man-made oasis systems.

Figure 7: Mixed Trees of Ecovillage Sekem Gardens
Photo Credit: Brochure, SEKEM (www.sekem.com)

Key Features:

- Creation of water lagoons and channels for effective irrigation in arid regions.
- Cultivation of rice alongside date palms, citrus trees, and other fruit trees.
- Use of biodynamic farming practices to enhance soil fertility and productivity.

Benefits:

- Efficient use of scarce water resources in arid environments.
- Increased biodiversity and ecological balance.
- Promotion of sustainable agriculture and rural development.

Quote from SEKEM:

Sekem. (2024 May) "The climate above the surface of the soil is one factor that determines how fast soil degrades and water evaporates. By planting trees around the fields, we achieve several effects, on top of a pleasant scent: The trees break the wind so that it cannot blow away the top soil; the shade brings cooler and more humid air, which creates a micro climate among the surrounding tree lines of a field; the photosynthesis of the trees uses carbon dioxide and emits the needed oxygen instead; and in the long term, the groundwater level slowly rises because of the cooler surface and brings additional micro-climatic change."

Webpage: AIR & WATER. Sekem. Retrieved from https://sekem.com/en/ecology/air-water/

SPEEDRICE Permaculture Project in Madagascar

Project Overview: The SPEEDRICE project, initiated by the Aga Khan Foundation in collaboration with the Innocent Foundation, focuses on improving rice yields and enhancing food security among vulnerable households in Madagascar. The project introduces the Zanatany Rice Permaculture System (ZRPS), which integrates various sustainable agriculture techniques aimed at boosting productivity while preserving the environment.

Key Components of ZRPS:

- Self-Made Inputs: Farmers are trained to produce their own high-quality seeds, natural pesticides, and organic fertilizers, significantly reducing costs and dependency on external inputs (AKF | The Learning Hub) (Serve Boldly With the Peace Corps).
- Direct Seeding: This technique reduces labor by up to 50% and produces larger, healthier, and more drought-tolerant plants. It also leads to earlier ripening crops (AKF | The Learning Hub).
- Crop Rotation and Mixed Cropping: Integrating legumes such as beans or cowpeas into rice fields improves soil fertility and moisture retention, supporting year-round crop production (AKF | The Learning Hub).
- Agroforestry Integration: Trees and shrubs are integrated into rice fields to enhance biodiversity, provide additional sources of income, and mitigate climate change impacts (AKF | The Learning Hub) (Aga Khan Development Network).

Minimal Tillage: Reduced tillage practices enhance soil structure, increase organic matter content, and improve the soil's water retention capacity (AKF | The Learning Hub).

Benefits:

• Enhanced soil fertility through natural mulching and organic matter from bamboo.

• Improved water retention and prevention of soil erosion.

• Diversified income streams for local communities from bamboo, rice, and fruits.

• Increased resilience of farming systems to climatic variations.

Challenges

Despite its promising approach, the SPEEDRICE project faces challenges such as limited access to agricultural tools and irregular rainfall patterns. Continued support and adaptation to local conditions are essential for the long-term success of the project. Expanding training programs and integrating more advanced water management systems could further enhance the resilience and productivity of rice farming in Madagascar (Aga Khan Development Network) (AKF | The Learning Hub).

Future Directions

The SPEEDRICE project in Madagascar demonstrates a comprehensive approach to tackling food security and environmental challenges through sustainable agriculture. By empowering local farmers with knowledge and resources to implement the Zanatany Rice Permaculture System, the project not only aims to increase rice yields but also promotes environmental sustainability and resilience against climate change. Continued investment and support for such initiatives are crucial for the long-term prosperity and food security of communities in Madagascar.

Linking Wetlands Agroforestry to Madagascar's Deforestation Issues

Madagascar has experienced extensive deforestation due to agricultural expansion, illegal logging, and the use of slash-and-burn farming methods. This deforestation has led to soil degradation, loss of biodiversity, and disrupted water cycles. Integrating permaculture principles, including water storage, groundwater management, and tree planting, can address these issues effectively.

Combatting Soil Erosion and Degradation

Tree Planting: Reforestation and agroforestry practices can restore degraded lands. Trees stabilize the soil, preventing erosion and improving fertility, which is essential for sustainable agriculture.

Permaculture Design: Implementing permaculture designs that include swales and contour planting can reduce soil erosion and enhance water infiltration, benefiting both the environment and agricultural productivity.
Restoring Biodiversity

Habitat Creation: Planting native trees and creating diverse agroforestry systems can restore habitats for Madagascar's unique wildlife, promoting biodiversity and ecological balance.

Integrated Systems: Permaculture systems that integrate trees, crops, and livestock create multifunctional landscapes that support a variety of species and ecological functions.
Improving Water Management.

Water Storage Solutions: Building ponds, reservoirs, and implementing rainwater harvesting systems can enhance water availability for agriculture, reducing pressure on natural water sources and improving resilience to drought.

Groundwater Recharge: Trees and other permaculture practices that enhance soil structure and water infiltration help recharge groundwater, ensuring a sustainable water supply for both agricultural and domestic use.
Promoting Sustainable Livelihoods

Economic Benefits: Diversified agroforestry systems provide multiple income sources, improving the economic resilience of communities. This reduces the need for destructive practices like slash-and-burn agriculture.

Community Engagement: Engaging local communities in permaculture projects can build awareness and skills for sustainable land management, fostering long-term environmental stewardship.

Figure 8: Madagascar Rice Production. Where are the Trees?
Photo Credit: Aga Khan Foundation (https://www.akf.org.uk/speedrice/)

Techniques for Enhancing Water Storage, Groundwater Health, and Tree Integration

Swales and Contour Planting

Swales: Swales are shallow, broad channels designed to capture and slowly release water into the soil. They are typically constructed along contour lines to maximize water infiltration and reduce runoff.

Contour Planting: Planting along contours helps slow water flow, enhancing infiltration and reducing erosion. This technique is particularly effective in hilly or sloped areas.

Ponds and Reservoirs

Water Storage: Constructing ponds and reservoirs within or adjacent to rice fields provides significant water storage capacity. These structures capture rainwater and runoff, making it available for irrigation during dry periods.

Microclimate Regulation: Ponds also help regulate microclimates by increasing humidity and providing habitat for beneficial wildlife.

Mulching and Ground Cover

Mulch: Applying organic mulch around rice plants helps retain soil moisture, reduce evaporation, and improve soil health. Mulch also contributes to the organic matter in the soil, enhancing its water-holding capacity.

Ground Cover Crops: Planting cover crops during off-seasons prevents soil erosion, improves soil structure, and enhances groundwater recharge.

Rainwater Harvesting Systems.

Collection Systems: Installing rainwater harvesting systems on rooftops or other structures captures and directs rainwater into storage tanks or directly into the fields. This water can be used for irrigation, reducing reliance on external sources.

Supplementary Irrigation: Harvested rainwater can supplement irrigation during critical growth stages of rice, ensuring that water needs are met without stressing groundwater resources.

Figure 9: Recirculating Wetlands Agroforestry.
Photo Credit: Coman, with assistance from Openart.ai

Conclusion

Effective water storage, groundwater health, and the integration of trees are vital components of a successful permaculture rice field. These practices can also play a significant role in addressing the deforestation issues in Madagascar. By implementing sustainable water management practices and integrating trees into farming systems, permaculture can contribute to reforestation efforts, soil restoration, biodiversity conservation, and community resilience. Embracing these strategies not only ensures the long-term sustainability of agricultural production but also supports the restoration and protection of Madagascar's valuable ecosystems. Through collaborative efforts and a commitment to sustainable land management, permaculture offers a promising pathway towards mitigating deforestation and promoting environmental stewardship in Madagascar and beyond.

Figure 10: Recirculating Wetlands Agroforestry.
Photo Credit: Coman, with assistance from Openart.ai

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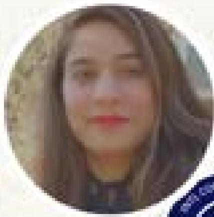

International Correspondent
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April 2024

Abstract

This article discusses sustainable techniques for paddy farming, the focus being on intercropping, permaculture and water management in particular. This study revealed the advantages of growing rice combined with other crops with the adoption of the Rice Intensification System (RIS) method. Bibliometric studies provide an overview of the emerging patterns in the research on rice intercropping; vast and rich datasets about irrigation drainage systems are there to address the issues of water inadequacy.

Introduction

Rice paddies, intercropping and permaculture, are emerging as novel solutions that optimise resource use and improve farmer incomes. This article examines the contribution of bibliometric analyses and irrigation management studies to the understanding of their function in sustainable rice agriculture.

Review

Climatic criteria of annual crops often influence crop systems, which are eventually determined by further procedures of cultivation. The rice paddy fields of the Indo-Pak and the Yangtze basins in China, which are followed by the crops of maize and wheat, respectively, are important for the purpose of global food security. But then the idea of intercropping crops may be practiced while both of them had similar climate preferences. These methods not only reduce the excess use of resources but also enhance the incomes of peasants. The case study area in this work is the Intercropping Systems in rice planting with the discussion of their role in achieving social development goals, improving the well-being of farmers and combating climate change (Sarwar et al., 2022).

Quote: " Rice intercropping allows sustained crop intensification in spite of ecological difficulties."

Rice production, though is a fundamental process of food security faces two main challenges such as water scarcity and soil deterioration. This study investigates the benefits that result when one plants beans together with rice using the System of Rice Intensification (SRI) technique. According to their observations, the weeds were greatly reduced by 65% after intercropping; hence, the complaint by SRI critics was tackled, and a huge problem that limits the yield, because weeds are a challenge to any farmer during crop production, was highlighted. Finally, we ascertained that SRI's water-saving tactics alongside intercropping boosted rice yield by 33% and an income increment of 57% compared to existing methods

Not only intercropping with the SRI technique has greatly reduced water consumption by about 40% but also; it has enhanced the efficiency of the system. This solution serves to be of great aid in conserving water resources as well as tackling the shortage of water in places where water is scarce (Shah, Tasawwar, Bhat, & Otterpohl, 2021).

Quote: " Intercropping reduced weed infestation by 65%, addressing a typical SRI critique and yield-limiting problem."

Permaculture, which is a movement that evolved in the late 1970s in Australia, promotes alternative agriculture, which encompasses a philosophy that concentrates on attaining harmony with the natural environment (Suh, 2022). The moral basis of permaculture, including Earth care, people care, and fair sharing, takes into account the intricate links between agriculture, human settlements, and the wider environment. Permaculture is not only about sustainable food production; it involves other components of human habitats, which range from industry to urban farms. The Ecological aspect is the priority of permaculture, but it is also open to technical innovations in the field of renewable energy (Hirschfeld & Van Acker, 2021).

Quote: " From its late 1970s beginnings as an alternative-agriculture movement in Australia, permaculture promotes harmony with nature."

Intercropping is a significant technique of supporting the crop intensification process during the time of the ecosystem obstacles. The present study is a bibliometric project which covers 187 publications written between 1980 and 2022. This relates to the worldwide study of rice intercropping, which will be presented. The analysis through the latest technology and applications point out the participation of 561 academicians from 36 countries within 68 various organizations. With South China Agricultural University and the Indian Council of Agricultural Research as some of the top leading institutions, India, China, Brazil, and Indonesia are dominating in the number of publications (Shahidullah, Shirazy, Sarkar, & Quais, 2024).

Quote: " Intercropping has become a viable agroecological method to improve resource-use efficiency, crop output, and agricultural sustainability."

The study here undertakes and describes the characteristics of intercropping research around the world and does it by means of a quantitative bibliometric from 1995 to 2021. The finding shows that from 2007, research productivity has significantly increased as envisaged, featuring a remarkable lead of Chinese researchers and research centers. In the meantime, the field crop research and the plant and soil journals have also served as major channels where the intercropping-related research is shared and disseminated, as evidenced by their astonishing h-indices and total citations. With the amount of time, studies of intercropping Systems are becoming increasingly emphasized on the issues of sustainability of agriculture. Intercropping, as this study implies, is a vital practice in the contemporary attempt to tackle agricultural problems. Research focus shall be given to the quest for ambient sustainability in agriculture (Tang, Qiu, Li, Xu, & Li, 2024).

Quote: "Sustainable agriculture subjects, including sustainable intensification, climate change adaptation, microbial community dynamics, biodiversity conservation, and soil fertility control, have been popular in intercropping research."

The practice of the cultivation of rice is a looming danger as the worsening of droughts induced by global warming continuously impacts freshwater resources. The efficiency of irrigation drainage issues does matter both in the sustainability and resilience domains of irrigation systems. The old traditional rice cultivation techniques, which relied on minor water bodies that are not now available, are leading to the expenditure of more freshwater, higher demand for water and higher risks of extreme natural hazards. The plan includes accounting for the protection of small water bodies that are not only for irrigating and draining rice in China but also supply public water. The reduction in freshwater use by 30% for rice production and 9% of freshwater savings can thus be achieved through the adoption of such measures.

It also has a positive effect of increasing water autonomy from 3% to 31% and making crop damage fall by 2-3% during drought seasons. Research findings concentrate on the implementation of rice irrigation drainage systems as an approach toward the water deficit condition that is compounded more by climate change (Li et al., 2023).

Quote: "Climate change-induced droughts make rice growing a major danger to freshwater supplies. Improving irrigation drainage systems boosts sustainability and resilience."

Conclusion

Rice sustainable production, possibly combined with intercropping, permaculture, and better irrigation, could be beneficially assisted by many other technologies as well. These can boost crop yields and earnings, but nevertheless, marginal gains and climate changes happen at the same time.

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Introduction: Ongoing Guidance for Technical Lagoon Planning and the Garden of Eden Project

Throughout the year, the Foundation has played an active role in providing ongoing guidance to the students in Madagascar as they worked to advance their technical lagoon planning. Recognizing the importance of developing practical, sustainable solutions, the Foundation offered regular insights into the technical aspects of the Garden of Eden project proposal, particularly in relation to the design and management of the lagoon system. These contributions were vital in helping the students refine their designs, ensuring they aligned with both environmental and practical considerations. The Foundation's expertise in water management, sustainable infrastructure, and ecosystem restoration was critical in shaping the students' understanding of how to implement a self-sustaining water system that could support the broader goals of the Garden of Eden model. The ongoing collaboration between the Foundation and the students has been a cornerstone of this initiative, ensuring that the knowledge and skills needed to realize this vision are passed on to the next generation of environmental leaders.

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Technical Guidance When Planning Constructed Wetlands: A Sustainable Solution for Water Management, Drinking Water Quality, and Agroforestry Integration

Abstract
In response to escalating environmental and water management challenges, constructed wetlands offer a sustainable and effective solution by mimicking the functions of natural wetlands. This technical guidance article explores the multifaceted benefits of constructed wetlands, including their capacity to improve water quality, control floods, create habitats, and contribute to climate mitigation. It delves into the design and operational characteristics of surface flow and subsurface flow models, identifying the optimal flow methods for treating wastewater and freshwater. The integration of agroforestry within these systems further enhances their ecological and economic benefits, creating multifunctional landscapes that support biodiversity, carbon sequestration, and local economies. Additionally, the article outlines the necessary stages for further filtering wetland-treated water to ensure its safety for drinking purposes. While the implementation of constructed wetlands presents several challenges, their ability to provide vital ecosystem services and enhance drinking water quality underscores their importance in sustainable development. Investing in these integrated systems is a proactive step towards environmental resilience and water security.

Introduction

In an era marked by rapid urbanization, industrialization, and climate change, the demand for sustainable and effective water management solutions has never been greater. Constructed wetlands (CWs) offer a promising answer to this challenge. These engineered systems mimic the functions of natural wetlands, providing a host of ecological, economic, and social benefits. As natural wetlands continue to disappear at an alarming rate, the implementation of constructed wetlands is becoming increasingly essential.

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Written: May 2024

This article provides technical guidance on planning constructed wetlands, exploring their multifaceted benefits and the crucial role they can play in improving drinking water quality. Additionally, integrating agroforestry within these systems can enhance their efficacy and provide further environmental and economic benefits.

The Decline of Natural Wetlands

Natural wetlands are among the most productive ecosystems on Earth, providing critical services such as water filtration, flood control, carbon sequestration, and habitat for a diverse range of species. However, according to the Ramsar Convention, the world has lost approximately 35% of its wetlands since 1970, with the rate of loss accelerating in recent decades. Urban expansion, agriculture, and infrastructure development are primary drivers of this decline. The destruction of wetlands not only diminishes biodiversity but also compromises the natural services they provide, leading to increased pollution, reduced water quality, and heightened vulnerability to floods and droughts.

Constructed Wetlands: An Overview

Constructed wetlands are designed to emulate the natural processes of organic water filtration, utilizing vegetation, soil, and microbial activity to treat polluted water. These systems can be used for various purposes, including wastewater treatment, stormwater management, and habitat restoration. Constructed wetlands can be classified into two main types: surface flow (SF) and subsurface flow (SSF) systems, each with distinct design and operational characteristics suited to different applications.

Surface Flow and Subsurface Flow Models

Surface Flow (SF) Constructed Wetlands

Surface flow constructed wetlands, also known as free water surface (FWS) wetlands, are designed to have water flowing above the soil surface, similar to natural marshes. These systems are characterized by the following features:

Design: SF wetlands consist of shallow basins with water flowing slowly over the soil or substrate. The water depth typically ranges from 0.2 to 0.6 meters. These basins are planted with emergent vegetation like reeds and cattails, which extend above the water surface.

Operation: The water flows horizontally from the inlet to the outlet over the vegetated surface. This type of wetland primarily relies on the interaction between water, plants, soil, and the atmosphere for treatment processes. The plants' roots provide a surface area for microbial growth, which plays a crucial role in breaking down pollutants.

Applications: SF wetlands are often used for secondary or tertiary treatment of municipal wastewater, stormwater management, and agricultural runoff. They are particularly effective in removing suspended solids, organic matter, and nutrients such as nitrogen and phosphorus.

Construction Layers:

- Base Layer: Typically, a waterproof liner or compacted clay layer to prevent seepage.
- Substrate Layer: A soil or sediment layer where plants can root.
- Vegetation Layer: Emergent plants that extend above the water surface.

Figure 1: Wildlife Habitat in Boulder, Colorado
Photo Credit:Getty/Canva Pro

Subsurface Flow (SSF) Constructed Wetlands

Subsurface flow constructed wetlands can be further divided into horizontal subsurface flow (HSSF) and vertical subsurface flow (VSSF) systems. These systems differ from SF wetlands in that the water flows below the surface, through a permeable medium such as gravel or sand.

Horizontal Subsurface Flow (HSSF) Constructed Wetlands

Design: HSSF wetlands are composed of a lined basin filled with gravel or other coarse material. Water flows horizontally through the substrate from the inlet to the outlet, remaining below the surface throughout the process. The system is planted with vegetation whose roots penetrate the substrate.

Operation: The horizontal flow ensures that water remains in contact with the substrate and plant roots, allowing for effective microbial degradation of pollutants. The lack of exposed water surface reduces the risk of odor and mosquito breeding.

Applications: HSSF wetlands are suitable for treating domestic and industrial wastewater, particularly for removing organic pollutants, pathogens, and some nutrients.

Construction Layers:

- Base Layer: An impermeable liner to prevent water from seeping into the ground.
- Drainage Layer: Coarse gravel or rocks at the bottom to facilitate water collection and movement.
- Substrate Layer: Medium-sized gravel that supports the root systems of plants and allows horizontal water flow.
- Vegetation Layer: Wetland plants whose roots extend into the substrate.

Vertical Subsurface Flow (VSSF) Constructed Wetlands

Design: VSSF wetlands involve water being distributed over the surface of the bed and then percolating down through the substrate before being collected at the bottom. These systems typically use sand or fine gravel as the substrate.

Operation: Water is intermittently loaded onto the surface, allowing air to fill the void spaces between cycles. This promotes aerobic conditions, enhancing the breakdown of organic matter and nitrification (conversion of ammonia to nitrate).

Applications: VSSF wetlands are particularly effective for treating high-strength wastewater and are often used in combination with HSSF systems to provide comprehensive treatment, including significant removal of ammonia and pathogens.

Construction Layers:

- Base Layer: An impermeable liner to contain the water.
- Drainage Layer: Coarse gravel or rock layer at the bottom to collect treated water.
- Filtration Layer: Fine gravel or sand to filter the water as it percolates down.
- Substrate Layer: Medium-sized gravel where plants are rooted.
- Distribution Layer: At the top, where water is distributed evenly across the surface.

Optimal Flow Methods for Wastewater and Freshwater

Wastewater Treatment

Horizontal Subsurface Flow (HSSF) Constructed Wetlands:

Best suited for treating domestic and industrial wastewater due to their ability to effectively remove organic pollutants, pathogens, and some nutrients.

The horizontal flow through a gravel or rock substrate provides ample surface area for microbial activity, which is essential for breaking down organic matter and reducing contaminants.

Vertical Subsurface Flow (VSSF) Constructed Wetlands:

Ideal for high-strength wastewater because of their capacity for enhanced nitrification and pathogen removal.

The vertical percolation of water through sand or fine gravel promotes aerobic conditions, which are crucial for the breakdown of ammonia and other organic compounds.
Freshwater Treatment

Surface Flow (SF) Constructed Wetlands:

More suitable for freshwater treatment, such as stormwater management and agricultural runoff, due to their resemblance to natural wetlands.

Effective in removing suspended solids, organic matter, and nutrients like nitrogen and phosphorus, making them excellent for polishing water before it enters natural water bodies or reservoirs.

Figure 2: Storm water Ponds integrated twith trees
Photo Credit:Aliaksandrbarysenka/Canva Pro

The Impact of Infiltration in Various Flow Models

Infiltration, or the movement of water into the soil and substrate, plays a critical role in the functioning of constructed wetlands. Its impact varies across different flow models:

Surface Flow (SF) Constructed Wetlands

Infiltration Impact: Limited due to the design where water flows over the surface rather than through the substrate. The primary water treatment processes involve sedimentation, plant uptake, and microbial activity on the surface.

Advantages: Minimal risk of groundwater contamination; effective in nutrient removal through plant uptake and microbial activity on the soil surface.

Horizontal Subsurface Flow (HSSF) Constructed Wetlands

Infiltration Impact: Moderate, as water flows horizontally through a gravel or rock substrate. The water remains in close contact with the substrate, which supports microbial degradation of pollutants.

Advantages: Efficient removal of organic matter and pathogens; reduced risk of surface water contamination; minimal exposure to mosquitoes and odors.

Vertical Subsurface Flow (VSSF) Constructed Wetlands

Infiltration Impact: High, as water percolates vertically through layers of gravel or sand, providing extensive filtration and contact with aerobic microorganisms.

Advantages: Enhanced nitrification and removal of ammonia; effective filtration and pathogen removal; compact design suitable for areas with limited space.

Figure 2: Stormwater Retention Basins, Belarus
Photo Credit:Grisha Bruev/Canva Pro

Ecological and Environmental Benefits

Water Quality Improvement: Constructed wetlands effectively remove contaminants such as nutrients, heavy metals, and pathogens from wastewater. The vegetation and microorganisms in these systems break down organic matter and absorb harmful substances, producing cleaner effluent suitable for reuse or safe discharge into natural water bodies.

Flood Control: By storing excess rainwater and reducing peak flow rates, constructed wetlands mitigate the risk of flooding. Their ability to absorb and slowly release water helps stabilize hydrological cycles, protecting communities from extreme weather events.

Habitat Creation: Constructed wetlands provide critical habitats for wildlife, including birds, amphibians, and insects. They serve as refuges for species displaced by urban development and contribute to biodiversity conservation.

Carbon Sequestration: Wetlands, both natural and constructed, act as significant carbon sinks. Through the process of photosynthesis and organic matter accumulation, they capture and store carbon dioxide, helping to mitigate climate change.

Benefits for Drinking Water Quality

Natural Filtration: One of the most significant benefits of constructed wetlands is their ability to naturally filter water, making it safer for human consumption. As water passes through the wetland, pollutants are trapped and broken down by plants and microorganisms. This natural filtration process significantly reduces levels of contaminants such as nitrates, phosphates, heavy metals, and pathogens, resulting in cleaner water that can be further treated for drinking purposes.

Reduction of Harmful Chemicals: Constructed wetlands help reduce the concentration of harmful chemicals like pesticides and herbicides, which often contaminate surface and groundwater sources. The vegetation in wetlands absorbs and breaks down these chemicals, reducing their presence in the water that eventually reaches drinking water reservoirs.

Pathogen Removal: Wetlands are effective in removing pathogens from water. The combination of physical filtration through plant roots and microbial degradation ensures that harmful bacteria and viruses are significantly reduced, lowering the risk of waterborne diseases.

Buffer Against Pollution: By acting as a buffer zone, constructed wetlands protect drinking water sources from pollution runoff. During heavy rainfall, wetlands can capture and treat stormwater before it reaches rivers and lakes that serve as sources for drinking water, ensuring that these bodies remain less contaminated.

Additional Stages for Filtering Drinking Water from Wetland Water

While constructed wetlands significantly improve water quality, additional treatment stages are necessary to ensure the water is safe for drinking. These stages typically include:

Pre-Treatment: Screening to remove large debris and sediments that could clog subsequent treatment processes.

Coagulation and Flocculation: Adding chemicals to water to facilitate the aggregation of fine particles into larger flocs, which can be easily removed.

Sedimentation: Allowing the water to sit in a basin so that heavier particles settle to the bottom.

Filtration: Passing water through filters, typically composed of sand, gravel, and activated carbon, to remove remaining particles and organic compounds.

Disinfection: Using methods such as chlorination, UV radiation, or ozonation to kill any remaining pathogens.

Advanced Treatment (if necessary): Processes such as reverse osmosis or activated carbon filtration to remove any specific contaminants or improve water quality to meet stringent drinking water standards.

Figure 3: Stormwater Management Infrastructure, Perforated Concrete Pipe
Photo Credit: Brian Guest/Canva Pro

Integrating Agroforestry with Constructed Wetlands

Agroforestry, the practice of integrating trees and shrubs into agricultural landscapes, can synergistically enhance the benefits of constructed wetlands. This integration creates a multifunctional landscape that offers numerous environmental, economic, and social benefits:

Enhanced Water Filtration: Trees and shrubs planted around and within constructed wetlands can enhance water filtration. Their roots stabilize soil, reducing erosion and sediment runoff into the wetlands. The additional root systems also increase the uptake of nutrients and contaminants, improving water quality further.

Biodiversity and Habitat: Agroforestry systems increase biodiversity by providing diverse habitats for various species. The combination of wetland and terrestrial habitats supports a wider range of flora and fauna, promoting ecological balance and resilience.

Carbon Sequestration: Integrating trees and shrubs with constructed wetlands amplifies carbon sequestration. While wetlands capture carbon in their soils and vegetation, trees and shrubs sequester additional carbon in their biomass and root systems, contributing to climate change mitigation.

Microclimate Regulation: Trees and shrubs can regulate the microclimate around wetlands, providing shade and reducing water evaporation rates. This helps maintain water levels and improves the efficiency of the wetland in water treatment.

Economic Benefits: Agroforestry can provide additional income streams for communities. Fruit, nuts, timber, and other products from trees and shrubs can be harvested sustainably, supporting local economies while maintaining the ecological integrity of the wetlands.

Soil Health Improvement: The deep roots of trees and shrubs improve soil structure and fertility. This benefits both the wetland ecosystem and adjacent agricultural lands, leading to more sustainable agricultural practices.

Figure 4: Storm Drain Outlet - the volume is not small.
Photo Credit: Nuttanun/Canva Pro

Challenges and Considerations

While the benefits of constructed wetlands and their integration with agroforestry are clear, several challenges must be addressed to maximize their potential. Site selection, design, and maintenance are critical factors that influence the effectiveness and longevity of these systems. Constructed wetlands require careful planning to ensure they meet the specific needs of the area and the types of pollutants they are designed to treat. Ongoing monitoring and adaptive management are essential to address any operational issues and optimize performance. Additionally, integrating agroforestry requires careful selection of tree and shrub species to ensure they are compatible with the wetland environment and do not negatively impact water quality or the wetland's ecological functions.

Figure 5: Stormwater Outlet Pipes - Typical rerouting of the storm flood
Photo Credit: Scott Kenneth Brodie/Canva Pro

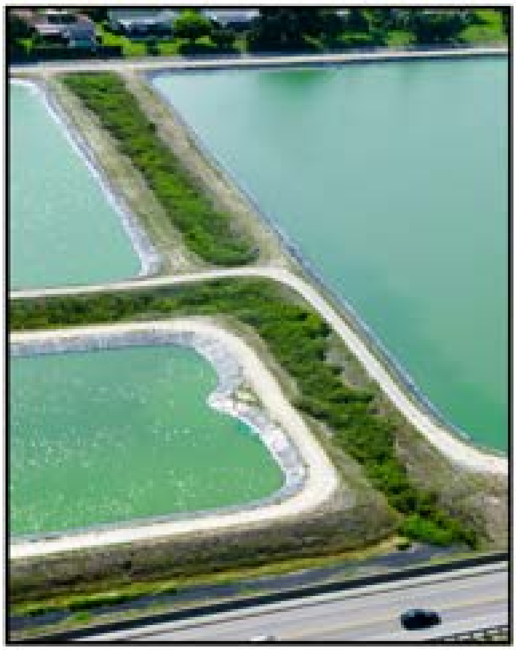

Figure 4: Water Treatment Ponds in Florida
Photo Credit: negaprion/Canva Pro

Conclusion

The urgent need for constructed wetlands is evident in the face of escalating environmental and water management challenges. As natural wetlands continue to vanish, constructed wetlands offer a sustainable solution that harnesses natural processes to provide vital ecosystem services. By improving water quality, controlling floods, creating habitats, and contributing to climate mitigation, constructed wetlands represent a versatile and cost-effective approach to sustainable development. Integrating agroforestry within these systems further enhances their benefits, creating multifunctional landscapes that support biodiversity, carbon sequestration, and local economies. Crucially, their ability to enhance the quality of drinking water underscores their importance in ensuring public health and water security. Investing in these integrated systems is not only a pragmatic response to environmental degradation but also a proactive step towards a resilient and thriving future.

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Introduction: The Prototyping Journey from Antananarivo to Niedersachsen

The original plan for the 2024 Fellowship prototyping was to take place in Antananarivo, where the system was to be built with the expertise of two distinguished engineers: Andriantsiferana Tafita Miarintsoa Eliasy and Razafimahatratra Tolotriniaina Michela. Their work in designing the photovoltaic-powered pumping and filtration system was instrumental in laying the groundwork for the prototype. The two experts meticulously documented the design process, guiding the technical specifications and ensuring that the system's architecture aligned with the goals of the project.

However, due to unforeseen and complex logistical challenges, the decision was made to move the prototyping phase to Niedersachsen, Germany. This shift was not without its challenges, as it resulted in the prototype's final costs being approximately double the initial estimates. Numerous small but significant hurdles were encountered along the way. Nevertheless, having the prototype located closer to the Foundation's leadership proved invaluable, as it allowed for direct oversight and the swift addressing of emerging issues. The lessons learned and the problems encountered were thoroughly documented, and many of these insights are shared in the following pages.

We extend our gratitude to Andriantsiferana Tafita Miarintsoa Eliasy and Razafimahatratra Tolotriniaina Michela for their tireless efforts in the design phase. Their contributions were critical, not only in the creation of the system but also in uncovering key insights that led to important discoveries and advancements this year.

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UNIVERSITE D'ANTANANRIVO
FACULTE DES SCIENCES
DOMAINE : SCIENCES ET TECHNOLOGIES
MENTION : PROCEDES ET ECOLOGIE INDUSTRIELLE
PARCOURS : GENIE DE L'EAU ET GENIE DE L'ENVIRONNEMENT

PRODUCTION OF DRINKING WATER via THE FILTRATION PROCESS

ANDRIANTSIFERANA TAFITA MIARINTSOA ELIASY
RAZAFIMAHATRATRA TOLOTRINIAINA MICHELA

Abstract

The document discusses the importance of good quality drinking water for health and the use of slow sand filtration as a biological purification method. It explains the evaluation of various physico-chemical and microbiological parameters of raw water to determine the appropriate treatment. The study aims to improve the drinking water supply for a low-consumption household using water from the Ikopa River.

The raw water analysis showed that certain parameters like pH, conductivity, and turbidity were beyond acceptable limits, indicating the need for treatment. A detailed sizing of the water treatment plant is described, including components like a turbidity removal unit, microbiological elimination unit, and UV treatment system.

The document also covers the site location conditions, environmental impacts, routine maintenance, and interviews for the treatment system. It emphasizes the importance of various filtration materials like sand and activated carbon in water treatment.

In conclusion, the study highlights the significance of proper treatment methods to ensure clean and safe water. It stresses the role of filtration materials and thorough analysis of water parameters for an effective filtration system that meets health standards.

The document provides detailed bibliographical references, appendices on water characteristics and estimates, and a summary of the slow sand filtration process confirming the reduction of turbidity and microbiological parameters in treated water.

Contents

INTRODUCTION

Good quality drinking water is essential for health [1]. There are several technologies to make water drinkable, namely the filtration process. Slow sand filtration is a biological purification method. It consists of passing the water to be treated through a filter bed, the most used material is sand [2]. The process provides a simultaneous improvement in the physical, chemical and bacteriological qualities of raw water. On the surface of the bed, the biological membrane is formed, in which the purification process takes place. This method is more economical because it offers the possibility of involving the community in the management, maintenance and operation of the installations [3]. This work is part of improving the drinking water supply of a low-consumption household. The water to be treated comes from the Ikopa River.

I. RAW WATER

The evaluation of the characteristic parameters of raw water indicates its quality and makes it possible to determine the appropriate type of treatment.

I-1- Physico-chemical parameters

I-1-1. pH

The pH of water represents its acidity or alkalinity. The measurement is carried out by an electrometric method using a pH meter [4].

I-1-2. Turbidity

Turbidity is due to the presence of suspended matter (clay, plankton, organic debris). Its determination is done by the electrometry method using a turbidimeter [4].

I-1-3. Conductivity

Conductivity gives the overall mineralization of water. The measurement is carried out by an electrometry method [4].

I-1-4. Alkalinity

The alkalinity of water corresponds to the presence of hydrogen carbonates, carbonates and hydroxides. The alkaline titer TA measures the content of water in free hydroxides and carbonates. The complete alkaline titer TAC corresponds to the content of free carbonate and hydrogen carbonate hydroxides. Alkalinity is measured using a strong acid standard solution in the presence of a colored pH indicator [4].

I-1-5. Hardness

The hardness of the water is linked to the leaching of the land crossed and it corresponds to the calcium (Ca) and magnesium (Mg) content. We speak of the total hardness of water or hydrometric titer (TH). The determination is made by neutralizing a volume of water with a dilute mineral acid [4].

I-1-6. Suspended matter

The suspended solids measurement provides the amount of undissolved substances present in the water. Its determination can be done by centrifugation or filtration [4].

I-1-7. Biochemical oxygen demand (BOD)

The biochemical oxygen demand should make it possible to assess the load of the environment considered in putrescible substances [4].

I-1-8. Chemical Oxygen Demand (COD)

Chemical oxygen demand determines the overall amount of oxygen needed for pollution degradation [4].

I-2- Microbiological parameters

Microbiological analyzes provide information on the health risks of water ; to be drinkable, it must not contain pathogenic microorganisms [6].

I-2-1. Coliforms fecal

Fecal coliforms are bacteria of fecal origin. These are microbiological contamination indicator bacteria and are easily eliminated by disinfection.

I-2-2. Escherichia Coli

Escherichia *coli* are bacteria that are part of the coliform group. Their presence also indicates the presence of pathogenic microorganisms such as bacteria, viruses and protozoa.

I-2-3. Streptococci fecal

Fecal streptococci are present in the feces of humans and animals. Their presence in water also presents an indication of recent fecal pollution.

I-3- Raw water quality

This work was carried out in the laboratory of the Research Unit in Process Engineering and Environmental Engineering (URGPGE) of the Faculty of Sciences of the University of Antananarivo The following table presents the physicochemical and bacteriological characteristics of the water to be treated.

Table 01: physicochemical and bacteriological characteristics of raw water

	MES (mg/L)	Turbidity (NTU)	EC (µS/cm)	pH
Sampl	68,059 <30	174,36	253,981	7.28 6.5
e VMA		5 <5	<3000	- 9.5

	BOD5 (mg/L)	COD (mg/L)	Fecal coliforms (CFU/100 mL)
Sample	24,358	50,762	100 <
VMA	<5	<20	0

	Escherichia. Coli (CFU/100 mL)	Fecal streptococci (CFU/100 mL)
Sample	10 <	10 <
VMA	0	0

Source : Authors

I-4- Data analyzes

According to the results of the analyzes carried out, the pH of the raw water is acidic and meets the standard required by the Malagasy state. The conductivity is of the order of 254.981 µ S/cm and the value also respects the potability standard. The turbidity is 172.365 NTU, means the raw water is turbid. The turbidity value is higher than the VMA and this confirms that the water must be treated before use. The BOD is 4.358 mg/L and the COD content is 50.762 mg/L. These values exceed the admissible limits and designate the importance of the organic polluting load. For the bacteriological parameters, the result showed that the raw water does not meet the potability standard and requires prior treatment.

II. Sizing of the processing unit

The treatment plant is sized for a production of drinking water of 0.5m 3 per day and is operated for 3 hours.

II-1- Reservoir raw water

The raw water tank has a capacity of 16 m3 and is divided into two compartments. With a filling frequency of four times per week, the plant can treat 3072m 3 of raw water per year. The treatment unit is supplied by pumping.

II-2- Treated water tank

The tank can have a capacity of 0.5m 3 .

II-3- Module sizing

Taking into account the quality of the raw water, the treatment plant includes:

- A turbidity removal unit
- A microbiological parameter elimination unit
- UV treatment; the system includes a stainless steel treatment chamber containing a 450L/h UV lamp , operation would be continuous in the event of disinfection. The lifespan of the lamp is estimated at one year.

The treatment unit is made on three plastic drums and in series with a capacity of 100L. The choice concerns the following criteria;

- Easy to handle ;
- Not very sensitive to temperature variations;
- Facilitates cleaning of filter components (gravel, sand and activated carbon);
- The system maintains the content of certain parameters such as color, pH, turbidity, BOD, COD and pH; unlike those built in concrete.

The module consists of a slow sand filter in series with an active carbon filter, which is preceded by a filter with variable particle sizes and is completed by a treatment chamber equipped with a UV lamp according to the following figure.

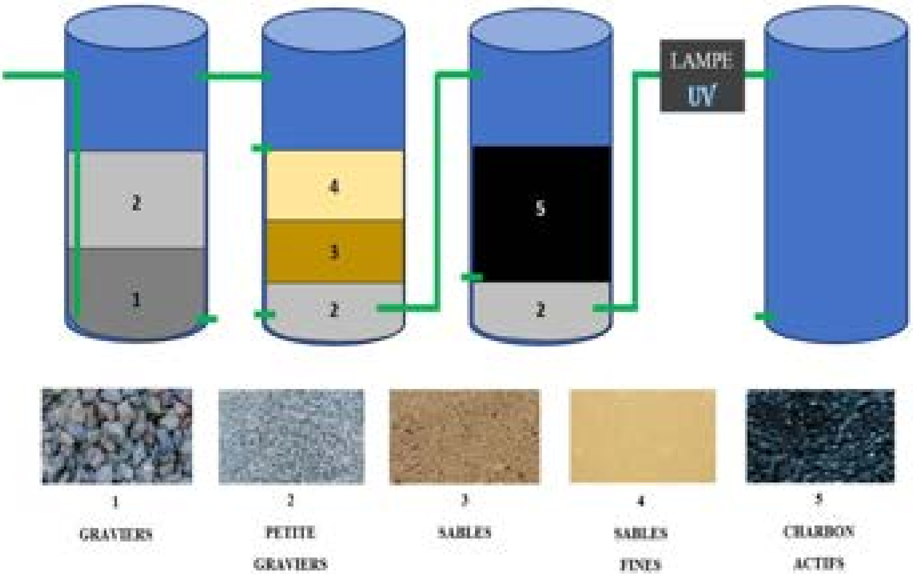

Figure 01 : simplified diagram of the processing unit

The following table presents the characteristics of each module

Table 02: module characteristics

Tanks	Component	Weight (kg)
1	Separation gravel	144
	Drainage gravel	24
2	Fine sand	50
	Sand	50
	Separation gravel	24
3	Charcoal Separation gravel	20
	Disinfection	24
UV lamp		

Source : Authors

III. Site Location Condition

The processing module is equipped with several components. The installation must respect the following conditions:

- Location having a surface area greater than that of the proposed module. It must be well protected, secure and above all fenced;
- Good accessibility to facilitate control, servicing and maintenance of equipment;
- At least 5m away from surrounding buildings and especially trees;
- Outside of a flood-prone and sunny area;
- The existence of a technical room for the location of materials and equipment , and of a supervisor specializing in the subject, is recommended.

Building A of the EGS faculty of the University of Antananarivo was chosen for the location of the treatment site according to the following coordinates:

- Position: 18°54'49''S 47°33'03''E
- Elevation: 1335.54m

Considering the characteristics of the processing module, the station has the following dimension:

- Length of 3.5m
- Width of 2.1m
- Height of 2.5m

The following figure shows the simplified diagram of the treatment station:

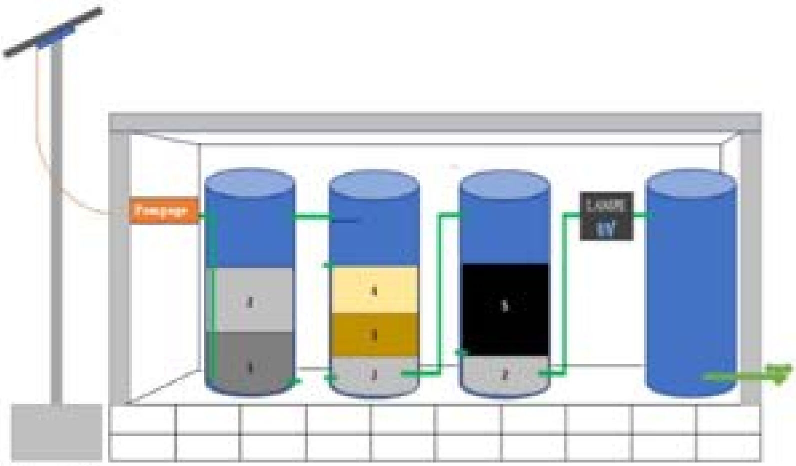

Figure 02

IV. Environmental impacts

The description of the treatment station allows certain measures to be respected, so here are some obligations and prohibitions; minimal noise, soil pollution, destruction of fauna and flora, especially ornamental plants, and also worker safety. Consumption of water treated by the sand filtration process does not present any health risk for consumers.

V. Interviews

Interviews can be done weekly, monthly or even annually. Routine maintenance includes operating the valves, checking the pumps and monitoring the quality of the treated water (perform once a week). For special maintenance, we focus on replacing the components of the filtration module (sand, gravel, activated carbon, lamp, etc.) to be carried out two to three times a year depending on the conditions of the equipment.

CONCLUSION

Water quality depends on the treatments applied, including physical, chemical and biological methods to remove contaminants. Filtration materials, such as sand, activated carbon and membranes, play a crucial role in the effectiveness of these treatments. Physicochemical parameters such as pH, conductivity and turbidity, as well as microbiological parameters, are essential to assess and improve water quality. An in-depth analysis of these parameters is necessary to correctly size a filtration prototype. Thus, a well-designed filtration system ensures clean, safe water that meets health standards.

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APPENDICES

Appendix 01: Physico-chemical and microbiological characteristics of raw water

The following table presents the quality of the water to be treated

Settings	Raw water	Unit	VMA
Ph	7.28		6.5 – 9.5
Conductivity	253,981	µS/cm	3000
Turbidity	174,365	NTU	5
Suspended matter	68,059	mg/L	30
Ammonium	0.192	mg/L	0.5
Magnesium	4,087	mg/L	50
Calcium	3,126	mg/L	200
Potassium	2,484	Mg/L	12
Full Alkalimetry Title	3,095	°F	-
Total hardnesses	24,751	°F	-
Nitrate	0.267	mg/L	50
Nitrite	0.089	mg/L	0.1
Sulfates	6,574	mg/L	150
Phosphates	0.396	mg/L	0.5
BOD	24,358	mg/L	5
COD	50,762	mg/L	20
Total coliforms	100 <	CFU/100 Ml	0
Fecal streptococci	10 <	CFU/100 mL	0
Escherichia coli	10 <	CFU/100 mL	0

Sources : Authors

Appendix 02: Characteristics of the filter bed

Filtration module components

The first components of the filter are the support gravels. They retain the sand and facilitate the distribution of washing water. Depending on the dimensions or particle size characteristics of the filter material, filtration can be carried out at the surface or at depth [7]. The process has three components, the first of which is composed of round sands of variable particle size favoring the reduction of turbidity, the second uses granular activated carbons allowing the improvement of organoleptic qualities and the last component concerns diatomaceous earths for the elimination of biological pollutants.

Granulometry

Determination of the size of the aggregates and their distribution according to their size. The following table presents the characteristics of the sands used.

Effective diameter d10 (mm)	0.52
Effective diameter d60 (mm)	0.71
Uniformity coefficient (CU)	1,365
Finish modulus (%)	4.78
Permeability (K)	0.375
Porosity (e)	0.062

Sources : Authors

Coal active

Preparation

Activated carbon is also a carbon-based material, obtained by calcination and activation of wood. As a very good adsorbent of organic matter, it also allows the elimination of compounds responsible for color, tastes and odors, and also organic micropollutants. The preparation consists of the carbonization of the precursors followed by grinding and sieving of the grains according to the particle size of 0.4 to 1 mm. Chemical activation consists of dehydration in an acidic medium at 500°C.

Regeneration

Regeneration is done with steam allowing the surface of the grains to be unclogged and sterilized.

Simulation

With the physico-chemical and microbiological characteristics of raw water, turbidity, MES and especially microbiological parameters largely exceed drinking standards. The process used is slow filtration, in fact, the water slowly passes through the layer of fine sand and the largest particles are stopped on the surface of the sand. Microbiological parameters are eliminated by activated carbon components. Our study confirmed the reduction of turbidity, suspended matter and also the total elimination of microbiological parameters. The following table summarizes the characteristics of the filter layers.

Component by location	Dimensions (mm)	Thickness (cm)
Charcoal	d<0.2	40
Fine sand	0.4<d<0.5	20
Sand	0.5<d<1	10
Separation gravel	4<d<8	10
Drainage gravel	10<d<15	10

Appendix 03: Estimated quotes

Physico-chemical and bacteriological analyzes of water before treatment

The following table presents the estimate for the physicochemical analyzes of raw water before treatment:

Settings	PU (MGA)	Quantity	Amount (MGA)
pH	20,000	01	20,000
Conductivity	20,000	01	20,000
Turbidity	20,000	01	20,000
Suspended matter	20,000	01	20,000
Ammonium	50,000	01	50,000
Magnesium	50,000	01	50,000
Calcium	50,000	01	50,000
Potassium	50,000	01	50,000
Full Alkalimetry Title	50,000	01	50,000
Total hardnesses	50,000	01	50,000
Nitrate	80,000	01	80,000
Nitrite	80,000	01	80,000
Sulfates	80,000	01	80,000
Phosphates	80,000	01	80,000
BOD	150,000	01	150,000
COD	150,000	01	150,000
Total coliforms	30,000	01	30,000
Fecal streptococci	30,000	01	30,000
Escherichia coli	30,000	01	30,000
		Total (excluding VAT) Ariary	1,090,000
		Total Euro	227

Sources : URGPGE Laboratory

Physico-chemical and bacteriological analyzes of water after treatment

The following table presents the quote for the physicochemical analyzes of raw water after treatment

Settings	PU (MGA)	Quantity	Amount (MGA)
pH	20,000	01	20,000
Conductivity	20,000	01	20,000
Turbidity	20,000	01	20,000
Suspended matter	20,000	01	20,000
Total coliforms	30,000	01	30,000
Fecal streptococci	30,000	01	30,000
Escherichia coli	30,000	01	30,000
	Total (excluding VAT) Ariary		**170,000**
	Total Euro		**36**

Sources : URGPGE Laboratory

Materials and equipment for installation

The following table presents the list of equipment

Settings	PU (MGA)	Quantity	Amount (MGA)
Bricks	180	5,000	900,000
Cements : Orimbato	38,000	2	76,000
Lova	35,000	6	210,000
Gravel	1,500	70	105,000
Sands	1,100	100	110,000
Protective grid (iron)	400,000	1	400,000
Boards	5,000	4	20,000
Doors	500,000	2	1,000,000
Window (PVC)	350,000	1	350,000
Madrie	15,000	4	60,000
Sheet metal (0.20)	45,000	4	180,000
Real estate	500,000	1	500,000
Complete solar panel	1,200,000	1	1,200,000
Drums (100 L)	110,000	4	440,000
Tank(500L)	500,000	1	500,000
Labor	800 000	1	800 000
	Total (excluding VAT) Ariary		**5,575,000**
	Total Euro		**1,157**

The following table shows the list of consumables

Settings	PU (MGA)	Quantity	Amount (MGA)
Gravel	1,500	4	6,000
Separation gravels	3,000	6	18,000
Sands	1,100	3	3,300
Fine sands	2,000	3	6,000
Activated carbon	600,000	1	600,000
UV lamp	1.5 million	1	1.5 million
Pipes	20,000	8	160,000
The stop valve	25,000	4	100,000
Elbow	2,000	10	20,000
Node	4,000	4	16,000
Suppressor pump	400,000	1	400,000
	Total (excluding VAT) Ariary		**2,829,300**
	Total Euro		**587**

Sources : Authors

Quote summaries

	Preliminary project		
Settings	**PU (Euro)**	**Quantity**	**Amount (Euro)**
Raw water diagnosis	227	1	227
Follow up	36	1	36
	Realization		
Settings	**PU (Euro)**	**Quantity**	**Amount (Euro)**
Facility	1,157	1	1,157
Consumables	587	1	587
	Process		
Settings	**PU (Euro)**	**Quantity**	**Amount (Euro)**
Interviews	-	-	-
	Total (excluding VAT) Ariary		**9,664,300**
	Total Euro		**2007**

Sources : Authors

SUMMARY

The slow sand filtration process is a technique recently used for water purification. Using this technology, our study confirmed a considerable reduction in some physicochemical parameters such as turbidity from 172 NTU to 3 NTU, MES from 30 N to 2.4 N. In addition we observed that the microbiological parameter are eliminated. This allowed us to propose water treatment of the Ikopa river with a view to supplying drinking water for small-scale uses. The system includes 4 modules in series, the first of which contains gravel weighing 168 kg, the second contains sand of variable dimensions weighing 100 kg, the third contains activated carbon. And the last constitutes the treated water tank.

Eliasy ANDRIATSIFERANA Michela RAZAFIMAHATRATRA

Introduction: Technical Design for Photovoltaic Pumping for a Campsite-Sized Filter System

The report by Tokiniaina Victoriot Randrianarisonolo delves into the technical design of a photovoltaic-powered pumping system for a campsite-sized filtration setup. This design work was pivotal in shaping many of the critical decisions made during the live prototyping phase in Niedersachsen, Germany, in 2024. A graduating Master's student in Electrical Engineering, Tokiniaina (Toki) has continued his studies while making an indelible mark on the 2024 Fellowship. His contributions to the project have been nothing short of exceptional, with his innovative approach to integrating photovoltaic energy into water filtration systems proving mission-critical to the project's success. His work, which addresses both the technical and practical challenges of off-grid water management, exemplifies the high level of skill and dedication that Toki brought to the Fellowship. The following pages offer an in-depth look at the design process, the key challenges overcome, and the profound impact of his contributions to this groundbreaking initiative.

JACQUELYN JESTINE SANDERS FOUNDATION
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DESIGN PROPOSAL FOR A PHOTOVOLTAIC-DRIVEN PUMPING SYSTEM FOR A 4000-LITER FILTER SYSTEM

A STUDY PROJECTS

By Tokiniaina Victoriot RANDRIANARISOLO

Author Note

Master in Electrical Engineering at Ecole Supérieure Polytechnique d'Antananarivo

JJSF Fellowship 2024, Rainwater Circulation and Aeration Team

Title:	Photovoltaic Pumping for Filtration
Revision:	Preprint
Issues:	Adding some detailed information about the system and its component
Prepared by:	Tokiniaina Victoriot RANDRIANARISOLO
Reviewed by:	Peer Review pending
Date:	May 29, 2024

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LIST OF FIGURES

1 Project Overview

This proposal outlines the design and implementation of a photovoltaic-driven pumping system to support a 4000-liter filter system. The system aims to lift water from phytoremediation tanks to a specified height, ensuring efficient filtration and additional utility functions. The design considers daily operational requirements, system sustainability, and energy efficiency.

1.1 System requirements

Filtration Capacity:
The filter system has a capacity of 4000 liters.
Daily water input requirement is up to 1000 liters. And an additional 200 L for Shower
Pumping Height:
The system needs to lift water to a height of 3 meters.
Flow Rate:
Although no specific flow rate is mandated, the system design must accommodate the total daily irradiation during the least favorable day to ensure reliable operation.

1.2 Objectives

The photovoltaic pumping system is designed to harness solar energy to power a water pump, ensuring an eco-friendly and sustainable operation capable of lifting water to a height of 3 meters. Water will be introduced from the top of the tank to promote sedimentation and enhance the filtration process. The pump will have multiple functions, feeding the filter and supplying water to a shower heater. Additionally, the system will generate surplus energy, sufficient to charge electronic devices like phones or power lighting.

System Components

Photovoltaic Panels: Selection of solar panels with adequate capacity to generate sufficient power during the worst irradiation conditions.
Water Pump: A DC water pump compatible with the photovoltaic system and that has the according requirement (Maximum height and average flowrate).
Energy Storage: Batteries to store excess energy generated during peak sunlight hours.
Control System: A controller to manage the distribution of power between the water pump, energy storage, and auxiliary devices.

We also have the following diagram that shows the proposed design for the system,

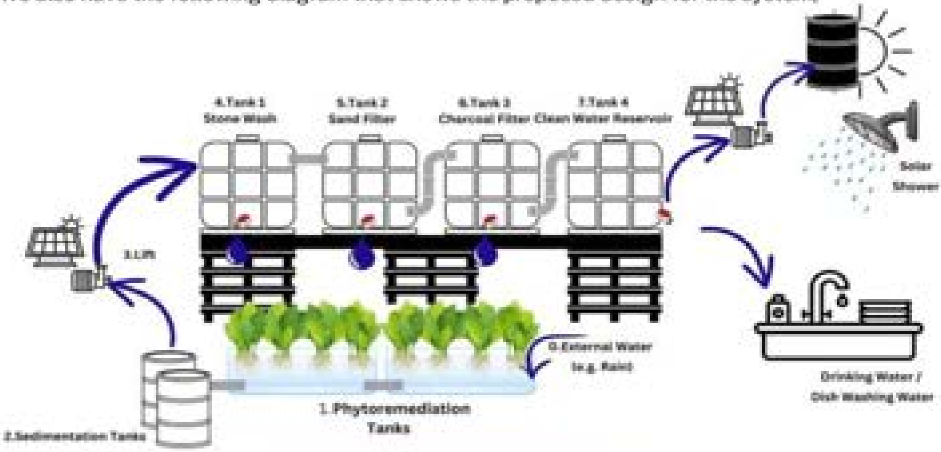


Figure 1 Illustration of the filtration system

2 Meteorological data

We agreed to dimensionate the System using the worst case in german in terms of daily irradiation and according to the data from Meteonorm we have the following graph :

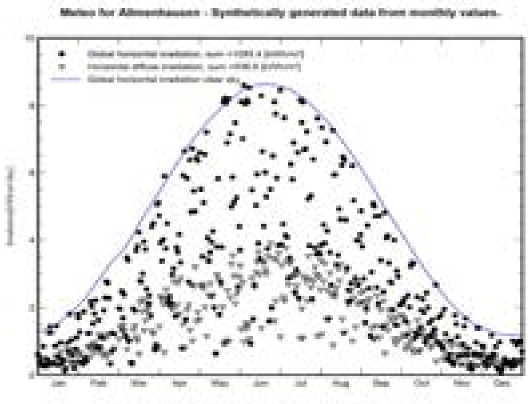


Figure 2 Irradiation data in German

It illustrates that the average irradiation for a day is between 2 kWh/m2/day and 4kWh/m2/day The calculation of the average irradiation gave a 2.97 kWh/m2/day From other source [1] we also have the following irradiation:

- Max : 3.4 kWh/m2/day
- Min : 2.6 kWh/m2/day

Figure 3 Average irradiation in German

3 System sizing baseline

We then use the following formula to get the appropriate Energy that the pump should have to lift the water and the relative solar panel that goes with it

$$E = \frac{V \cdot mH \cdot 2.725}{np}$$

- E represents the energy required in Watt-hours per day [Wh/d]
- V represents the volume in cubic meters per day [m3/d] (~ 1200L)
- mH is the manometric height (sum of the heights: NS+ ND+ Loss) in
- meters [m] (~ 3m)
- 2.725 represents the hydraulic coefficient np represents the efficiency of the pump (~ 0.4)

The pump should then get the necessary power to pump during the day where the sun is available (~ 3 kWh/m2/day)

The power the pump should then be:

$$P = \frac{E}{n\hbar}$$

Where:

- P represents the power of the pump in Watt [W]
- We assume the next value :

After the calculation, we have the following result :

- E= 27Wh
- P=9 W

4 PV sizing

To size the PV system, we should take into account the daily solar irradiation, which depends on the region, as well as the efficiency of the pump and the PV, which varies with the type of materials used.

$$Pp= \frac{E}{Dr \times K}$$

Where

- Pp represents the total panel power to be installed in Watt-peak [Wp]
- E represents the energy required in Watt-hour per day [Wh/d]
- Dr represents the daily radiation in Kilowatt-hour per square meter per day [kWh/m2/d] (~3 kWh/m2/day)
- K represents the efficiency coefficient of the photovoltaic array (depending on the type of panel support and operating conditions)

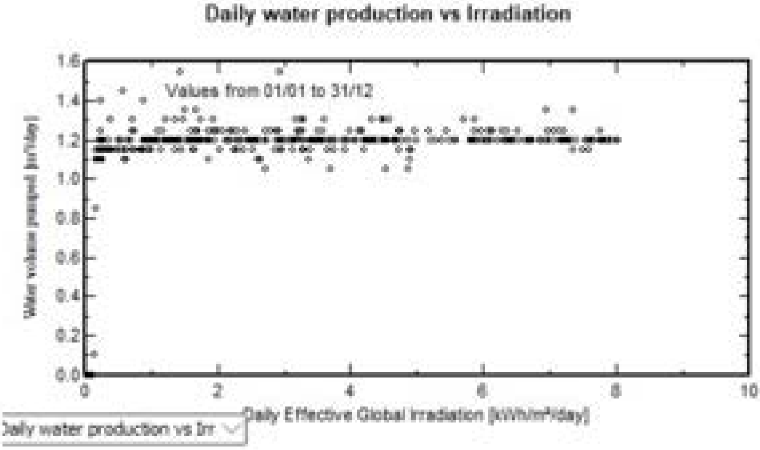
We need a PV of only 12 W if we want to lift the water

5 Simulation with PVSyst

The Simulation with PV syst give a detailed sizing of the system that take into account many parameters that may be unknown for some materials and situation but it can give an estimation of what we may need.

We did the Simulation with a 150 W Solar panel, and 50 W , 2-30 m Head Pump that has a 2m3 – 0.8 m3 Flowrate and also a MPPT controller.

There is an operative threshold which is lower than 0.2 kWh/m2/day and the missing water is 1.9%.



The Monthly result is shown in the table Bellow where the daily average of missing water is 0.1 m3/day

	GlobEff	EArrMPP	E_PmpOp	ETkFull	H_Pump	WPumped	W_Used	W_Miss
	kWh/m²	kWh	kWh	kWh	meterW	m³/day	m³/day	m³/day
January	47.1	7.12	0.478	4.21	3.275	1.108	1.102	0.098
February	69.4	10.48	0.468	6.43	3.212	1.202	1.200	0.000
March	111.0	16.29	0.521	9.90	3.247	1.202	1.200	0.000
April	137.0	19.65	0.508	12.62	3.244	1.202	1.200	0.000
May	150.7	21.03	0.522	12.85	3.193	1.200	1.200	0.000
June	147.6	20.34	0.503	13.04	3.162	1.200	1.200	0.000
July	148.3	20.37	0.521	13.36	3.175	1.200	1.200	0.000
August	142.5	19.49	0.512	12.79	3.194	1.198	1.200	0.000
September	119.1	16.65	0.498	10.60	3.258	1.200	1.200	0.000
October	85.8	12.43	0.525	8.28	3.237	1.195	1.200	0.000
November	49.5	7.32	0.466	4.65	3.229	1.128	1.130	0.070
December	37.6	5.78	0.479	3.62	3.265	1.095	1.094	0.106
Year	1246.1	176.96	5.991	111.94	3.229	1.177	1.177	0.023

- W_missed : Missing water
- W_Used : Water used
- WPumped : Water pumped
- EArrMPP Energy at Maximum Power Point
- ETkFull : Unused Energy because the tank is full

We have a maximum of 13 kWh of unused energy each month that is equivalent of an average of 400 Wh/ day . this energy can be stored in a battery of 12V and 50 Ah and can be used for other usage.

6 Simulation with other Load with PVSyst

6.1 Suggested Configuration

Component	Caracteristic	Comment
Solar Panel	410 W / 33 V	
Battery	12 V 100 Ah	
Controller	12-24 V 30 A MPPT	
Pump	12 V , Flowrate 0.8-2 m3/h P = 50W	Need to work about 1-2 hour to fill the tank. We choose the 50W pump so we can have a flexibility when we will choose it

Then we got the following charge Profile:

From 10 Am to 2 Pm , we got the Pump working and we estimated its maximum power to 50 W. The rest is residual needs like Light and Phone charger USB , We limited the user's need during the winter because we want to prioritize the pumping system and the light in the night.

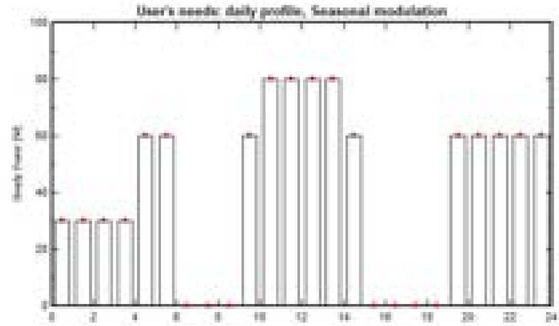


Figure 4 Summer daily profile

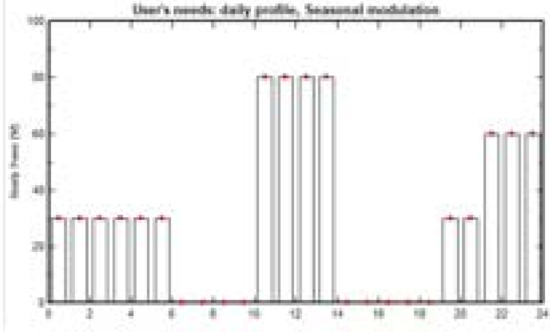


Figure 5 other Season's daily profile

After the simulation, we have the following result:

	GlobHor kWh/m²	GlobEff kWh/m²	E_Avail kWh	EUnused kWh	E_Miss kWh	E_User kWh	E_Load kWh	SolFrac ratio
January	22.7	47.3	17.03	1.23	8.79	14.15	22.94	0.617
February	39.8	69.5	25.60	6.67	2.71	18.01	20.72	0.869
March	81.8	118.8	40.31	13.68	1.27	21.67	22.94	0.945
April	124.2	136.7	49.14	21.58	0.00	22.20	22.20	1.000
May	158.7	150.2	52.78	23.15	0.00	22.94	22.94	1.000
June	164.8	147.4	50.89	16.78	0.38	29.02	29.40	0.987
July	162.0	147.9	50.90	15.12	0.00	30.38	30.38	1.000
August	137.5	142.2	48.83	13.61	0.15	30.23	30.38	0.995
September	95.1	118.8	41.67	15.43	0.00	22.20	22.20	1.000
October	57.3	85.8	30.47	5.14	0.00	22.94	22.94	1.000
November	28.8	49.6	17.49	1.31	7.02	15.18	22.20	0.684
December	17.7	38.1	13.58	0.00	10.74	12.20	22.94	0.532
Year	1085.4	1244.4	438.79	133.12	31.06	261.12	292.18	0.894

- GlobHor : Global horizontal irradiation
- GlobEff : Effective Global, corr for IAM and Shading
- E_Avail : Available Solar Energy
- EUnused- Unused Enegy (battery full)
- E_Miss : Missing energy
- U_User Energy supplied to the use
- E_load Energy need to the user (load)
- SolFrac Solar fraction (EUsed/ELoad)

We observed a missing energy range of 2 to 11 kWh per month, averaging 300 Wh per day. However, this shortfall won't impact the pumping system if we prioritize pumping. From April to October, the system operates with zero missing energy, demonstrating its high efficiency during this period.

6.2 Solar Pumping System Diagram

Component		Ref
Solar Panel	410 W 35V	JA Solar JAM72-S10-410-PR
Battery	12V 100 Ah	Pb Seald Gel
Controller	MPPT 500 W 35 A	SmartSolar MPPT 150/35 12 V
Pump	50 W	To be defined

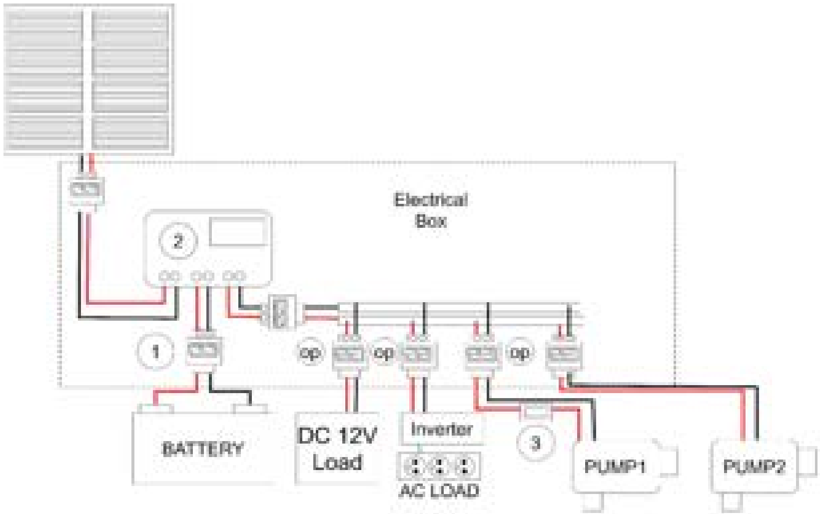


Figure 6 Illustration of the System

1- Circuit Breaker (Some of the Circuit breaker are Optional)

The Circuit breaker should have a calibre more than the flowing current and tension – for our case a 50 V 30 A will work fine.

2- Controller

3- Switch (if the pump use more than 10 A it will be wise to use relay)

6.3 Suggestion

Presence of the Battery

Indeed, we don't need battery for the puping part, However if we want to store all the unused energy, it will be better to use battery to allow us to use the energy when the sun won't be available.

The battery should be dimensionate up to the needed energy during the day

$$Energy\ during\ the\ day = \quad Power\ of\ device{\cdot}hour\ of\ operation$$

The capacity of the Battery is then determined by:

$$Capacity = \frac{Energy\ during\ the\ day}{Voltage * 0.6}$$

0.6 is the safety factor for voltage drop of the battery

For our case (load profile in Summer) we have a total of 460Wh that means we need a 64 Ah Battery。 We then can work with a 100 Ah Battery with few irradiation for 2 days and still got enough power if the battery was full.

There are two main types of batteries used in solar power systems: Lead-Acid and Lithium-Ion. Lead- Acid batteries, including Flooded (FLA) and Sealed (SLA) types, are cost-effective and reliable, with FLA requiring regular maintenance and SLA being maintenance-free but more expensive. Lithium-Ion batteries, particularly Lithium Iron Phosphate (LiFePO4), offer high energy density, longer lifespan, and better efficiency. They are maintenance-free and, despite a higher upfront cost, can be more cost- effective over time due to their durability.

A DC System rather than using inverter for AC needs

Opting for a DC system instead of using an inverter in a solar-powered house offers several advantages. Inverters, which convert DC from solar panels to AC for household use, result in energy losses. A DC system avoids this conversion, retaining more of the generated power and improving overall efficiency. Additionally, inverters add to both the initial setup and maintenance costs, so eliminating the inverter reduces these expenses, making the system more economical. A DC system is also simpler, with fewer components that can fail or require maintenance, leading to increased reliability and ease of installation and troubleshooting. Overall, a DC system can offer a more efficient, cost-effective, and reliable solution for solar-powered homes compared to using an inverter.

The power of the inverter should be calibrated based on the total AC load it will need to support simultaneously. According to the daily usage profile, the peak load is estimated to be 80 W. However, this may vary depending on the user's habits and usage patterns. Therefore, it is essential to consider potential variations in power consumption to ensure the inverter can handle occasional surges and maintain reliable operation under different conditions. By accurately matching the inverter capacity to the anticipated load, users can optimize performance and efficiency.

A small DC Pump that meet the requirement

There are many Pump on the internet that have a Lower Power but still has the ability to pump at the needed Head and Flowrate that we want.

A 23W 12 V DC pump with 0.9 m3/h and 5m Head :

Figure 7 example of pump

https://www.walmart.com/ip/CIVG-Mini-Water-Pump-DC-12V-Submersible-900L-H-Durable-High-Flow-Pumps-Compact-Lift-Diesel-Oil-House-Shower-Garden-Drainage- System/1462449915

A 19W 12 V DC pump with 0.8 m3/h and 5m Head :

Figure 8 example of pump

https://fr.aliexpress.com/i/1005004528293507.html?gatewayAdapt=glo2fra

An automated system that will shut off the pump when the tank is full

The system should include an automated feature that shuts off the pump when the tank reaches full capacity. This ensures efficient water management by preventing overflow and conserving energy. By automatically stopping the pump at the appropriate time, the system reduces the need for manual monitoring and intervention, enhancing overall convenience and reliability. It can replace the swithc in the figure 5

The Choice of the regulator

There are two types of regulators: PWM (Pulse Width Modulation) and MPPT (Maximum Power Point Tracking). The MPPT regulator is more efficient than the PWM regulator but can be more expensive. Regardless of the type chosen, the regulator should have a power rating higher than that of the PV system and be capable of handling the input current.

In our scenario, we have a single solar panel rated at 410 W and 35 V, which produces a current of 11 A. We have selected an MPPT regulator with a power rating of 500 W and a maximum current capacity of 30 A. This setup ensures the regulator can manage the input from the panel efficiently.

In some cases, the system may include additional strings or series of PV panels. The configuration will depend on the input voltage and current specifications of the controller. Properly matching these parameters ensures optimal performance and protection of the PV system.

Remark : In some cases, the regulator may not have a Load output pin but only a Battery charge controller. In such systems, the load should be connected directly to the battery. The solar panels will connect to the regulator, which then charges the battery. The inverter, if used, and other loads will draw power directly from the battery, ensuring continuous power supply even when solar input fluctuates.

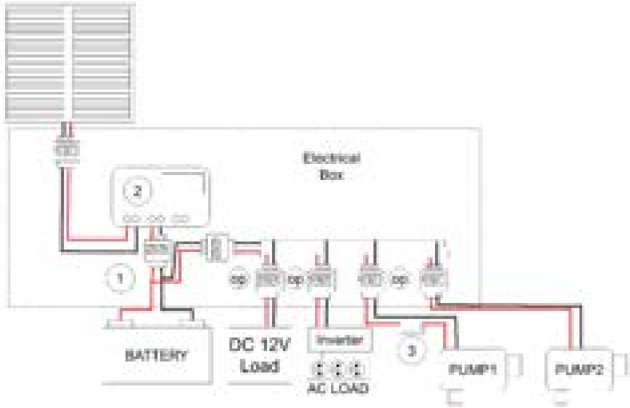


Figure 9 Illustration of the system with a controller without load Pin

Here is the summary of the system where we can use two of the 23 W Water pump to lift water for each need

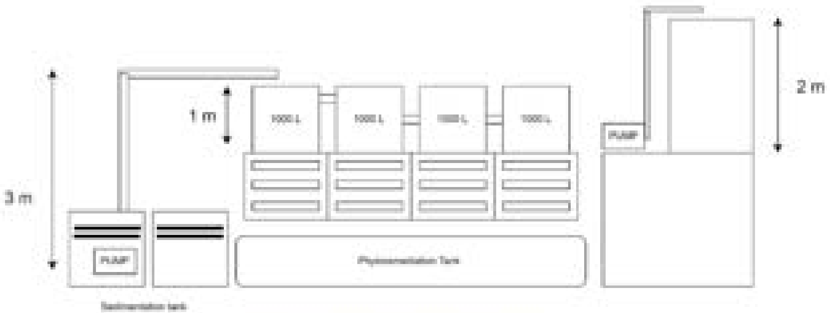


Figure 10 Illustration of the System

7 Conclusion:

In Conclusion a system that has a 410 W – 33 V Solat panel added to a 500 W MPPT Controller and a 12 V 100 Ah Battery can support two Mini Water Pump to lift the water to a 4000 L Filter with a 1000L/day Flowrate and to a shower with 200 L/day. Additionaly we can use the unused energy for lightning and phone charging or other use. This system was designed for worst case so that we can always pump during the day.

8 References:

[1] https://globalsolaratlas.info/download/germany

[2] PVsyst SA – Pompage au fil du soleil – Circuit Hydraulique

[3] Guillaume Aubourg et Jean-Marie Ily (pS-Eau), Denis Dangaix (Arene Ile-de-France). Le pompage solaire Options techniques et retours d'expériences Des repères pour l'action

[4] M.BAKRI LE POMPAGE SOLAIRE PHOTOVOLTAIQUE ,Manuel de cours, CDER

The Benefits of Using Potassium Polyacrylate in Reforestation Projects

Reforestation, the process of planting trees in deforested areas, is critical for restoring ecosystems, combating climate change, and preserving biodiversity. However, the success of these projects often hinges on the availability of water, a resource that can be scarce in many regions. One innovative solution to this challenge is the use of potassium polyacrylate, a superabsorbent polymer that can significantly enhance the effectiveness of reforestation efforts.

What is Potassium Polyacrylate?

Potassium polyacrylate is a water-absorbing polymer that can retain large amounts of water relative to its own mass. When mixed with soil, it acts as a water reservoir, capturing and storing water that would otherwise drain away. This stored water is then gradually released back into the soil, providing a steady moisture supply to plant roots.

Benefits in Reforestation

Enhanced Water Retention: One of the most significant advantages of potassium polyacrylate is its ability to retain water. In areas prone to drought or irregular rainfall, this property ensures that saplings have access to the moisture they need to survive and grow. The polymer can absorb up to 500 times its weight in water, dramatically improving soil moisture content and reducing the frequency of watering required.

Improved Survival Rates: Young trees are particularly vulnerable to water stress. By ensuring a more consistent water supply, potassium polyacrylate can help increase the survival rates of saplings. This is especially important in arid and semi-arid regions where reforestation projects often struggle with high mortality rates due to insufficient water.

Cost-Effective: While the initial cost of potassium polyacrylate may be higher than traditional irrigation methods, its ability to reduce the need for frequent watering can lead to long-term savings. Less frequent watering not only lowers labor and water costs but also minimizes the logistical challenges associated with transporting water to remote reforestation sites.

Soil Improvement: Beyond water retention, potassium polyacrylate can improve soil structure. By maintaining consistent moisture levels, it helps prevent soil compaction and erosion, promoting healthier root growth and soil aeration. This contributes to the overall fertility and resilience of the soil, creating a more supportive environment for young trees.

Environmental Sustainability: Potassium polyacrylate is biodegradable and breaks down into non-toxic components, making it an environmentally friendly choice. Its use can reduce the need for chemical fertilizers and pesticides, which are often harmful to the surrounding ecosystem.

Climate Resilience: As climate change intensifies, regions around the world are experiencing more extreme weather patterns, including prolonged droughts. Potassium polyacrylate can help reforestation projects adapt to these changing conditions by ensuring trees have access to water even during dry spells. This resilience is crucial for the long-term success of reforestation efforts.

Potassium polyacrylate is not yet widely adopted in reforestation projects, but it has seen increasing interest due to its promising benefits. Here are some key points regarding its usage and potential in reforestation:

Limited but Growing Usage

Experimental and Pilot Projects:
Potassium polyacrylate has been used in some experimental and pilot reforestation projects to evaluate its effectiveness. These trials have shown positive results, particularly in arid and semi-arid regions where water scarcity is a major limiting factor for tree survival and growth.

Agriculture and Horticulture:
While not yet mainstream in reforestation, potassium polyacrylate has been more commonly used in agriculture and horticulture. Its success in these fields suggests potential benefits for reforestation, especially in improving soil moisture retention and plant survival rates.

Potential Benefits in Reforestation
Water Scarcity Solutions: Reforestation projects often face challenges due to inconsistent or insufficient rainfall. Potassium polyacrylate can help mitigate these issues by storing water and releasing it gradually, ensuring a more reliable water supply for young trees.

Increased Survival Rates:
By providing a consistent source of moisture, potassium polyacrylate can help increase the survival rates of saplings, particularly in their critical early growth stages.

Reduced Watering Frequency:
This polymer can significantly reduce the need for frequent watering, making reforestation projects more sustainable and cost-effective, especially in remote or difficult-to-access areas.

Challenges and Considerations
Cost: The initial cost of potassium polyacrylate can be higher compared to traditional watering methods. However, the long-term savings in water and labor costs might offset this initial investment.

Environmental Concerns:
While potassium polyacrylate is generally considered safe and biodegradable, there are ongoing studies to fully understand its long-term environmental impacts. Ensuring that the polymer used is of high quality and environmentally friendly is essential.

Awareness and Adoption:
Wider adoption of potassium polyacrylate in reforestation requires increased awareness among forestry professionals and policymakers. Demonstrating its effectiveness through successful case studies and pilot projects can help build confidence in its use.

Conclusion
While potassium polyacrylate is not yet a common tool in reforestation projects, its potential benefits make it an attractive option for enhancing the success of these initiatives. Continued research, pilot projects, and increased awareness could lead to broader adoption, ultimately helping to improve reforestation outcomes, particularly in challenging environments.

References:
- "Water-absorbing gel increases crop yields in drought-prone areas" - This article discusses the use of superabsorbent polymers, including potassium polyacrylate, in agriculture to improve water retention and crop yields.
- "Superabsorbent polymers (SAPs) in agriculture and environmental management: A review" - This comprehensive review explores various applications of superabsorbent polymers, including their potential in enhancing soil moisture retention in agricultural and environmental settings.
- "Effectiveness of water-absorbing polymers on tree establishment in arid environments" - This study examines the impact of superabsorbent polymers on the survival and growth of trees in dry regions.

Nick Coman
Board Member, JJSF

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07.Aug.2024 – Coman, K.D. – JJS Foundation

Introduction

Constructed wetlands offer a cost-effective and sustainable solution for managing rainwater on sites where runoff currently escapes to rice production fields or flows back into the sea. These engineered ecosystems mimic the functions of natural wetlands, providing efficient wastewater treatment and enhancing freshwater storage capabilities. By harnessing the natural processes of sedimentation, filtration, and biological uptake, constructed wetlands effectively remove pollutants from wastewater, thus reducing the environmental impact on surrounding agricultural and marine ecosystems. Additionally, the ability to store and gradually release freshwater improves water availability for rice cultivation and other uses, promoting water security and resilience. However, careful consideration must be given to the choice of materials, particularly for the pond liners, to ensure long-term effectiveness and cost efficiency. This report will delve into the cost analysis of implementing constructed wetlands, emphasizing their dual benefits and the challenges associated with material selection.

Comparison of Synthetic Liners vs. Natural Liners (Clay) in Wetlands Construction

Constructed wetlands serve a variety of purposes, from water purification to habitat creation. When constructing a wetland over a large area, such as the example we explore here – 20,000 square meters, choosing between synthetic liners and natural clay liners involves a detailed analysis of costs, labor, and environmental impacts. This essay provides a rough estimation of labor and material costs for both options, and introduces an economical compromise using a bentonite-amended soil base under a synthetic liner. This approach balances initial cost savings with long-term maintenance considerations.

Project Context:
University of Antananarivo Garden of Eden Constructed Wetlands (circa 20,000 square meters of ponds)

The goal of the University of Antananarivo Garden of Eden Constructed Wetlands project is to create a sustainable and effective wetland area for wastwater treatement and also for Fresh water storage - in seperate areas of the large university landscape. The question here centers on whether to use a full clay liner, a synthetic liner, or a hybrid approach involving a bentonite-amended soil base under a synthetic liner.

Estimation of Labor and Material Costs

Synthetic Liners (e.g., EPDM, PVC)

Materials:

- Liner Cost: High-quality EPDM liner costs approximately $3 to $5 per square meter.
  - Total Cost: 20,000 m^2 x $4 (average) = $80,000.
- Geotextile Underlay: To protect the liner, a geotextile underlay is typically used, costing around $1 per square meter.
  - Total Cost: 20,000 m^2 x $1 = $20,000.
- Additional Materials: Adhesives, tapes, and other materials for seams and repairs, roughly estimated at $5,000.
  - Total Material Cost: $105,000.

Labor:

- Installation: Labor costs for installation are approximately $2 to $4 per square meter, considering the need for skilled labor to ensure proper installation.
  - Total Cost: 20,000 m^2 x $3 (average) = $60,000.
  - Total Labor Cost: $60,000.

Total Estimated Cost for 20,000 square meters installed Synthetic Liner: $165,000

Bentonite Clay Liner

Materials:
- Bentonite Cost: Bentonite clay costs about $0.50 to $1 per kilogram. Assuming a layer thickness of 10 cm and a density of 1.5 kg per liter:
- Volume Needed: 20,000 m^2 x 0.1 m = 2,000 m^3.
- Weight Needed: 2,000 m^3 x 1,500 kg/m^3 = 3,000,000 kg.
  - Total Cost: 3,000,000 kg x $0.75 (average) = $2,250,000.

Labor:
- Installation: Labor costs for spreading and compacting the clay are higher due to the volume and weight involved, approximately $5 to $7 per square meter.
- Total Cost: 20,000 m^2 x $6 (average) = $120,000.
  - Total Labor Cost: $120,000.

Total Estimated Cost for 20,000 square meters installed Bentonite Clay Liner: $2,370,000.

Bentonite-Amended Soil Base Under Synthetic Liner

Materials:
- Bentonite Amendment: Adding a bentonite layer (approximately 5 cm) under the synthetic liner to improve the sealing. This requires less bentonite.
- Volume Needed: 20,000 m^2 x 0.05 m = 1,000 m^3.
- Weight Needed: 1,000 m^3 x 1,500 kg/m^3 = 1,500,000 kg.
  - Total Cost: 1,500,000 kg x $0.75 = $1,125,000.
- Synthetic Liner Cost: As previously estimated.
  - Total Cost: $105,000.

Labor:
- Installation of Bentonite and Liner: Combined labor cost is lower than installing a full bentonite layer but higher than installing only a synthetic liner.
- Total Cost: 20,000 m^2 x $4 (average) = $80,000.
  - Total Labor Cost: $80,000.

Total Estimated Cost for Bentonite-Amended Soil Base and Synthetic Liner: $1,310,000.

Environmental Impact Assessment

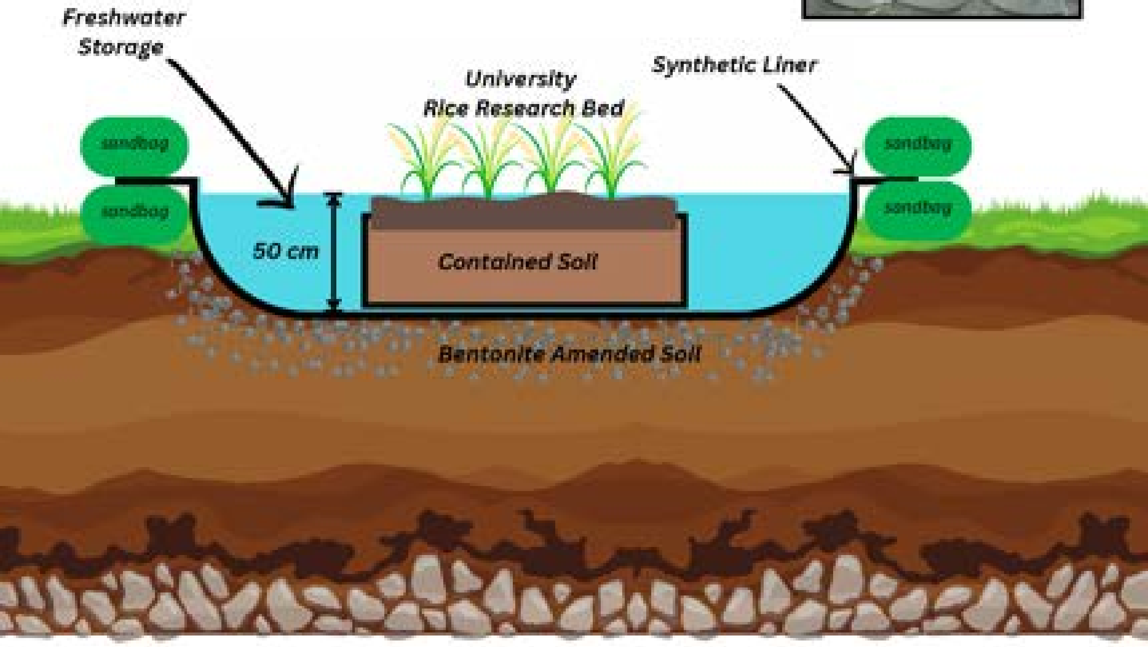
Studies comparing the environmental impacts of synthetic and clay liners highlight several important factors:

Synthetic Liners:
- Environmental Impact: Production and disposal of synthetic liners contribute to plastic pollution and carbon emissions (Mitsch & Gosselink, 2015).
- Durability and Longevity: Synthetic liners are durable and require less frequent replacement, reducing long-term environmental impact (Kadlec & Wallace, 2008).

Bentonite Clay Liners:
- Environmental Impact: Bentonite is a natural material with a lower environmental footprint in terms of production. However, the mining and transportation of large quantities can still have significant impacts (Boyd, 2000).
- Ecological Integration: Clay liners integrate more seamlessly into the natural environment and support more natural wetland functions (Hammer, 1992).

Hybrid Approach:
- Environmental Impact: Using a bentonite-amended soil base reduces the volume of synthetic materials required and leverages the natural sealing properties of bentonite, minimizing overall environmental impact (Hammer, 1992).

07.08.2024 - Coman
Freshwater Storage / Rice Research Bed



Pond Construction with synthetic Liner. Photo Credit: Canva

Pond Construction with Bentonite amended soil. Photo Credit: Canva

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Conclusions and Cost Comparison

The table below summarizes the costs for each option:

Option	Cost Per Square Meter	Total Projected Liner Cost (20,000 m2)
Synthetic Liner	$ 8.25	$165,000
Bentonite Clay Liner	$ 118.50	$2,370,000
Bentonite-Amended Soil Base and Liner	$ 65.50	$1,310,000

Cost Comparison - Qualitätive

Given the significant cost difference, the synthetic liner is the most economical option initially, followed by the hybrid approach. The full bentonite clay liner, while natural, is the most expensive. The hybrid approach using a bentonite-amended soil base under a synthetic liner provides a balanced solution, offering cost savings while leveraging the benefits of both materials.

Each of the three options for constructing the University of Antananarivo Garden of Eden Constructed Wetlands — using a synthetic liner, a bentonite clay liner, or a bentonite-amended soil base under a synthetic liner — is viable, with unique advantages and considerations. While this essay focuses on the economic aspects of liner construction, it is essential to recognize that the final decision will depend on a variety of factors beyond cost, including environmental impact, durability, and specific project requirements. This analysis solely compares the construction costs of the three liner options and does not address other critical issues such as water quality for drinking, showering, or research purposes, which are being thoroughly investigated in parallel.

References

Boyd, C. E. (2000). Water Quality: An Introduction. Springer Science & Business Media.

Hammer, D. A. (1992). Creating Freshwater Wetlands. CRC Press.

Kadlec, R. H., & Wallace, S. D. (2008). Treatment Wetlands. CRC Press.

Mitsch, W. J., & Gosselink, J. G. (2015). Wetlands (5th ed.). John Wiley & Sons.

Case Study: Engaging International Fellows to Advance the Foundation's Strategic Academic Goals

As part of our ongoing commitment to fostering global collaboration and advancing our strategic initiatives, the Foundation launched a pilot Fellowship program in 2024 aimed at engaging young professionals from around the world in targeted research endeavors. This program, which we are developing into a reproducible model, seeks to harness the expertise and local knowledge of emerging leaders in various fields, aligning their efforts with the Foundation's broader goals of sustainability, conservation, and social impact.

One of the standout participants in this inaugural cohort is Mr. Samuel Kimani, an industrial engineer living and working in Kenya. Mr. Kimani's role in this program has been instrumental in shaping the Foundation's approach to reforestation in Africa—a critical area of focus given the continent's unique environmental challenges and opportunities.

Fellowship Overview:

Objective: The Fellowship is designed to provide young professionals with the opportunity to contribute to high-impact research projects that are of strategic importance to the Foundation. In this case, Mr. Kimani was tasked with investigating the current state of reforestation efforts across Africa, identifying successful projects, and profiling key stakeholders involved in these initiatives.

Scope: Mr. Kimani conducted in-depth research, leveraging his engineering background and local insights to produce a comprehensive report on Africa's most important reforestation projects. His work not only highlights the current landscape but also identifies critical success factors and challenges, offering a roadmap for future interventions.

Impact: Mr. Kimani's research serves as a launching pad for upcoming fundraising activities, as the Foundation seeks to support tree conservation efforts at the University of Antananarivo in Madagascar. However, the implications of his findings extend far beyond this specific initiative. His report is a valuable resource for anyone interested in reforestation and collaboration in Africa, offering insights that could inform policy, direct funding, and inspire further research.

Towards a Reproducible Model:

The success of Mr. Kimani's Fellowship has provided valuable lessons that will shape the Foundation's approach to future engagements. By developing a structured, yet flexible, framework for these fellowships, the Foundation aims to replicate this model across different regions and thematic areas. The goal is to create a network of international Fellows who can contribute to the Foundation's mission while advancing their own professional development.

In conclusion, Mr. Kimani's work exemplifies the potential of this Fellowship program to drive impactful research and foster international collaboration. As we refine and expand this initiative, we look forward to engaging more young professionals like Mr. Kimani, whose contributions are essential to achieving the Foundation's vision of sustainable development and environmental stewardship.

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From Deforestation to Reforestation: A Historical and Contemporary Analysis of Africa's Forests

JJSF Fellowship: International Correspondent Engagement

A Report by JJSF Fellow: Samuel Kimani
(Industrial Engineering Graduate in Kenya)

Prepared as part of the JJSF Fellowship Program 2024

Table of Contents

Editor's Note for future Engaged Scholarship Management Teams:

Logistics: The original formatting by the author has been mildly altered on this report to fit it to the page size of the book. In changing fonts, and reformatting - some white space developed. In future report preparation iterations - a better result can be achieved by standardizing on a page size in advance of any publications. Extensive editing work could lead to fewer pages - it is true!

Africa's Green Legacy

The forests of Africa exude an ambiance that has become known, to many, as the continent's cultural totem of natural wealth. The expanse of this important resource has ignited pristine dialogue around the unique interaction between nature and the social, economic, political, and religious frontiers of African living. How a forest could be the lifeblood of natural flora and fauna and still hold deep ancestral significance to rural communities has remained a defining feature of Africa's vast jungles. The woodlands and rainforests of sub-Saharan Africa (SSA) account for the largest proportion of Africa's dry forests and constitute between 14 and 16% of the earth's total forest cover (the Food and Agriculture Organization [FAO], 2020; GFZ, 2024). These vast forestlands host a rich biodiversity that balances natural phenomena, including water flow, climate patterns, and soil retention (Chidumayo & Marunda, 2010).

The importance of rainforests as a natural source of livelihood in Africa stems from the reality that this continent is the most poverty-stricken in the world. As ever, humans continue to exert tremendous pressure on Africa's rainforests by unsustainably harnessing natural resources to meet and sustain their livelihood demands. For instance, about 60 to 80% of Africa's rural households depend on charcoal as wood fuel, with wood products contributing roughly 75% of all household energy needs in SSA (Chidumayo & Marunda, 2010; Yirdaw, 1996). The extensive use of Africa's forestland and its resources in activities such as agriculture, livestock farming, urbanization, fuelwood sourcing, and logging has resulted in severe deforestation and other related ecological repercussions. This paper aims to explore the extent and status quo of deforestation against the backdrop of SSA's geographically different forest regions. The paper then details a chronological history of deforestation across Africa's forestlands, a discussion of its causes and effects, and the current state of awareness regarding forest protection and activity control. In the interest of exploring current efforts in eradicating deforestation across SSA, this paper also outlines current initiatives focusing on reforestation and land restoration.

The Poverty-Deforestation Cycle in Sub-Saharan Africa

Human encroachment and agricultural activity on forestlands have existed for millennia; in fact, deforestation may have been occurring for as long as humans have been practicing agriculture (Hosier, 1988). It was not until recently, following the emergence of global awareness to combat climate change, that deforestation became a pressing issue demanding urgent preventive and restorative action for SSA's forests (Chatham House, 2023). A sensible first step to understanding the nature of deforestation would be to source a definition for the term. The FAO termed it as "the conversion of Forest to other land use independently whether human-induced or not" (FAO, 2020a, p. 6). A more human-centered definition of deforestation, offered by the United Nations Framework Convention on Climate Change (UNFCCC), is "the direct human-induced conversion of forested land to non- forested land." (UNFCCC, 2002, as cited in Chirwa & Adeyemi, 2020, p. 197). In both definitions, human activity plays an undeniable role in the depletion of forestland.

Understandably, then, the extent of deforestation, as witnessed in SSA, alludes to the pressure applied to forestland by human activity. Much of this activity is driven by poverty and limited livelihood choices (Chidumayo & Marunda, 2010). Forests constitute a bountiful ecosystem that provides SSA's rural inhabitants with a plethora of edible fruits, plants, and game meat to avert famine and food insecurity. Much as human dependence on forestland offers a safety net for nutritional needs, SSA's woodlands and dry forests also support local industrial activity through the production of wood and non-wood forest products. Commodities ranging from timber to beeswax help sustain a formal revenue economy in SSA, which critically lowers the bar for overexploitation (Chidumayo & Marunda, 2010).

There has been extensive research probing into the impact of deforestation across the world's tropical rainforests; however, the effects of deforestation on dry forests and semiarid ecosystems remain less known (Hosier, 1988). Some, like Lugo and Brown (1982), have reasoned that deforestation occurs in consonance with life zones; that is, drier areas experience more deforestation due to accessibility that is limited in heavily moist areas. Therefore, drier forestlands may have undergone relatively more denudation over the centuries compared to rainforests and subhumid woodlands (Hosier, 1988). Another argument is the absence of strong advocacy against encroachment in tropical semiarid forests, which results in wider destruction than densely moist forestlands (Janzen, 1987). Drier zones have a lesser capacity to support sustainable agriculture, extensive pasturage, or charcoal production and will thus be easily destroyed.

The Statistical Canopy: Numbers and Narratives

The largest proportion of forest cover in the world is in SSA – this region alone accounts for 80% of all dry forests in the world. The largest proportion of these forests are in central (37%) and southern Africa (28%) (Nair & Tieguhong, 2004). Despite this tremendous figure, forestlands cover a mere 6% of Africa's total land area despite being a source of sustenance to over half of the continent's population (Bodart et al., 2013; Freedman, 1995). The highest volume of global deforestation within the last century occurred in Africa's dry forests. There was a record 70% loss within the last 25 years of the twentieth century (Bodart et al., 2013), with humid tropical forests constituting about a sixth of this loss in SSA (Brink & Eva, 2009).

Globally, forested areas have been declining at a rate of about 0.13% each year between 1990 and 2015 – much of this decline has occurred in Africa and Europe (Sánchez et al., 2018). Over this period, forest cover in Africa's forestlands dropped from 24.9% to just over 21% (African Forestry and Wildlife Commission [AFWC], 2022). The 2020 Global Forest Resource Assessment (FRA) report by the FAO indicated that Africa had the worst annual deforestation of the 2010s, with the forested areas of eastern and southern Africa accounting for the largest loss (FAO, 2020b). A depreciation rate of 4.1 million hectares over ten years, starting in 1990, rose to 4.31 million hectares in the decade leading up to 2010 and further up to 4.41 million hectares between 2010 and 2020 (FAO, 2020). Despite these increments, the annual deforestation rate was reduced by 4.9% between 2010 and 2018 (FAO, 2022).

A Geographical Rundown of Africa's Forestlands

The forestlands of West and Central Africa constitute the largest forest coverage in Africa. The West African woodlands and dry forests stretch along the Atlantic coast, nestle vastly across the southernmost fringes of the Sahara Desert, and fray into the Ethiopian highlands and coastal Red Sea of Northeast Africa (see Figure 1). Similarly, the subhumid forestland of West-Central Africa starts on the Guinean Atlantic coast, traverses four West African countries (Ivory Coast, Ghana, Nigeria, and Cameroon), and settles in the Central African Republic and northern region of the Democratic Republic of Congo (DRC) (Chirwa & Adeyemi, 2020).

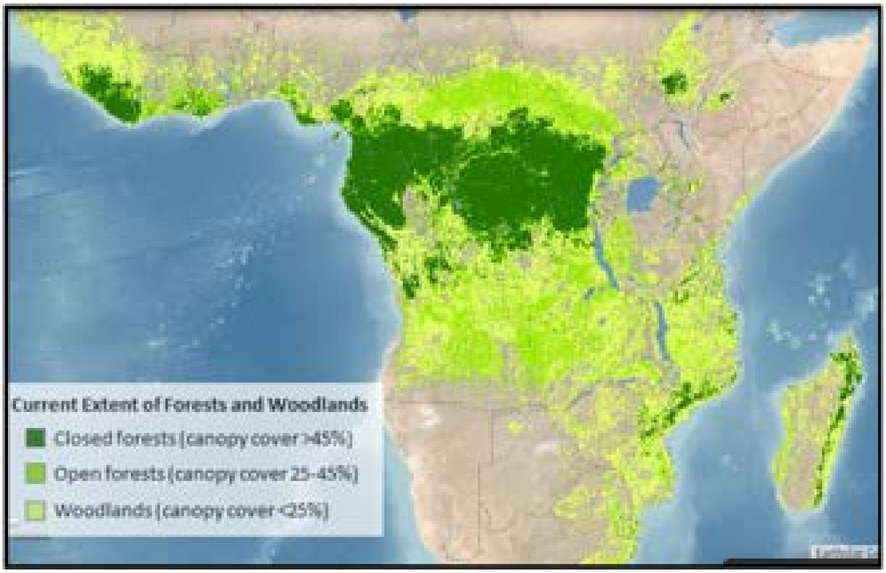


Figure 1. The current expanse of SSA's forests according to the Atlas of Forest Landscape Restoration Opportunities by the World Resources Institute (WRI, 2014).

A further extension of the subhumid forestland is the famous Congo Basin, an intact expanse that covers 1.4 million square kilometers (sq. km) spanning six countries. The total land mass occupied by the West-Central African tropical rainforest is approximately 2 million sq. km, making this the second-largest rainforest in the world after the Amazon jungle (Malhi, 2018). It is home to variant tree species, including the 20-meter tall Parinari excelsa and the invasive human-planted Elaeias quineensis oil palm variety. The Congo Basin has been aptly called the "Lungs of Africa," a befitting moniker hailing its vast 70% contribution to ecological gaseous exchange among all forestlands in Africa (Nater, 2023).

Parallel to the Guinean dry forest is the northern mesic dry woodland, stretching over 2.6 million sq. km from the Senegalese Atlantic coast, through Mali, Ghana, and Nigeria, and into the south of Sudan and Ethiopia (see Figure 1). Human activity has disrupted this forested belt, leaving fragmented woodland, bush fallows, and wooded grasslands containing trees that rarely rise above five meters (see Figure 2). Scattered remnants of the baobab and Acacia trees are common in the mesic dry forestland. Finally, the East and Southern African forest zone is home to the Miombo woodland, which covers about 10% of the entire African land mass, the teak and Acacian woodlands, the Mopane woodland and shrubland, and the vastly degraded East African semiarid dry woodland comprising some 1.6 million sq. km of deciduous bushland dominated by the Commiphora and Acacia genus.

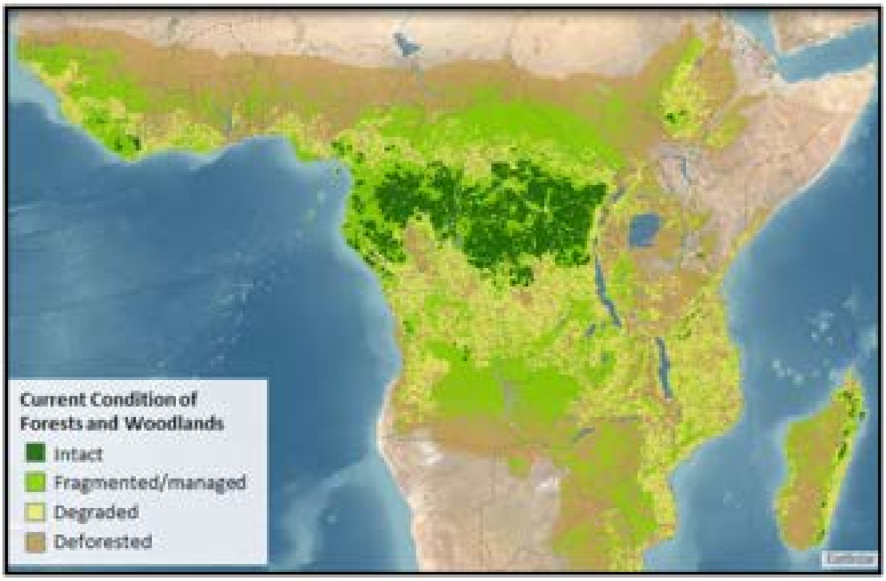


Figure 2. The current condition of SSA's forests and woodlands (WRI, 2014). The northern mesic dry woodlands (topmost green color) are mostly fragmented shrublands whereas the East and Southern African forestlands are severely degraded. Only the dark green rainforest of the Congo Basin remains intact in the whole of SSA.

Tracing Africa's Deforestation Through History

Deforestation caused by variations in tropical land use has been a major contributor to anthropogenic climate change, carbon and greenhouse gas emissions, modified gaseous/water cycles, and biodiversity depletion. While Africa's tropical forests have not warranted exclusive attention in the global fight against environmental degradation, their exceptional diversity accounts for one of the largest terrestrial instruments for carbon sequestration. As such, SSA's forest cover contributes significantly to global carbon budgeting with sustainable feedback across the sub-Saharan climate system. Estimating the impact of forest clearance and land encroachment through human activity over time helps situate its impact on SSA's climate system. Current global biospheric trends rely on the accuracy of historical forest estimates for tropical deforestation (Aleman et al., 2018).

One of the earliest and perhaps most striking deforestation phenomena, dating back about 2,000 to 3,000 years, was the late Holocene rainforest crisis (LHRC). Evidence of extensive forest loss earmarked by the disappearance of a blanket of forest in the heart of West-Central Africa's rainforest raised numerous questions. Amid what was a relatively warm period caused by the glaring arid climates of the Holocene epoch, a vast area of forestland retreating into a pocket of isolated savanna backwoods sparked numerous debates about what caused it. Researchers obtained irrefutable evidence of the LHRC from sediments collected on the floor of Lake Barombi.

Nonetheless, justifying forest decline during the LHRC was complicated by the fact that a major Neolithic expansion was building southwards as farmers migrating from West African border regions entered West-Central Africa. Despite this contemporaneous human resettlement process, anthropogenic activity has not become a major influence on forest transformation. One hypothesis was that farmers were leveraging a naturally occurring forest denudation caused by the arid climate. The opposing view was that it was these farmers' activities that caused the forest loss. Recent studies have since established that the LHRC was due to human disruption of the rainforest ecosystem as opposed to naturally occurring hydrological changes (Bayon et al., 2012; Garcin et al., 2018).

The early Iron Age incited a wave of human settlement in West Central Africa around 900 BC; however, after about 500 years of anthropogenic activity, there was a subsequent decline in human activity (Malhi, 2018). Forestlands in the Congo Basin recovered variably triggered by what is thought to have been a human epidemic, which wiped out most rural settlers. Another population decline happened around 100 A.D., resulting from despoilation and rural emigration triggered by colonial unrest during the transatlantic slave trade (Malhi, 2018). Today, most forestlands in the West Central region bear topological markers signaling intermittent periods of declined human activity. For instance, palaeo-data from Benin and Togolese forestlands reveal that there was a transitional phase circa 4,000 years ago caused by aridity. Most encouraging is how all cases of degraded forestland resulted in vegetational re-rotation even after long periods of severe anthropogenic deforestation.

The next most rampant period in deforestation across SSA was the twentieth century. Most estimates show that the 1900s were a period of astronomically high deforestation (Sodhi et al., 2010; Ter Steege et al., 2015). Anywhere between two-fifths and one-half of Africa's tropical rainforests were deforested during the twentieth century (Aleman et al., 2018). West Africa's forestlands account for 90% of this depletion, while East Africa lost at least 75% of its woodlands. Some of the worst affected countries underwent severe forest dilapidation in the 1900s. Ivory Coast's forestlands, the most affected of the West African states, reduced from 15 million hectares in 1900 to a mere 4.46 million hectares in 1980. These forests had remained virtually untouched until around 1880, and deforestation did not advance significantly until 1951. The total Ivorian forest cover had only reduced by 3 million hectares between 1900 and 1956 but plummeted by 8 million hectares less than 25 years after that (Fairhead & Leach, 2003).

Localized studies assessing geological forest maps have suggested that European timber traders sourced the bulk of their products from West and East African forests in the 1900s. Anthropogenic activities explain virtually all historical forest events in SSA dating back thousands of years. Since the last century, forestland has re-encroached over 135,000 sq. km of tropical African savannah (Aleman et al., 2018). Expansion of this nature may be indicative of colonial policies for the containment of wildfires, carbon sequestration favoring C3 tree growth over C4 savannah grasslands, vegetation regrowth in response to paleo-climatic variations, or a disruptive pattern of decreased seasonal rainfall during the Holocene crisis (Aleman et al., 2018). The twentieth century was fraught with war and conflict—this partly explains the atypical trend in the Congo Basin, where deforestation slowed down over the years. While these forestlands had been encroached prior to the European annexation, colonization concentrated settlers in open environments, thus reducing the effects of cultivation (Van Gemerden et al., 2003). Similarly, violent conflicts may have hindered the growth of infrastructure for industrial-scale deforestation and agriculture (Debroux et al., 2007).

Current Efforts to Address Deforestation: A Focus on Reforestation

The current global environmental lens holds the consensus that deforestation is fundamental to climate change and is a recurrent problem. However, there is no unanimous agreement as to the causes or solutions for deforestation. Proposed solutions have included regulation of commercial logging, tightening forest protection, increased reforestation efforts, and regulating anthropocentric activities causing deforestation. Landscape restoration movements are gaining positive momentum in SSA, with several initiatives working to address current deforestation issues and promote sustainable forest conservation.

Project: African Forest Landscape Restoration Initiative (AFR100)

Project Details

As perhaps the most prolific reforestation initiative in SSA, the AFR100 targets the restoration of 100 million hectares of forestland by 2030. The initiative's grants and loans funding scheme, dubbed TerraFund for AFR100, disburses donor funds to a cohort comprising the "Top 100" organizations within AFR100-sponsored countries across SSA.

Project Stakeholders/Targets

The initiative's latest round of funding, the second cohort, has allocated $17.8 million to 92 organizations spread across three SSA subregions: the Greater Rift Valley in Kenya, the Ghana Cocoa Belt, and the Lake Kivu and Rusizi River Basin, a cross-border catchment area shared by Burundi, the DRC, and Rwanda.

Financiers and Partners

Jeff Bezos funded the second cohort through the Bezos Earth Fund. Other financiers include the Audacious Project (founder of TED conferences) and the Bridgespan Group. Other sponsors of the initiative include the AKO Foundation, Caterpillar Foundation, DOEN Foundation, Good Energies Foundation, Lyda Hill Philanthropies, and Meta. TerraFund's managers are the World Resources Institute, One Tree Planted, Realize Impact, and Barka.

AFR100-Funded Sub-Projects

Some of the largest projects in the AFR100 cohort from each of the five countries are as follows:

Project: The Goshen Global Vision Project

Project Details

Goshen Global Vision (GGV) is a Ghanaian non-profit organization that has collaborated with AFR100 to establish financial associations across rural Ghanaian communities that empower farmers to conserve and restore landscapes. For over seven years, GGV has been involved in community-driven natural resource management by concerting its efforts towards expanding tree cover across Ghana's croplands and forestlands. To date, this organization has replanted over 220,000 trees across seven coastal districts and supported over 2,400 beneficiaries.

Project Goals

The project targets planting 275,000 trees across 8,096 hectares in West Ghana. GGV mobilizes farmers working in fields, mostly women and youth, to restore deforested land and forests depleted by agricultural encroachment. Powered by the AFR100 initiative, GGV will reforest the Subri Forest Reserve and interplant biodiverse native species across Ghana's westmost cocoa farms.

About 50% of GGV's beneficiaries are women, with about 1,300 junior and senior high school students in Ghana having awareness about environmental stewardship. Photo Credit: GGV, https://goglobalvision.org/about/

GGV Program Impact

GGV has partnered with the United States Forest Service International Program (USFS-IP) and is currently active in 72 communities across Ghana's Western Region (Werengo, n.d.). In conjunction with other organizations like the Forestry Commission of Ghana and the United States Department of Agriculture, GGV spearheaded the Greening Sekondi-Takoradi project in Ghana to spread awareness for greenery preservation and encourage replantation for recreational purposes. Stakeholders for this project have collectively planted 20,000 trees in deforested/degraded areas of Sekondi-Takoradi to restore balanced forest distribution and promote equitable access to green infrastructure (Borelli et al., 2023).

Project Approach and Outcomes

GGV's niche focus has been on disrupting the dormancy of indigenous tree species across cocoa communities by combining scientific knowledge on interplanting with rural knowledge for sustainable intercropping. Other important activities have included mangrove forest restoration projects, agroforestry across West Ghana's cocoa farms, loans and savings schemes for farmers, establishing restoration woodlots, and building Community Resources Management Areas (CREMAs) for biodiversity conservation across fringe communities.

The GGV AFR100 project. Photo Credit: AFR100,
https://www.africa.terramatch.org/landscapes

Joint Project: The Ebenezer Ministry International & Plant With Purpose

Project Details

The Plant With Purpose project in the DRC will empower over 10,000 farming families to practice sustainable land activities, including tree planting, along degraded watersheds.

Project Goals

Plant With Purpose has collaborated with Ebenezer Ministry International, a local affiliate in the DRC, to plant 300,000 trees across 810 acres in Uvira and Fizi, South Kivu. These trees are planted and protected by individual farmers on their land and in their local communities and forests. For over three-and-a-half decades, Plant With Purpose has steered rural community movements for reforestation and watershed replenishment projects.

Program Impact

Since its launch in 2015, the Plant With Purpose program in the DRC has resulted in the establishment of 7 watersheds and has empowered over 89,000 participants to plant over

4.3 million trees in DRC's forestlands. The collaborative project with Ebenezer Ministry International is one among 127 church partnerships in the DRC (Plant With Purpose, 2024). An impact evaluation conducted in 2017, two years after launching the DRC reforestation project, showed that poverty levels around the Kakumba watershed had reduced, with families becoming more food secure (Lazaro, 2024).

Other Related Projects

Plant With Purpose has directed several projects in SSA over the last decade, including a joint replantation project with Arbor Day Foundation targeting 260,000 trees across seven countries, a series of collaborative projects with Plant-for-the-Planet, including the Mutsindozi watershed project, and a reforestation project with Tentree targeting the planting of 10 trees for each Tentree product sold.

Plant With Purpose has intensified efforts for sustainable agroforestry systems by interplanting crops with trees to improve SSA's degraded croplands. Photo Credit: Plant With Purpose, https://plantwithpurpose.org/reforestation/

Joint Project: Joint Initiative between APRN/BEPB and 3C

RE: The Association Protection des Ressources Naturelles pour le Bien-Etre de la Population au Burundi (APRN/BEPB) & Association Conservation et Communauté de Changement (3C) Joint Project

Project Details

The joint initiative between APRN/BEPB and 3C advances environmental protection work in Bujumbura by growing trees to protect the Ntahangwa and Nyabagere watersheds from floods and degradation.

Project Outcomes

APRN/BEPB's objectives over the years have included educational awareness, risk reduction in the natural environment, informal youth awareness regarding environmental issues, training on natural resource management, local empowerment for active participation in biodiversity conservation, project execution for sustainable uman- environment interaction, and regional and international cooperation for ecosystem protection.

The APRN/BEPB-3C collaborative replantation project. Photo Credit: AFR100. https://www.africa.terramatch.org/landscapes

Project: Rwandaise Pour Le Développement Endogène (ARDE/KUBAHO)

Project Details

The AFR100, in conjunction with Rwanda's ARDE/KUBAHO, will replant 358,000 trees over a 1,500-hectare forestland.

Project Stakeholders/Targets

ARDE/KUBAHO sensitizes local farmers on agroforestry activities in Rubavu District, Rwanda.

The ARDE/KUBAHO and AFR100 collaborative tree replantation project. Photo Credit: AFR100, https://www.africa.terramatch.org/landscapes

Project Goals

The goal of this AFR100-funded project is to mobilize small-scale farmers to grow fruit, native tree species, and bamboo clumping to curb the effect of gullies. Alongside forest conservation, ARDE/KUBAHO provides Rwanda's underserved communities with access to clean water, school hygiene, and improved school completion rates by providing water, sanitation, and hygiene (WASH) solutions. The ARDE/KUBAHO project complements current efforts by the Rwanda Green Fund, which has done important work in reforesting, regenerating, and expanding forestland to promote tree species diversity and protect the natural environment in Rubavu and Nyabihu Districts. Forest regeneration and planting expansive tree varieties, especially fruit trees, helps prevent soil erosion and restore firewood supply among communities that depend on it.

Project: The Network for Natural Gums and Resins in Africa (NGARA)

Project Details

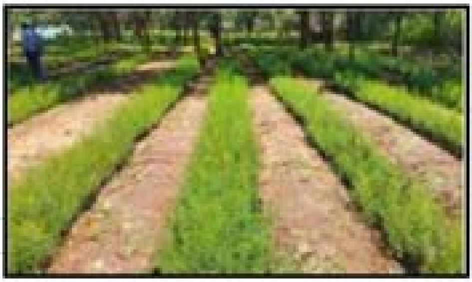
As one among hundreds of Kenyan initiatives dedicated to environmental conservation, NGARA is an AFR100 top cohort targeting the replantation of 700,000 trees across 500 hectares of forestland in SSA. NGARA focuses its conservation efforts on African producers of natural gum/resin to help them develop sustainable means for planting, harvesting, and marketing products.

Project Outcomes

Through the AFR100 initiative, NGARA will plant more Acacia senegal trees and aloe plants in the Kenyan counties of Elgeyo Marakwet, West Pokot, and Baringo. Specifically, NGARA's current project in Baringo County, called Bolstering Resilience and Livelihoods: Strengthening Non-Timber Forest Products in Baringo County, is being implemented in Tenges and Marigat wards with the aim of restoring forestland by replanting 700,000 trees. NGARA collaborates with AFR100 as part of its long-term environmental conservation project geared toward the fulfillment of the program's 2030 Framework of Priorities.

Project Stakeholders/Targets

With the support of FAO, the African Union Commission (AUC), and the Africa Forest Forum (AFF), NGARA has extended its operations to 16 countries and overseen the production of over ten kilotons of gums and resins.



NGARA's projects have comprised tree nurseries for aloe and other tree varieties for reforestation across all its target territories. Photo Credit: NGARA, https://ngara.org/wp- content/uploads/2024/BolsteringResilienceandLivelihoods-Baringo.pdf

Previous Work

Some of NGARA's notable projects include the Acacia Operation Project (AOP), a collaboration with FAO that led to the reforestation of about 13,000 hectares in six countries, and the Food for Assets project funded by the World Food Programme.

Project: PANORAMA Restoration

Project Details

The PANORAMA Restoration community program focuses on the restoration of tree-rich croplands and forest areas. The program pays close attention to regaining ecological balance by enhancing the human-nature relationship in SSA's deforested and degraded forestlands. In addition to tree planting, the PANORAMA project portfolio targets the restoration of degraded landscapes, improving SSA's climatic conditions, improving food security, and expanding SSA's life-supporting watersheds.

In concert with other initiatives like the AFR100 and the Bonn Challenge, the PANORAMA Restoration project continues to empower local practitioners to implement and scale up forest restoration efforts. Photo Credit: PANORAMA Restoration, https://panorama.solutions/en/portal/panorama-restoration

Financiers and Partners

The PANORAMA Restoration program is jointly funded by a network of partners including the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), the International Union for Conservation of Nature (IUCN), the United Nations Development Programme (UNDP), GRID-Arendal, United Nations Environment Programme (UNEP), Rare, EcoHealth Alliance, ICCROM, World Bank Group, OCTO Group, the International Council on Monuments and Sites (ICOMOS), and IFOAM. Collectively, over 1,000 partners form the backbone of the PANORAMA initiative, contributing a body of knowledge and innovative conservation solutions for sustainable change.

Project Stakeholders/Targets

PANORAMA's restoration project targets AFR100 host countries, which, in the current cohort, are five East and Central African countries.

Project: The Bonn Challenge

Project Details

The Bonn Challenge is a worldwide project that targeted the restoration of 150 million hectares of deforested/degraded forestland by 2020 and a total of 350 million hectares by 2030. As of 2024, there were 31 restoration pledges in Africa alone, contributing to a current global pool of just over 210 million hectares in pledged reforestation acreage. Of these, over 110 million hectares, or just over half of the total pledged acreage, were within SSA. The Bonn Challenge megaproject launched in 2011 and achieved its 150-million-hectare milestone only six years later, in 2017.

Project Approach and Outcomes

The Bonn Challenge adopts a nuanced reforestation methodology called forest landscape restoration (FLR). The FLR approach helps restore ecological balance while promoting the well-being of those dependent on forest resources for their livelihood.

Avocado trees are an essential part of Madagascar's forest restoration efforts. Upon replantation from the nurseries, these seedlings become part of a nationwide initiative to repopulate Madagascar's forestlands with 60 million trees by 2025.
Photo Credit: The Duke Lemur Center, https://lemur.duke.edu/restoring- forests/

Financiers and Partners

The Bonn Challenge was the brainchild of the German government through the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety, and Consumer Protection, in conjunction with the Norwegian government through the Ministry of Climate and Environment and the Global Environment Facility (GEF) investment fund. Key sponsors and facilitators include IUCN, UNDP, GIZ, and UNEP.

Project Stakeholders/Targets

At present, there is a global total of 83 pledges from over 60 countries responding to the project's overall goal to address land degradation, offer relief to 3+ billion people, and restore about a third of the world's arable croplands. The project targets countries, organizations within and external to states, and private actors who can help meet the program's ambitious targets.

Project: Regreening Africa

Project Details

Regreening Africa is a five-year, multi-country, research-in-development project launched in 2017 with the goal of improving livelihoods, building resilience to climate change, and increasing food security through agroforestry. The project targets 500,000 households in SSA with the aim of increasing their household income by 10%. The project also targets the sustainable management, through agroforestry, of 1 million hectares of cropland, a 5% decrease in soil erosion, and a 10% increase in tree cover in each of eight target countries: Kenya, Ethiopia, Somalia, Rwanda, Ghana, Mali, Niger, and Senegal.

Project Impact

In Ethiopia, the project targets four regional states – Peoples' Region (SNNPR), Oromia, Southern Nations Nationalities, and Tigray – to improve the lives of 120,000 farming families and restore over 200,000 hectares of degraded landscapes. In Kenya, the project targets 150,000 hectares and 50,000 farming households in the counties of Migori, Homa Bay, Nakuru, Elgeyo Marakwet, Baringo, Isiolo, Laikipia, Marsabit, and Samburu, in partnership with World Vision Kenya, ICRAF, and the national/county government. In Somalia, the project will restore 12,890 hectares of arid land and support 19,857 households in Dweyne, Awdac, Sanaag, Karkar, and Bari districts in partnership with World Vision Somalia, ICRAF, and CARE Somalia. In Rwanda, the project targets 100,000 hectares and 70,000 households across four Eastern Savanna districts in collaboration with World Vision Rwanda and ICRAF Rwanda. In Mali, the project targets 160,000 hectares and 80,000 farming households in Koutiala, Yorosso, Tominian, and San, in partnership with Oxfam Mali, Sahel Eco, World Vision, Catholic Relief Services, and ICRAF Sahel. In Niger, Regreening Africa continues its land restoration efforts targeting 90,000 hectares across Maradi and Zinder to expand the already restored 5 million hectares of cropland and forestland. The official in-country partner is World Vision Niger. In Senegal, Regreening Africa will restore 160,000 hectares and support

80,000 farming households in the Kaffrine, Kaolack, and Fatick regions in partnership with World Vision Senegal and ICRAF Sahel. In Ghana, the project targets 90,000 hectares of forestland and 40,000 farming households in the districts of Bawku West, Garu Tempane, and Mion. In-country collaborating partners included World Vision Ghana, Catholic Relief Services, ICRAF Sahel, government agencies, and local communities.

Regreening Africa has empowered the Chongoo Women's Nursery Group to further its reforestation efforts in Elgeyo-Marakwet County, Kenya. Photo Credit: Regreening Africa. https://regreeningafrica.org/regreening- heroes/

Financiers and Partners

The European Union funds Regreening Africa and has partnered with international NGOs to steer in-country implementation. These partners include CIFOR-ICRAF, which helped launch the project, World Vision, Catholic Relief Services, CARE International, OXFAM, Sahel Eco, and the Global EverGreening Alliance.

Project: WeForest

Project Details

Since 2009, WeForest has spearheaded extensive project work across East, West, and Southern Africa. The Great Green Wall program of East/West Africa comprises three projects in Ethiopia. In comparison, the Miombo Belt Regeneration Program of Southern Africa includes six active projects in Zambia and Malawi, and the Blue Carbon Program in West Africa consists of two active projects in Senegal. These projects continue to maximize the impact of trees on people and the ecosystem, driven by the vision of founders Bill Liao and Marie-Noelle Keijzer. Current projects include the Desa'a Forest restoration project targeting one of Ethiopia's oldest dry Afromontane ecosystems, the Gewocha Forest and Wof Washa Forest restoration projects, both also in Ethiopia, and the Ferlo zone restoration project in Senegal.

The Katanino Forest restoration project in Zambia is one of WeForest's reforestation efforts in the Miombo Belt Regeneration Program of Southern Africa. Photo Credit: WeForest. https://www.weforest.org/blog/weforest-in-the-media/conservationists-assist-a-forest-reserve-in-zambia-to-regrow-itself/

Project Goals

Each project in the WeForest portfolio has defined goals. For instance, The Ferlo zone project under the Great Green Wall program aims to regreen 10,000 hectares through local community work. The project will also plant 15 native tree species to boost non-timber income and fodder availability during the arid season. The first phase of the project, currently underway, will oversee the restoration of 1,000 hectares of forestland. Similarly, the Gewocha Forest project will restore over 7,900 hectares of forestland, rehabilitate over 1,100 hectares of degraded communal land, and introduce agroforestry across 925 hectares of smallholder farmland.

Project Impact

So far, the Great Green Wall program has regreened 21,679 hectares with over 21.9 million trees accounting for 183 different species. In comparison, the Miombo Belt Regeneration Program has replanted over 33,000 hectares with over 36.3 million trees for the benefit of more than 12,700 families. For the Blue Carbon Program, over 7,700 hectares are under restoration, housing 21.8 million trees.

Financiers and Partners

WeForest Ethiopia has partnered with Tigray Plan and Finance, EFCCC, Mekelle University, TBOARD, EEFRI, and the Hunger Project. In Senegal, the official partners are Agronomes et Vétérinaires Sans Frontière (AVSF), Eclosio, ISRA, CIRAD, Oceanium, and Pôle Pastoralisme zone sèche (PPZS). Similarly, WeForest Zambia has partnered with BeeSweet, LFCA, Rainlands Timber, and DFCA, while WeForest Malawi works with the Forest Department and Cedar Energy.

Best-Practice Recommendations

Forestland and cropland management for better tree survival rates:

The short-term survival rate for planted trees is favorable for most reforestation projects across SSA; for instance, Plant With Purpose reported a 60% survival rate over three years of monitoring (Plant With Purpose, 2022), while PANORAMA Restoration cites a 98% survival rate for its agroforestry projects (PANORAMA, n.d.). Higher survival rates for SSA's restoration projects are a determinant factor for affordable reforestation across local communities (CIFOR- ICRAF, n.d.). More projects have focused attention on agroforestry, cropland management, farming-driven activities such as weed and pastoral control, and improved roadway access to reforested areas. These activities collectively improve the survival rate for trees in reforested areas. Le et al. (2013) have established a statistically significant influence of cropland activities and road conditions on tree survival rates. The chances of a reforestation project having a high tree survival rate (over 80%) improve up to twenty-fold with cropland and forestland management strategies such as grazing management, weed/pest control, and improved road access.

Progress monitoring to diagnose project health:

Most project facilitators conduct short- and long-term progress monitoring for reforestation projects. Progress monitoring allows programs to meet their objectives, identify issues and challenges impeding progress, detect when reforestation efforts are ineffective or need improvement, and notice the early signs of project success or failure (AFR100, n.d.). As witnessed across most restoration projects in SSA, it is not enough to only monitor land coverage and the number of trees planted in reforested areas. Instead, facilitators should consider other critical progress indicators such as carbon sequestration outcomes, ecological succession patterns, species diversity, and the economic benefits realized at the community level.

Diverse tree varieties to interweave ecological benefits:

The potential benefits of emphasizing genetic species variations are numerous, including effective product provision and ecosystem balance, higher resource production, greater wood yields, and improved soil protection. These benefits may explain the rising preference for agroforestry systems and interplanting activities as a central agenda for many of SSA's reforestation projects.

Tree-based innovations to repair ecosystems and ameliorate climate change effects:

Current market trends continue to offer a wide variety of tree-based technologies ranging from tropical fruits to agroforestry systems. For instance, Faidherbia albida is an indigenous variety of nitrogen-fixing trees exhibiting a unique leaf abscission pattern whereby leaves are shed in advance of crop growth. Therefore, this tree species will not compete with crops for light and will nourish the soil with leaf litter. Leaf litter from one hectare of F. albida trees will inject over 100 kg of nitrogen into the soil (Program on Forests [PROFOR], 2011). Similarly, cocoa agroforestry promotes sustainable reforestation by extending the replantation lifecycle of cocoa trees from a maximum of 20 years to as much as 60 years.

Sustainable woodfuel plantation:

As tighter regulations address deforestation in the woodlands, the gap widens between woodfuel supply and demand. Resultantly, private actors have resorted to interplanting trees with other commercial plantations using woodlots and croplands. To this end, a balance prevails as natural forests remain uncleared for plantation and woodlots continue to thrive under responsible management. Contrary to the myth that woodfuel cannot be produced sustainably, SSA projects have introduced strategies such as assisted natural regeneration, agroforestry systems, and invasive tree species to mitigate environmental degradation. For instance, CIFOR and World Agroforestry have tested the use of invasive P. juliflora species to produce charcoal sustainably in Kenya and reduced mangrove wood consumption in Cameroon (Mollins, 2020).

Policy reorientation towards decentralizing restoration efforts:

Devolving cropland and forestland restoration efforts to local communities and organizations has become a key requirement for shaping the outcomes of natural resource management in SSA. While decentralizing reforestation is not a failsafe guarantee for success in restoration, localized control improves the chances of better resource management. The challenge, therefore, becomes one of empowering and legitimizing local management organization efforts with the goal of ensuring that local projects can implement effective management mechanisms. Legitimization also shields local organizations from falling victim to elite capture.

Cross-sector rural development efforts to encourage synergy:

Increasing investment in trees/landscape restoration meaningfully would require partner-led initiatives to go beyond targeting the forest sector solely. Instead, engagement with a wider range of stakeholders in other sectors, such as lands, water, energy, livestock, agriculture, and environmental finance, would bolster reforestation outcomes. Further, restoration efforts should target socioeconomic drivers such as civil societies, food companies, business associations, and private investors. Public authorities, producer associations, and private sector players such as exporters and processors play a significant role in offering project monitoring capabilities. Expectedly, these roles will continue to evolve as forestlands and the communities surrounding them become more market-oriented.

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Technical Brief:
Constructed Wetlands & Filtration Prototype for Drinking Water

JACQUELYN JESTINE SANDERS FOUNDATION
BUILDING VISION, REALIZING CHANGE

02.08.2024
The New World Garden, Hessisch Oldendorf, Germany

Abstract

This technical briefing outlines the development and objectives of a constructed wetlands prototype being built at The New World Garden in Hessisch Oldendorf, Lower Saxony, Germany. This initiative, part of the Jacquelyn Sanders Foundation 2024 Fellowship project, aims to demonstrate a cost-effective, sustainable water purification system based on collected rainwater being stored in manmade lagoons. Let us call these "drinking water permaculture lagoons." Some like to call them free flowing contructed wetlands ponds. The filtration prototype will supply approximately 850 liters per day of drinking water and between 200 to 400 liters of solar-heated shower water. This briefing includes system design, operational principles, and expected outcomes, with a focus on the prototype's role in enhancing water solutions for Madagascar, and other off grid communities seeking water and photovoltaic infrastructure solutions.

Introduction

Constructed wetlands offer a promising solution for sustainable water purification, combining ecological benefits with practical applications. This prototype, situated on the wild grassland of The New World Garden, managed by Kenneth Coman, leverages natural processes to address the growing need for accessible and low-cost water purification systems.

The project aligns with the Jacquelyn Sanders Foundation's 2024 Fellowship objectives, collaborating with 15 students from three Malagasy universities to develop water solutions for their respective institutions. The Hessisch Oldendorf prototype will serve as a model for a larger initiative aimed at constructing a similar system at the University in Madagascar, with projected costs of approximately 1 billion Ariary (about $250,000 USD).

The Sustainable Vision Academic Journal 2024 & WHY this Prototype is relevant

This technical brief forms part of a broader report, soon to be published in the Sustainable Vision Academic Journal 2024, chronicling the comprehensive planning and implementation efforts by the Jacquelyn Sanders Foundation and students from three Malagasy universities this year. The journal documents the collective endeavor to address the critical water issues facing the University of Antananarivo, which are symptomatic of larger problems such as insufficient infrastructure and widespread deforestation in many parts of the country. Water is a barrier at this time to reforestation - efforts of those seeking to build tree nurseries are hampered by lack of water. And the solution for the University, based on our research this year - is rain capture. Yes - the rain period is short - therefore storage infrastructure is needed. And the suggested most economical and also, by the way, environmentally friendly method … is the building of lagoons. Such lagoons were also suggested for wastewater treatment by ARAFA in 202. We concur and also suggest them as part of the drinking water solution. Constructed Wetlands (CWL) appear to be the best way to address the pressing water needs of the University. It is asserted that the design holds relevance for others in off grid situations as an important Case Study in rainwater lagoon storage and bio- and phtyto- filtration.

The journal aims to serve as a foundational resource for further research and prototyping efforts, illustrating the viability of self-sufficiency for off-grid residents. By harnessing rainwater and utilizing solar energy to drive water through simple filtration media, the constructed wetlands prototype demonstrates that even low-tech solutions can significantly impact water availability and quality. This approach holds promise for residents in Madagascar, Tunisia, Thailand, the Philippines, the United States, and beyond. It encourages consideration of how individuals might secure drinking water should municipal systems fail, offering a potentially vital solution for diverse global contexts.

System Overview

The constructed wetlands prototype features a photovoltaic-powered biological filtration system, designed to be affordable and environmentally friendly. Key components include:

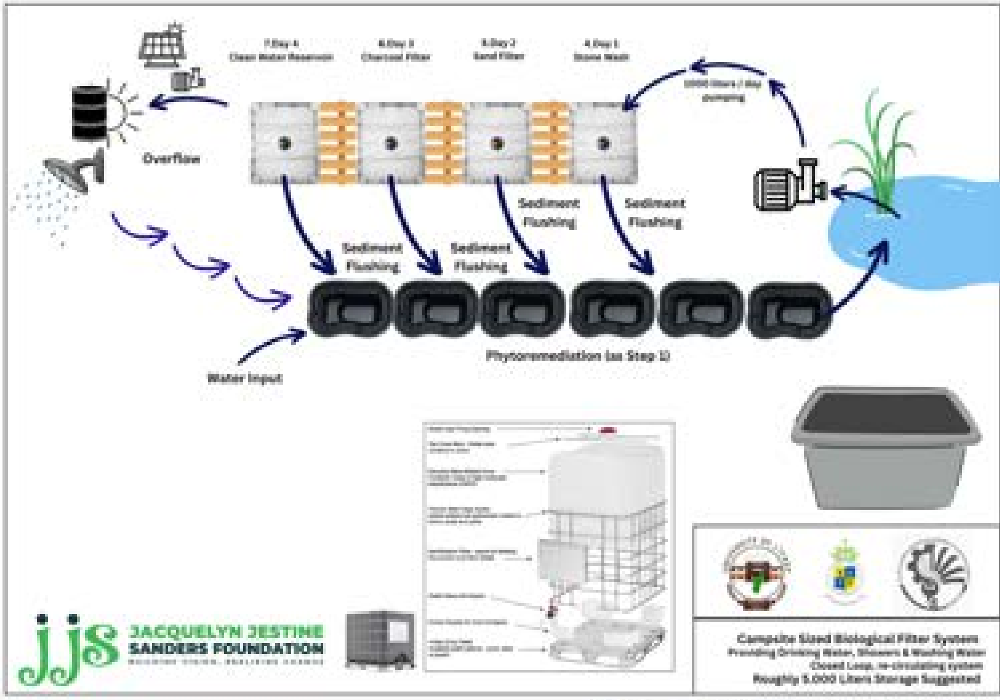
Rainwater Collection: The system utilizes rainwater harvested from ponds located on the farm. This water serves as the initial feedstock for the filtration process.

Filtration Unit: Modeled after Joshua Kearn's design, the system employs a four-stage filtration unit constructed from four Intermediate Bulk Containers (IBC). Each stage is engineered to progressively purify the water.

Photovoltaic Power: An off-grid island photovoltaic system powers the biological filtration unit. This setup supports energy independence and minimizes reliance on external power sources.

Optional Enhancements: The prototype may include additional filtration options such as a membrane filter and/or a UV filter to further ensure water purity.

Diagrams of the System: Diagrams of individual components and their integration are provided, illustrating the flow of water through the filtration stages and the interaction with the photovoltaic system and constructed wetlands for storage and phytoremediation.



Operational Principles

Constructed Wetlands: These systems use natural processes to treat wastewater through soil, plants, and microbial activity. The prototype's wetlands are designed to optimize these processes for drinking water production, integrating several filtration stages to enhance water quality.

Photovoltaic Island System: According to Wikipedia, an island photovoltaic system is a self-contained energy setup that operates independently from the main power grid. The advantages include:

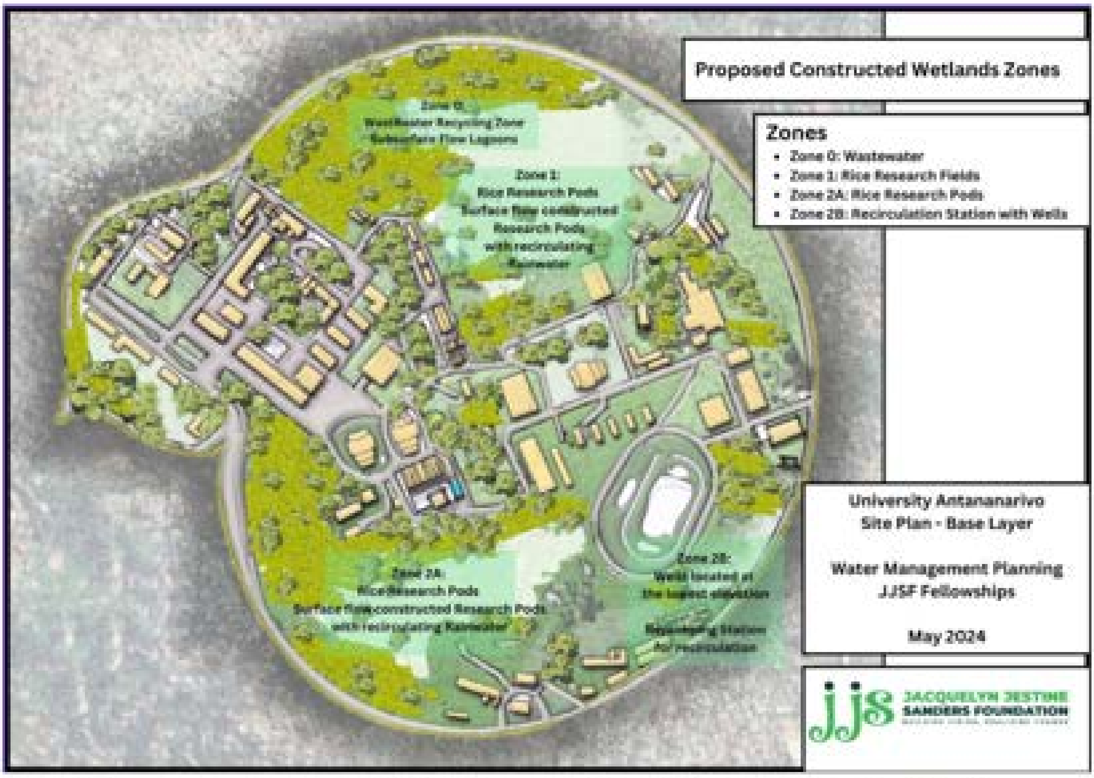
Energy Independence: Reduces reliance on external power sources, ensuring continuous operation of the filtration system.

Sustainability: Lowers carbon footprint by using renewable energy.

Reliability: Provides a stable power supply in remote or off-grid locations.

Extra Considerations:

- **Maintenance**: Regular maintenance of both the photovoltaic system and filtration unit is required to ensure optimal performance.
- **Weather Variability**: The effectiveness of the photovoltaic system is influenced by local weather conditions, which may impact water production rates.
- **Diagram of Photovoltaic System**:The system is presently being designed - diagrams will be added shortly illustrating the setup of the photovoltaic panels, battery storage, and their connection to the filtration system.



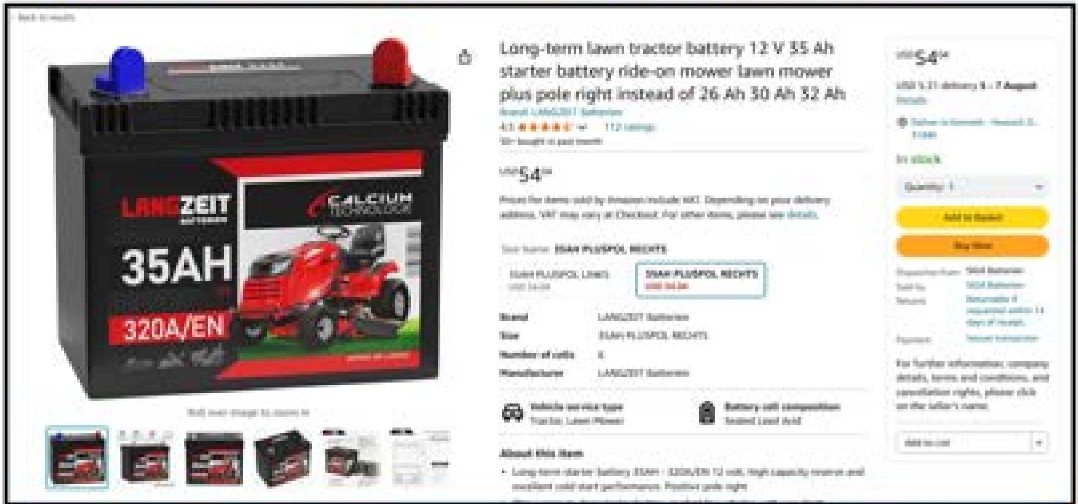
Here you see - why we are prototyping in Germany. We seek to demonstrate the feasibility for this larger scale project at the University of Antananarivo. But, the relevance is broader than this one off-grid situation. This is a great case study in solving a larger scale water infrastructure problem, by responding with wetlands as the solution. A return to a green Madagascar requires better water management. Trees follow, and forests can follow that.

Cost and Impact Assessment

The filter prototype is expected to cost under $1,000, a figure that includes materials and construction for the filtration system and photovoltaic pumping components. Some extra electircity will be available for lighting of the system at night (or even for perhaps in the livign space.) The cost of the contructed wetlands being built on a small scale is expected to be another $1,000 - bringing the total cost for the prototype to approximately $2,000 for a system that produces roughly 850 liters per day. That is 310,000 liters of clean water per year for an investment of $2,000. Once tested, this prototype will provide critical data for solidification of the scaling of the solution to the Malagasy Capitol's primary University, where the roughly estimated cost of implementation is approximately 1 billion Ariary, or $250,000 for the wetlands construction and the much larger scaled filter system, providing relief for 35,000 students. If international funding can be found, it would be a stretch goal to build also a central shower and environmentally friendly laundry facility as part of the project. That would cost additionally - but we are still looking at a very cost effective solution for such a large off grid facility.

Testing and Evaluation:

- Water Quality: Comprehensive testing will be conducted on water entering and exiting the system to ensure compliance with drinking water standards.
- System Performance: Monitoring will focus on the system's ability to consistently produce the desired volumes of drinking and shower water.



Sizing of all components are based on design factors which are site specific. There is not a one-size fits all solution. Your specific site situation will drive the size of your pump, battery, photovoltaic panel, and so forth. But this example is shown as part of the ongoing effort to identify good, working examples of component configurations. We are working on theoretical examples for other scenarios as well.

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Detailed Complete Cost Analysis will be added to this Technical Brief in the next iteration.

Conclusion

This constructed wetlands and biological filtration prototype represents a significant step towards demonstration of sustainable and cost-effective water purification. By demonstrating the feasibility of such a system, the project aims to pave the way for similar initiatives in Madagascar, addressing critical water needs in an environmentally responsible manner. The same kind of system can be built anwhere in the world, with some site specific modifications of the assumptions. At this time, we are discussing water planning cooperation with a community in the Phillipines, as a further example. Any home or small off-grid community will need clean water. How will they achieve it? This prototype seeks to demonstrate a viable option, and invites commentary on how to improve upone the sytem in any way.

Future Updates: This technical brief will be updated periodically over the next 12 months as testing progresses and new findings and data emerge.

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Commercial Pond Liner used for creating impermeable lagoon based water storage.

Yes - evaporation is an issue!

Storage in IBC Containers might be even cheaper per liter, until attempting to connect them all together, and keep the water fresh - making tank based solutions impractical. Concrete Tanks are also a viable option but less environmentally friendly.

WATER FILTRATION PROTOTYPING LARGER SCALE FOR UNIVERSITY USE

By Manjaka Fitia Frédéricka RANDRIATSIHOARANA

"The value of this fellowship to me is immense, it would greatly accelerate both my technical and soft skills development in service of promoting water sustainability in Madagascar."

Editorial Notes:

Ms. Manjaka Fitia Frédéricka Randriatsihoarana, a dedicated and passionate master's degree student in Hydraulic and Infrastructure Engineering from the "Ecole Supérieure Polytechnique d'Antananarivo," has undertaken a crucial research project under the auspices of the Jacquelyn Sanders Foundation. Her work focuses on planning biological water filtration at the university level, specifically targeting the pressing need for sustainable water management solutions in Madagascar.

As a young engineer with a strong technical foundation and a commitment to addressing water resource challenges, Ms. Randriatsihoarana has brought both enthusiasm and expertise to this project. Her background in hydraulic engineering and her desire to implement innovative, context-appropriate solutions make her an ideal candidate for this fellowship. In her own words, she is "fully committed to applying [her] engineering knowledge to push forward progress in sustainable water resource development in Madagascar and other countries."

Initially, there was consideration for Ms. Randriatsihoarana to use Canva for her project planning, potentially incorporating graphics as part of the design process. However, she ultimately chose to deliver her work in PDF format. This decision highlights the importance of flexibility in the tools and methods employed by our fellows. Moving forward, the Jacquelyn Sanders Foundation recognizes that training in unified design software for our team may lead to more consistent and visually impactful results across our projects.

Ms. Randriatsihoarana's report represents a significant contribution to the ongoing efforts to optimize water filtration systems in off-grid settings and university environments in Madagascar. Her work is not only technically sound but also reflects a deep understanding of the local context and a commitment to making a tangible difference in her community. As we continue to support projects like hers, we emphasize the importance of early-stage planning and design that align with our Foundation's values and mission.

JACQUELYN JESTINE SANDERS FOUNDATION
BUILDING VISION, REALIZING CHANGE

WATER FILTRATION PROTOTYPING LARGER SCALE FOR UNIVERSITY USE

JJSF – Jacquelyn Jestine Sanders Foundation

A STUDY PROJECTS

By **Manjaka Fitia Frédéricka RANDRIATSIHOARANA**

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Title	Water filtration prototyping – larger scale for university use
Revision	Preprint
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Prepared by	Manjaka Fitia Frédéricka RANDRIATSIHOARANA
Reviewed by	-
Date	June, 2024

TABLE OF CONTENT

INTRODUCTION

The scarcity of clean drinking water is a pressing issue worldwide, affecting both developing and developed regions. Universities, as microcosms of larger communities, face similar challenges in providing safe, potable water to their inhabitants. This dissertation explores the prototyping of a large-scale water filtration system, specifically designed for use on a university campus. By utilizing four 10,000-liter water tanks, this system aims to collect and filter rainwater, ensuring a sustainable and reliable source of clean water for university students and staff.

The problem of water scarcity and contamination highlights the critical need for effective water management and filtration solutions in educational institutions. Universities, often housing thousands of individuals, require substantial amounts of water for various needs, including drinking, cooking, and sanitation. The proposed water filtration system not only addresses the immediate need for clean water but also promotes environmental sustainability by leveraging rainwater harvesting.

The primary objectives of this research are to design a comprehensive water filtration system, analyze its effectiveness in providing potable water, and ensure its maintainability over the long term.

1. Literature Review

The design and implementation of water filtration systems are rooted in various theories and models, which provide the necessary framework for developing effective and efficient solutions. This section reviews the relevant literature, focusing on the key theories, models, and previous research findings that inform the design of a large-scale water filtration system for university use.

1.1. Theories and Models

One of the foundational theories in water filtration is the hydrological cycle, which describes the continuous movement of water on, above, and below the surface of the Earth. Understanding this cycle is crucial for designing systems that effectively capture and filter rainwater. Additionally, the theory of adsorption and filtration is essential, as it explains the mechanisms by which contaminants are removed from water. Adsorption involves the adhesion of particles onto a surface, while filtration physically separates impurities based on size.

1.2. Previous Research and Findings

Numerous studies have explored the effectiveness of various water filtration technologies. For instance, research on slow sand filtration has demonstrated its ability to remove pathogens and suspended solids from water. Similarly, activated carbon filters are widely recognized for their capacity to adsorb organic compounds and chlorine, improving water taste and odor.

1.3. Gaps in the Existing Literature

While there is a wealth of research on individual filtration methods, there is limited literature on the integration of multiple filtration technologies into a single system designed for large-scale applications, such as a university campus. Furthermore, existing studies often focus on small-scale or household filtration systems, leaving a gap in the understanding of how these technologies can be scaled up effectively. Additionally, the long-term maintenance and sustainability of large-scale filtration systems remain underexplored, highlighting the need for comprehensive maintenance plans that ensure continuous operation and water quality.

This literature review provides the theoretical and empirical foundation for the design and implementation of a large-scale water filtration system for university use. The subsequent sections will build on these insights, detailing the methodology, technical design, water flow projections, and maintenance plan necessary to develop a robust and efficient system.

2. Methodology

The methodology section outlines the research methods used to design, develop, and evaluate the large-scale water filtration system for university use. It provides a rationale for the chosen approaches and details the data sources and collection techniques employed in the study.

2.1. Description of Research Methods

This research employs a combination of design-based research (DBR) and experimental methods. DBR is utilized to iteratively design, test, and refine the water filtration system, ensuring it meets the specific needs of the university setting. The experimental methods involve laboratory testing and field trials to assess the system's performance in real-world conditions.

2.2. Justification of Methodology Choice

The choice of DBR is justified by its emphasis on developing practical solutions through continuous refinement based on feedback and testing. This approach is particularly suitable for prototyping the water filtration system, as it allows for adjustments and improvements in response to observed challenges and performance data. Experimental methods complement DBR by providing empirical evidence of the system's effectiveness, ensuring that the design is grounded in robust scientific principles.

3. Technical Design of the Water Filtration System

This section details the technical design of the water filtration system, including the design techniques, a comprehensive list of required parts and components, and a detailed technical conception of the system.

3.1. Design Techniques

The design of the water filtration system incorporates multiple stages to ensure the effective removal of contaminants and the provision of clean, potable water. The key design techniques include:

Pre-filtration: This initial stage involves removing large debris and sediments from the rainwater using mesh screens and sedimentation tanks.

Filtration: The system uses a combination of sand filters, and activated carbon filters

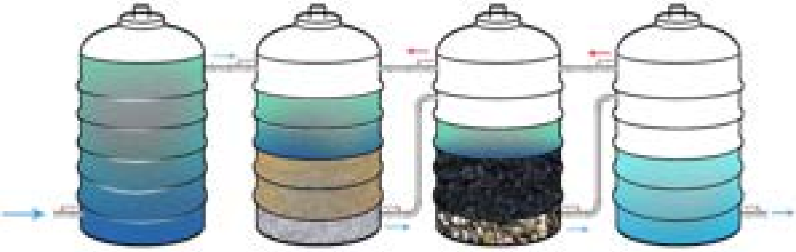
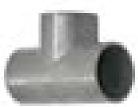
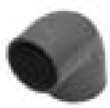


Figure 1: Design Techniques

3.2. Parts and Components List

The construction of the water filtration system requires the following key components:

Water Tanks	Mesh Screens	Sand filters	Activated carbon filters
			
10.000 Liters Ø 2,16 m x 3,10 m	50 µm	70 µm	Ø ≈ 30 mm

T-Joint	Pipe PVC	Shut-off Valve	PVC Elbow 90°	PVC Threaded Coupling
				
Ø40 mm	Ø40 mm x 4	PPR Ø40 mm	Ø40 mm	Ø40 x 1.1/4M
2 600 Ar	41 600 Ar	31 500 Ar	1 900 Ar	1 700 Ar

3.3. Detailed Technical Design

The technical design involves the integration of the components into a cohesive system that ensures efficient water filtration. The following steps outline the detailed design process:

Rainwater Collection: Rainwater is collected from the rooftops and funneled into the first 10,000-liter tank. Mesh screens are placed at the inlets to remove large debris.

Sedimentation: Water from the first tank flows into sedimentation tanks where heavy particles settle at the bottom.

Sand Filtration: Water passes through sand filters to remove flocs and suspended particles.

Activated Carbon Filtration: The water then flows through activated carbon filters, removing organic compounds and chlorine.

4. System Diagram

The following diagram illustrates the flow of water through the filtration system.

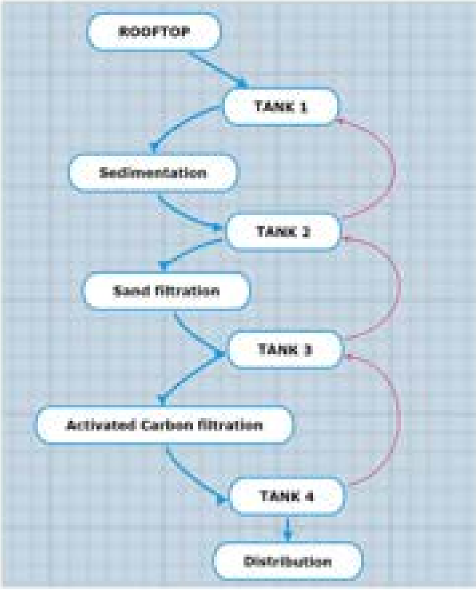


Figure 2: System diagram

This technical design ensures that the rainwater collected is thoroughly treated and safe for consumption, meeting the needs of the university campus. When tank became full they return to the previews tank.

5. Water Flow Projection

This section presents the projected potable water flow rate for the water filtration system, including the methods and assumptions used in the calculations and data analysis.

5.1. Projected Potable Water Flow Rate

To ensure the system meets the water demand of the university campus, it is crucial to accurately project the flow rate of potable water. The calculation considers the average rainfall, catchment area, filtration efficiency, and daily water consumption needs of the campus population.

5.2. Calculation Methods and Assumptions

a) Assumptions:

Average Rainfall: The university receives an average annual rainfall of 1000 mm.

Catchment Area: The rooftops used for rainwater collection have a combined area of 2000 square meters.

Collection Efficiency: The efficiency of rainwater collection is assumed to be 80%, accounting for losses due to evaporation and spillage.

Filtration Efficiency: The filtration system is assumed to have an overall efficiency of **90%.**

Daily Water Consumption: The campus population (students and staff) is estimated at 5000 people, with an average daily water consumption of 50 liters per person.

b) Calculations:

Annual Rainwater Harvesting Potential:

$$Annual\ Rainwater\ (liters) = Average\ Rainfall\ (mm) \times\ Catchment\ Area\ (m^2) \times Collection\ Efficiency = 1000 \times\ 2000 \times\ 0.8 = 1.600.000\ liters/year$$

Daily Rainwater Harvesting Potential:

$$Daily\ Rainwater\ (liters) = \frac{Annual\ Rainwater}{365}$$

$$= \frac{1.600.000}{365} \approx 4384\ liters/day$$

Filtered Water Output:

$$Filtered\ Water\ \left(\frac{liters}{day}\right) = Daily\ Rainwater \times Filtration\ Efficiency\ = 4384 \times\ 0.9$$
$$\approx\ 3946\ liters/day$$

Total Daily Water Demand:

$$Total\ Daily\ Demand\ (liters) = Campus\ Population \times Daily\ Consumption$$
$$= 5000 \times 50 = 250{,}000\ liters/day$$

Given these calculations, the projected water flow from the filtration system is significantly lower than the total daily demand of the campus. This highlights the need for supplementary water sources or additional water conservation measures.

5.3. Data Analysis

The calculated filtered water output of approximately 3946 liters per day provides a substantial but insufficient contribution to the university's water needs. This shortfall underscores the importance of integrating the filtration system with existing water supply infrastructure and implementing water-saving practices across the campus.

5.4. Recommendations

To maximize the effectiveness of the water filtration system:

- Expand Catchment Area: Increase the rooftop collection area to capture more rainwater.
- Improve Collection Efficiency: Enhance the collection system to reduce losses.
- Supplementary Sources: Integrate the system with municipal water supplies or additional rainwater harvesting systems.

Water Conservation: Implement water-saving measures to reduce overall consumption.

6. Maintenance Plan

Ensuring the longevity and reliability of the water filtration system requires a comprehensive maintenance plan. This section outlines regular maintenance procedures, a preventive maintenance schedule, and guidelines for troubleshooting and repairs.

Solutions: Clean or replace clogged filters, inspect and repair or replace the pump, and check piping for blockages.

f) Poor Water Quality:

Possible Causes: Ineffective filtration, exhausted filter media, or malfunctioning disinfection unit.

Solutions: Inspect and clean filters, replace filter media, and check the UV disinfection unit for proper operation.

g) System Leaks:

Possible Causes: Damaged piping, loose connections, or faulty valves.

Solutions: Repair or replace damaged piping, tighten connections, and replace faulty **valves.**

h) Pump Failure:

Possible Causes: Electrical issues, mechanical failure, or wear and tear.

Solutions: Check electrical connections and power supply, inspect for mechanical faults, and replace worn components.

By adhering to this maintenance plan, the water filtration system will operate efficiently and reliably, ensuring a continuous supply of clean water for the university campus.

CONCLUSION

The proposed water filtration system appears to be a comprehensive solution to the potable water needs of the university campus. The systematic design, supported by calculations and projections, suggests a robust framework capable of addressing water scarcity and contamination challenges effectively.

While the theoretical framework suggests a promising solution, it's important to note that practical implementation may introduce unforeseen challenges. Variations in environmental conditions, regulatory requirements, and operational factors could impact the system's performance.

Nevertheless, the comprehensive maintenance plan and adherence to industry standards provide a strong foundation for practical implementation. It's recommended to conduct pilot tests or simulations to validate the system's performance before full-scale deployment, allowing for adjustments and optimizations as needed.

In conclusion, while the theoretical model appears sound, practical implementation may require adaptation and fine-tuning. With careful planning, monitoring, and adjustment, the water filtration system has the potential to provide a sustainable and reliable source of potable water for the university campus, contributing to the well-being and resilience of the community it serves.

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In Africa, **wetlands are not merely components of the landscape**; they are vital lifelines for both the environment and human communities. The continent's diverse wetland ecosystems range from the Nile Delta in the north to the Okavango Delta in the south, each providing unique services that are crucial for reforestation projects. In the context of Africa, wetlands contribute significantly to reforestation efforts by offering a buffer against climate extremes. They mitigate the impacts of droughts by storing water during the rainy season and releasing it slowly during dry periods, which is essential for the survival of newly planted trees.

The importance of wetlands in African reforestation is also evident in their role as **biodiversity reservoirs**. They support a wide array of fauna and flora, some endemic to these habitats, which are essential for maintaining the ecological balance. This biodiversity is not only important for the environment but also for the local communities who rely on wetland resources for their livelihoods. For instance, the papyrus swamps of Uganda are known for supporting industries such as mat and paper production, which are based on sustainable harvests from the wetlands.

Moreover, wetlands in Africa play a critical role in **soil conservation and fertility**. They trap sediments and nutrients that would otherwise be lost, thereby enriching the soil and making it more suitable for the growth of forest species. This is particularly beneficial in areas where soil degradation has been a challenge, making reforestation efforts more viable and successful.

In terms of **carbon sequestration**, African wetlands are powerful allies in the fight against climate change. Peatlands, for example, store large amounts of carbon, and their preservation is essential for maintaining the carbon balance. Reforestation projects in Africa often aim to restore these peatlands to their natural state, which not only helps in carbon storage but also in maintaining the hydrological balance of the region.

The **socio-economic benefits of wetlands** in reforestation projects in Africa cannot be overstated. They provide non-timber forest products, which are a source of income for many rural households. Wetlands also offer opportunities for ecotourism, which can bring additional revenue to local communities while promoting conservation awareness. Furthermore, the cultural significance of wetlands in many African societies adds an intangible value to these ecosystems, which reforestation projects must acknowledge and respect.

However, the integration of wetlands into reforestation projects in Africa faces several challenges. One of the main issues is the **lack of awareness and understanding of the functions and values of wetlands** among policymakers and the general public. There is also a need for more research to inform sustainable wetland management practices that can be harmonized with reforestation objectives. Additionally, the pressures of agricultural expansion, urbanization, and infrastructure development pose significant threats to wetland integrity, necessitating robust conservation strategies.

In conclusion, wetlands are indispensable to reforestation projects in Africa, **offering environmental, economic, and social benefits that are essential for the success** of these initiatives. Their preservation and wise use are key to achieving sustainable reforestation and landscape restoration on the continent. It is imperative that reforestation projects in Africa incorporate wetland conservation into their strategies, ensuring that these vital ecosystems continue to thrive and support the overarching goals of environmental restoration and sustainable development.

JACQUELYN JESTINE SANDERS FOUNDATION
BUILDING VISION, REALIZING CHANGE

DESIGN OF CONSTRUCTED WETLANDS FOR WASTEWATER & DRINKING WATER MANAGEMENT
A STUDY PROJECTS for the University of Antananarivo Site

Author: FINARCH, Rafatro Tsiambanavalona

"This Fellowship offers a unique opportunity to gain specialized knowledge, explore innovative solutions, and develop practical skills in a field crucial for preserving our environment and the well-being of communities worldwide. Moreover, by working on a concrete project, fellows can have a real and measurable impact, further enhancing the value and relevance of this experience. " - Mr. Finarch

Editorial Notes: A Vision for Sustainable Water Management at the University of Antananarivo

The University of Antananarivo stands at the forefront of sustainable water management and rice research, thanks partially to the innovative research and design efforts of Mr. Finarch Rafatro Tsiambanavalona. As a key member of the 2024 Jacquelyn Sanders Foundation Fellowship team of engineers, Mr. Finarch brings experience and passion for environmental sustainability, specifically in water management, to the project.

Mr. Finarch's academic background in Petroleum Engineering from the Ecole Supérieure Polytechnique d'Antananarivo has equipped him with a profound understanding of water treatment and management processes. His commitment to sustainability is exemplified in his thesis, which focused on enhancing the efficiency of a wastewater treatment plant for an agro-food company. This project required him to conduct thorough diagnostics and formulate strategic recommendations, showcasing his ability to apply theoretical knowledge to practical, real-world challenges.

In the context of the University of Antananarivo, Mr. Finarch has meticulously investigated the campus landscape to design a technical plan that transforms several acres into a constructed wetland system. This system is envisioned not only to serve as an effective water storage area but also to position the university as a premier facility for rice research in Africa. By harnessing the natural processes of wetlands, Mr. Finarch aims to enhance the water management capabilities of the university, thereby contributing to a sustainable and ecologically sound environment.

His role in the design of the ponds is a critical step towards realizing the university's vision of becoming the largest rice permaculture agroforestry facility in Africa. The innovative approach to water sustainability spearheaded by Mr. Finarch promises to offer a blueprint for similar water management across the continent and beyond.

As we embark on this journey towards a more sustainable future, we are grateful for the expertise and dedication of motivated Students like Mr. Finarch, whose work not only supports the technical aspects of the project but also champions a broader commitment to environmental stewardship and resource preservation. His contributions are invaluable in our pursuit of creating a model of excellence in sustainable water management and agricultural research, and in engaged scholarship.

JACQUELYN JESTINE SANDERS FOUNDATION
BUILDING VISION, REALIZING CHANGE

DESIGN OF CONSTRUCTED WETLANDS FOR WASTEWATER & DRINKING WATER MANAGEMENT
A STUDY PROJECTS for the University of Antananarivo Site

Author: FINARCH, Rafatro Tsiambanavalona
Peer Review: Coman (Environmental Engineer, JJSF)

Bachelors in Petroleum Engineering
at Ecole Supérieure Polytechnique
d'Antananarivo

Contents

Abstract

The University of Antananarivo's "Garden of Eden Constructed Wetlands Rice Permaculture Agroforestry Initiative" aims to integrate innovative ecological solutions for wastewater treatment and water storage on campus. This project seeks to optimize artificial wetlands using vegetative filtration, specific substrates, and appropriate plants, addressing both wastewater treatment and stormwater management while supporting sustainable agriculture. The initiative includes subsurface and surface flow wetlands and a pond, each designed to meet the university's needs for water management and agricultural research. The project plans to implement subsurface flow lagoons for wastewater treatment and surface flow lagoons for water storage and rice cultivation. Key decisions include selecting cost-effective and environmentally beneficial lagoon lining materials. This project not only aims to enhance water management and agricultural practices but also positions the university as a leader in ecological engineering and sustainable development, providing practical research opportunities and contributing to environmental sustainability.

Keywords: Constructed wetlands, rice permaculture, water management, wastewater treatment, sustainable agriculture

Introduction

The University of Antananarivo Garden of Eden Constructed Wetlands Rice Permaculture Agroforestry Initiative aims to implement innovative ecological solutions for water management and pollutant treatment on the university campus. This document explores the concepts of subsurface flow wetlands and rice permaculture in the context of the University of Antananarivo, providing a detailed overview of the methods and systems proposed for optimizing the efficiency of these artificial aquatic environments. By incorporating elements such as vegetative filtration, specific substrates, and suitable plants, the initiative aims to create systems that not only treat wastewater and manage stormwater but also support sustainable agriculture. The following sections will examine the proposed designs for a subsurface flow wetland, a surface flow rice permaculture wetland, and a pond, tailored specifically to the needs and environment of the University of Antananarivo.

I. Case Study: University of Antananarivo Facility

The University of Antananarivo, located in Antananarivo, Madagascar, is embarking on a project to rescue its aged water management and to build up mission critical tree conservation & agricultural research capabilities, dependent upon abundant water. The facility requires efficient wastewater treatment solutions and reliable water storage systems for drinking water. To address both of these discrete these needs, the project will implement a series of subsurface flow lagoons for wastewater treatment and free flowing and connected surface flow lagoons for water storage and rice research beds.

I.1 Facility Needs

The primary objectives for the University of Antananarivo's project are:

1. Wastewater Treatment: Efficiently treat wastewater generated by the university to meet environmental standards and reuse the treated water for agricultural purposes.
2. Drinking & Agricultural Water Storage: Ensure a reliable supply of water for drinking and agricultural research, particularly for rice cultivation.
3. Research and Education: Provide practical research opportunities for students and faculty in sustainable agriculture and water management.

The "University of Antananarivo Garden of Eden Constructed Wetlands Rice Permaculture Agroforestry Initiative" represents a groundbreaking opportunity for the university to lead the way in Africa by integrating permaculture principles with traditional rice production. This initiative addresses the pressing need for efficient water use in a region where water scarcity is a critical issue. Conventional rice production is highly water-intensive and often diverts water from essential drinking water needs, leading to inefficiencies and shortages. By implementing this innovative plan, the university can demonstrate that man-made wetlands are precisely what is needed to solve its water demands. The project exemplifies a significant environmental advancement, showcasing that sustainable, constructed wetlands can provide a dual solution: enhancing water management and supporting agricultural productivity. This initiative not only meets immediate water needs but also positions the University of Antananarivo as a leader in sustainable agricultural practices and ecological responsibility.

II. Design and Layout

II.1 Subsurface Flow Lagoons (for Wastewater Treatment)

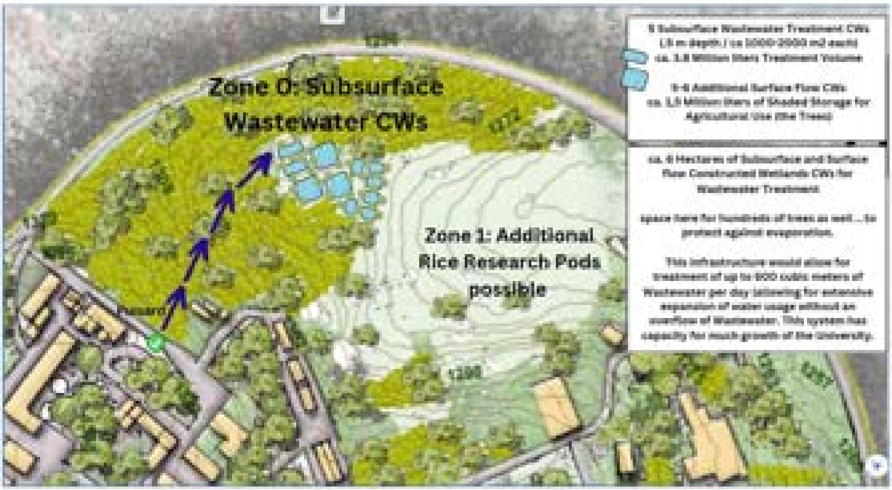

Figure 1 : Zones 0, 1, University of Antananarivo Source: Coman, JJSF - Sustainable Vision Journal - Summer, 2024

The subsurface flow lagoons are designed to treat wastewater through a natural biological filtration process. These lagoons will be strategically placed to maximize their efficiency and integration with the university's infrastructure.

Key Features for Planning

- Dimensions: Each lagoon will have a depth of 0.3 to 0.9 meters.
- Substrates: Layers of gravel, sand, and soil to facilitate filtration and root growth.
- Plants: Common reed (Phragmites australis) will be used for his pollutant removal capabilities.
- Flow System: Horizontal flow system to maintain a saturated environment for optimal filtration.

Design: The subsurface flow lagoons will be designed with an inlet area of 2 meters, an outlet area of 1 meter, and a central filtration area with specific granulometry as per the Austrian standard ÖNORM B 2505.

II.2 Surface Flow Lagoons for Drinking Water Management

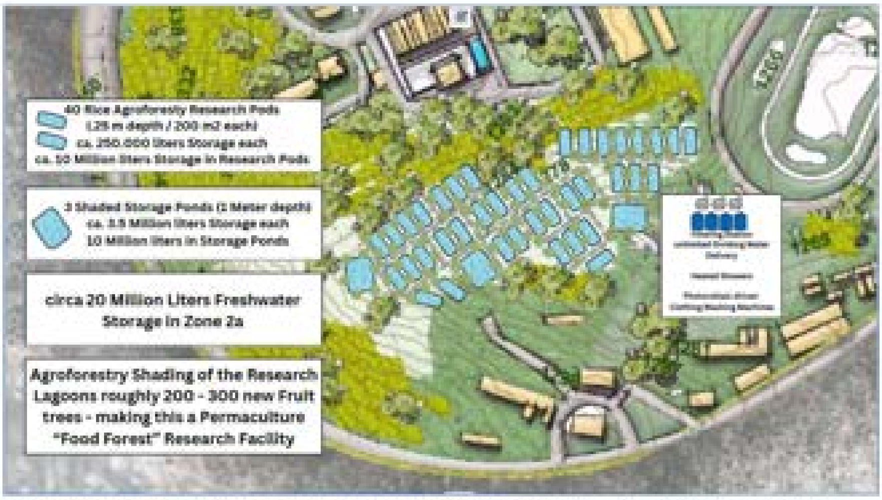

Figure 2: Zone 2A, University of Antananarivo Source: Coman, JJSF - Sustainable Vision Journal - Summer, 2024

The surface flow lagoons will be utilized for storing drinking water and supporting rice research beds. These lagoons will be designed to ensure minimal evaporation and maximum water retention.

Key Features

- Dimensions: Maximum depth of 2 meters, with additional depths of 2.5 to 3 meters for winter fish survival.
- Substrates: Layers of gravel, sand, and soil for water storage and rice cultivation.
- Plants: Fruit plant like papaya, citrus and banana around the periphery to provide shade and reduce evaporation.

Design: The surface flow lagoons will include embankments upstream to prevent sediment deposits and downstream for fish management. A synthetic lining will be used to ensure water impermeability, with a geotextile underlayer to protect the liner.

II.3 Integration with the Site

The layout of the lagoons will be designed to harmoniously integrate with the existing university landscape. The placement of lagoons will ensure easy access for maintenance and monitoring while providing an aesthetically pleasing environment for students and staff.

Proposed Layout

- Wastewater Treatment Lagoons: Located near the main wastewater discharge points to minimize the distance for wastewater transport.
- Water Storage and Research Lagoons: Positioned in areas with optimal sunlight for rice cultivation and easy access for research activities.

II.4 Expected Benefits

- Environmental: Significant reduction in pollutants from wastewater, contributing to cleaner local water bodies.
- Agricultural: Enhanced research opportunities in rice cultivation and permaculture techniques, leading to improved agricultural practices.
- Educational: Hands-on learning experiences for students in sustainable water management and ecological engineering.

Case Study – Antananarivo

The University of Antananarivo's project represents a comprehensive approach to integrating wastewater treatment and water storage solutions. By implementing subsurface flow lagoons for wastewater treatment and surface flow lagoons for water storage and rice research, the university will not only address its immediate water management needs but also contribute to the field of sustainable agriculture.

III. Subsurface Flow Constructed Wetland for Wastewater Treatment

Constructed wetlands, with depths ranging from 0.3 to 0.9 meters, immerse substrates and roots, thereby promoting the growth of biofilm and the removal of pollutants. Plants such as bulrush and common reed are commonly used in subsurface drainage systems. Numerous studies have proven the effectiveness of artificial wetlands in treating urban wastewater and removing various pollutants. Horizontal and vertical flow systems operate in different environments, whether aerobic or anaerobic, to degrade pollutants, with hydraulic retention times varying according to studies.

In horizontal subsurface flow systems, wastewater moves horizontally through substrates located in a bed planted beneath the surface of macrophytes. Horizontal filters are uniformly filled with gravel, imported sand, or in-situ soil, in which reeds take root. Water circulates horizontally through the filter, often continuously, thus keeping the filter beds saturated permanently. There is no water surface exposed to the atmosphere, as the water level is maintained 5-10 cm below the surface of the gravel layer. The horizontal filter does not receive raw effluent, as it is pre-treated to reduce suspended solids that could clog the filter.

Horizontal filters are saturated with water thanks to an outlet siphon system that allows adjusting the water height in the basin. Phragmites reeds planted in the horizontal filter effectively reduce many pollutants. The optimal bed depth is 0.6 meters, corresponding to the maximum depth reached by the reeds' rhizomes in a saturated environment. Additionally, the bed slope is 1% to allow the filter to drain. According to the Austrian standard ÖNORM B 2505, it is recommended to use granulometries of 40 to 80 mm for the inlet and outlet areas. The inlet area should be 2 meters long, while the outlet area should be 1 meter long. Finally, the substrate granulometry in the middle should be between 20 and 30 mm.

This thorough analysis process and various recommendations from literature and standards, such as the Austrian standard ÖNORM B 2505, led me to propose the subsurface flow wetland system described below. By considering the optimal depths of substrates, the types of plants to use, as well as the appropriate dimensions and granulometries for the inlet and outlet areas, I was able to develop a detailed and efficient design proposal. This design, illustrated in the following figure, integrates all these considerations to ensure optimal wastewater treatment while minimizing clogging risks and maximizing pollutant degradation efficiency.

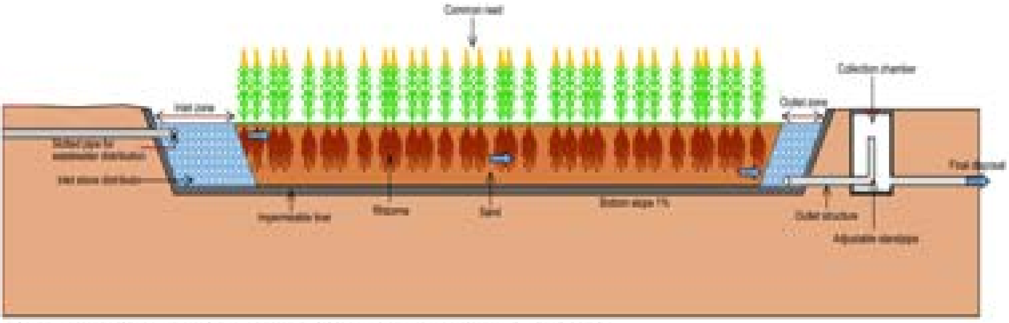

Figure: Subsurface Lagoon Planning: Source: Finarch 2024 (Author)

IV. Freshwater Rice Permaculture Lagoon with Surface Flow

A freshwater rice permaculture lagoon with surface flow is an integrated system that combines permaculture techniques with rice cultivation in an aquatic environment. The constructed wetland for stormwater management is designed to manage stormwater by storing and treating it through vegetative filtration and substrates such as gravel and sand. Subsurface flow occurs in the middle of this system, and aquatic plants can be planted above it.

Research shows that the combined cultivation of rice and citrus on marshy lands greatly benefits from the integration of advanced agricultural technologies and institutional support for farmers. Banana trees, often grown in association with rice and fruit trees like papaya, play an intermediate shading role and provide a food source for households, while the surplus is intended for sale.

By combining these two concepts, it is possible to plant rice above the subsurface flow and position fruit trees around the wetland. The composition of the substrates in the artificial subsurface flow wetland, made up of soil, sand, and gravel, allows for planting rice above this soil, as rice paddies are used in managed wetlands in Southeast Asia.

To illustrate the concept of the freshwater rice permaculture lagoon with surface flow and integrate the dimensions of the previously described subsurface flow lagoon, here is a detailed diagram of the proposed design.

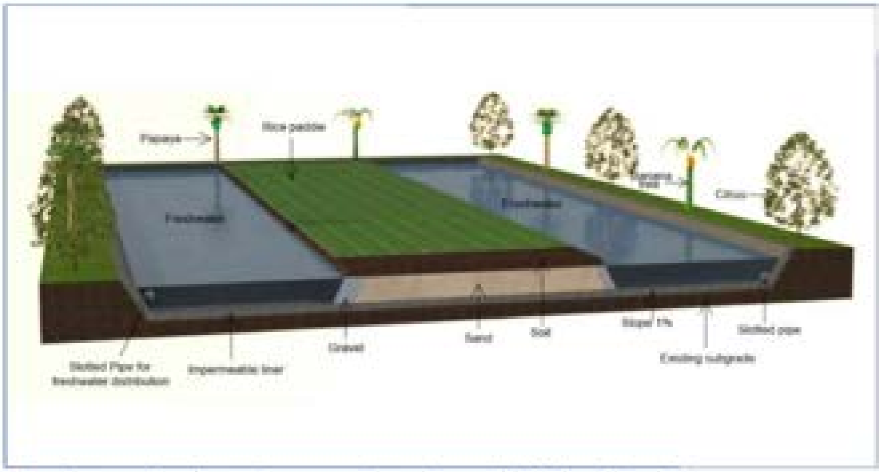

Figure: Proposed freshwater rice permaculture lagoon with Surface Flow design
Source: Finarch – 2024 (Author)

V. General Pond / Lagoon Considerations

A pond is a shallow, generally artificial, stagnant freshwater body that can be drained, resting in a basin with an impermeable bottom. A pond of varied shape is the most suitable. Due to their transitional nature between terrestrial and aquatic environments, ponds can also resemble wetlands.

Hillside reservoirs are ponds fed by runoff and precipitation, but not by rivers. A wetland naturally develops around these ponds. They serve as water reservoirs during heavy rainfall and can be connected in succession, requiring embankments upstream to prevent sediment deposits and downstream for fish management. A pond should not be too deep to promote the development of aquatic and amphibious vegetation and to limit thermal stratification. A pond can have a maximum depth ranging from 1.5 to 2 meters. For the survival of fish during winter, an additional depth of 2.5 to 3 meters is necessary.

Water is the structuring and driving element of ponds. Each pond is characterized by the balance between water inflows and outflows. In our case, embankments upstream and downstream of the pond are used since the pond is fed only by runoff and rainwater. The size of the structure is limited to reduce the evaporation of stored water.

After a thorough analysis of the different options, it appears that a synthetic liner, combined with a geotextile underlay, is often preferred due to its cost and durability.

For instance, although natural liners are an option, they can be more expensive. Additionally, among the various synthetic materials, an EPDM rubber liner is considered a better alternative to PVC, particularly for its longevity and lower environmental impact during disposal. Planting trees and hedges is also recommended to provide shade and reduce evaporation.

Building on this foundation, it's important to carefully consider the subsequent steps in the pond's development to ensure its ecological balance and sustainability. It is recommended to cover this layer with 20 cm of soil. The vegetation associated with stagnant water should be suited to the pond's mode of operation, with limited plant introduction. Common reed, for example, is advised for its purifying properties. Similarly, the introduction of fauna should be limited, with only a few small fish in very small quantities.

Considering these essential characteristics and requirements of ponds and hillside reservoirs, I have proposed a layout that harmoniously and effectively integrates these elements.

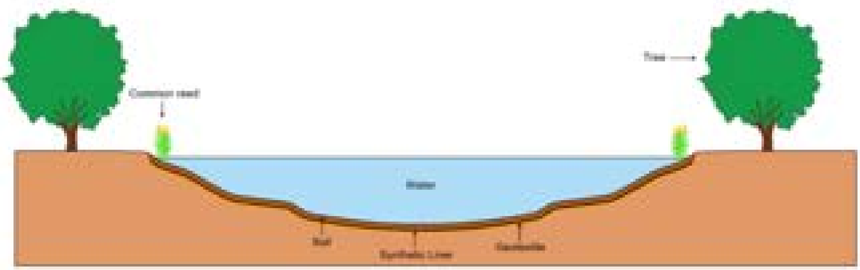

Figure: Freshwater Storage Concept Source: Finarch – 2024 (Author)

Conclusion

The University of Antananarivo's "Garden of Eden Constructed Rice Permaculture Wetlands" project represents a visionary approach to integrating wastewater treatment and water storage solutions, serving as a model for sustainable water management and agricultural research. The proposed design at this stage underscores the technical vision for the project, setting the foundation for detailed planning and site-specific analysis, in cooperation with constructed wetlands experts. The next steps will involve conducting a comprehensive on-site survey of the site to inform the precise placement and dimensions of the subsurface and surface flow lagoons. Additionally, a critical decision remains regarding the lining materials for the lagoons. While a strictly synthetic liner is the most cost-effective option, the potential use of bentonite provides a more natural solution, albeit at a significantly higher cost. This choice will require careful consideration of both budgetary constraints and environmental benefits. The environmental benefits for the university should not be underestimated. The proposed functional landscape will support the local ecosystem and substantially improve water management at the university. Unlike traditional solutions, such as water tanks, which have been tried and found wanting, this project offers a renewable, natural solution. By implementing constructed wetlands, the University of Antananarivo positions itself at the forefront of utilizing green infrastructure for comprehensive and environmentally responsible water management. This project will create a beautiful and sustainable landscape, enhancing the university's role as a leader in ecological engineering and sustainable practices. The holistic approach demonstrated here has the potential to address current and future environmental challenges, ensuring that the University of Antananarivo not only meets its immediate water management needs but also contributes positively to the environment and community.

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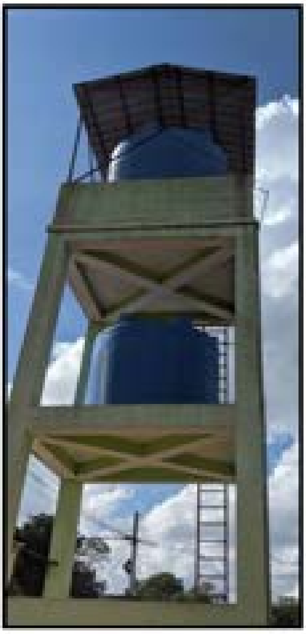


Global Deforestation and its Impact on Madagascar

Deforestation is a global crisis that has left indelible scars on landscapes around the world, and Madagascar is no exception. The island nation, renowned for its unique biodiversity, has experienced extensive deforestation, primarily due to agricultural expansion, logging, and charcoal production. This environmental degradation has had severe repercussions, particularly in the southern regions of Madagascar, where the lack of trees has led to soil erosion, decreased rainfall, and the collapse of ecosystems.

The situation in southern Madagascar is dire, with communities suffering from acute water and food shortages. This humanitarian crisis can be traced back to poor environmental planning and management by previous generations. The absence of sustainable practices has resulted in desertification, making it increasingly difficult for people to find the resources they need to survive.

Urbanization and Infrastructure Strain in Antananarivo

As rural areas become increasingly uninhabitable, many people have migrated to urban centers in search of better living conditions. Antananarivo, the capital city, has seen significant population growth as citizens flock to the city in search of electricity, water, and food. This rapid urbanization has placed immense strain on the city's infrastructure, which has not been able to keep up with the growing demand.

Recent statistics indicate that urban population growth in Madagascar is approximately 4.5% per year, with Antananarivo being the primary destination for internal migrants. The city's population is now estimated to be over 1.4 million, a number that continues to rise as more people seek refuge from the harsh conditions of rural areas.

Many residents of Antananarivo live without basic necessities such as running water, electricity, and sanitation infrastructure. The city's waste management systems are overwhelmed, leading to an accumulation of trash in the streets. The water supply system is particularly inadequate, failing to reach the highest elevations of the city and leaving entire zones without reliable access to water. As a result, residents often rely on water delivery trucks, which are inconsistent and unpredictable.

Water Challenges at the University of Antananarivo

The University of Antananarivo mirrors the city's broader water infrastructure challenges. Despite having some water infrastructure in place, the system is inefficient and cannot adequately supply water to the campus, especially to the higher elevations. Many areas within the university depend heavily on water delivery trucks, and when water is delivered, it is quickly distributed and depleted, forcing students to be constantly vigilant to secure their daily water needs. Rationing is common, and the lack of a predictable delivery schedule exacerbates the problem.

The university possesses numerous tanks that could store water, but these often sit empty due to the ineffective distribution system. This inconsistent water supply poses a significant challenge, not only for daily living but also for the university's academic and environmental initiatives.

Environmental Initiatives and Water Management

Despite these challenges, the University of Antananarivo is proactive in environmental conservation, particularly in tree propagation efforts. The university has been actively producing at-risk tree species, such as ebony and rosewood, to support local reforestation. However, the extended dry periods, which can last up to nine months without rain, coupled with the general water shortage on campus, threaten these young trees' survival.

In recent years, there have been plans to build water recycling facilities using constructed wetlands to manage and reuse wastewater on campus. Recognizing the importance of sustainable water management, the Jacquelyn Jestine Sanders Foundation stepped in to build upon these plans. The Foundation aimed to address the broader water issues at the university by evaluating and developing solutions for both wastewater management and drinking water supply.

The focus is on enhancing the university's self-reliance through rainwater harvesting, storage, filtration, and distribution systems. By leveraging rainwater rather than relying on delivery trucks, the university seeks to create a more sustainable and dependable water supply.

Engaging Students for Sustainable Solutions

To tackle these multifaceted challenges, the Foundation engaged students from the university and other local institutions to assess the water issues and develop comprehensive solutions. This initiative, termed "Engaged Scholarship for Sustainable Solutions," involves students in real-world problem-solving to foster practical learning and innovation.

The students' tasks included designing systems for rainwater capture, efficient storage, filtration, and equitable distribution. This ambitious undertaking not only aims to solve the immediate water issues but also to serve as a model for sustainable water management that can be replicated in other regions facing similar challenges.

In summary, the water problems at the University of Antananarivo and Madagascar as a whole are deeply interconnected with global environmental issues, urbanization pressures, and inadequate infrastructure. By addressing these problems through engaged scholarship and sustainable practices, there is hope for a more resilient and self-sufficient future.

JJS JACQUELYN JESTINE SANDERS FOUNDATION
BUILDING VISION, REALIZING CHANGE

From Crisis to Opportunity: Leveraging Constructed Wetlands & Rice Fields for Sustainable Water Management at the University of Antananarivo"

Author: Coman, Kenneth Dale (Sr.)

"The JJSF Fellowship Program at the University of Antananarivo took many unexpected turns in 2024. It felt like God wanted to guide us to a solution which was both divine and also obvious. We might give a bit of stewardship, and nature returns an abundance of wealth. The Garden of Eden Concept developed as the natural solution. The beauty in nature is ironically, in it's complexity and it's simplicity."
- Coman

JACQUELYN JESTINE SANDERS FOUNDATION

Abstract

This essay explores the integration of constructed wetlands and rice fields as viable solutions for addressing severe water management challenges. Using the University of Antananarivo in Madagascar as a case study, it highlights the urgent need for innovative water treatment and storage solutions. With its 35,000 students suffering from a failing water infrastructure and intermittent water deliveries, the university represents a microcosm of the broader water crisis in Madagascar. The essay delves into the historical context of rice agriculture as a natural response to the lack of centralized water treatment and advocates for the "Garden of Eden" concept—an ecologically diverse, water-recycling landscape. It argues that the answer to water scarcity and quality issues lies in embracing these sustainable, nature-based solutions.

Introduction

Madagascar is currently facing a severe water crisis, with inadequate infrastructure failing to meet the needs of its population. This issue is particularly pronounced at the University of Antananarivo, the largest university in Madagascar, where 35,000 students rely on an intermittent and insufficient water supply. The university's failing water infrastructure has led to a dependence on sporadic water deliveries, significantly affecting daily life and academic activities. Meanwhile, the island's abundant rainfall is channeled into surrounding rice fields, hinting at a solution embedded in the natural landscape. This scenario underscores an urgent need for innovative water management engineering to transform the university's water scarcity into an opportunity for sustainable development.

In the south of Madagascar, survival often means family members must carry water. Hours of walking daily is common.
Photo Credit: Sibo (Fellow)

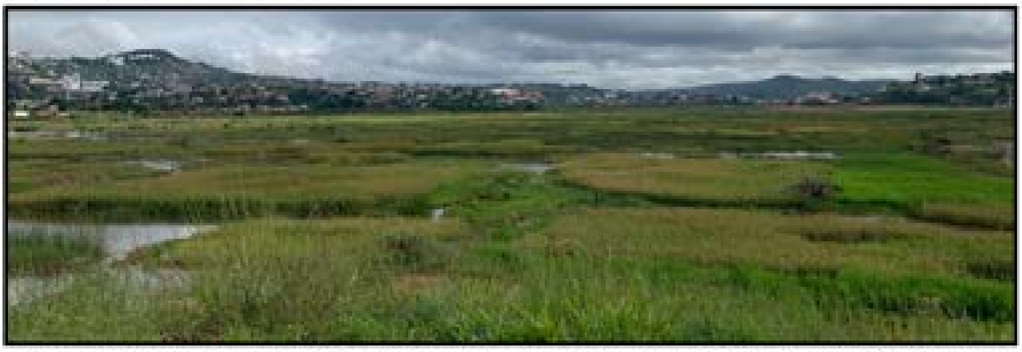
Given the urgency of the situation, the potential of integrating constructed wetlands and rice fields as part of a comprehensive water management strategy becomes increasingly relevant. These systems not only offer a means to enhance water quality and availability but also provide ecological and educational benefits. This essay aims to explore the historical and contemporary applications of wetlands and rice fields in water management, highlighting the opportunity to turn the University of Antananarivo into a reproducible model for sustainable water infrastructure in Madagascar and beyond.

Historical Context:

The Genesis of Rice Agriculture

The use of wetlands for water storage and purification is not a novel concept but an ancient practice refined over millennia. The cultivation of rice in flooded fields, or paddies, emerged as a natural response to the lack of centralized water treatment. Early civilizations observed that wetlands, with their rich biodiversity and complex ecosystems, could naturally cleanse water. This observation led to the innovation of planting edible crops in these lagoons, giving birth to rice agriculture.

Today, rice fields cover approximately 162 million hectares globally, accounting for about 3.4% of the world's total agricultural land, excluding forests. This extensive use of land underscores the effectiveness of rice fields as natural water treatment systems. Rice paddies are more than just agricultural landscapes; they are intricate systems where water purification, nutrient cycling, and food production occur simultaneously.



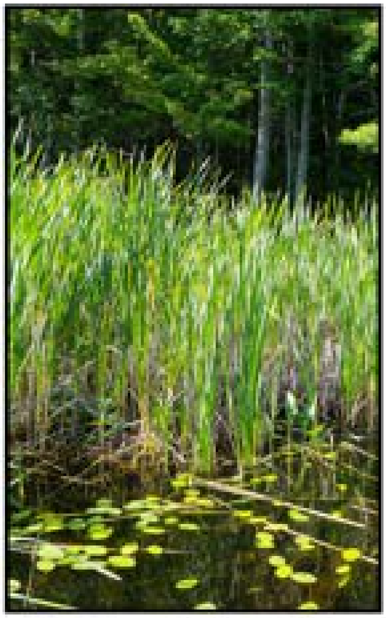
In the heart of the Madgascar, in the capitol city of Antananarvio, ubiquitous rice fields sprawling into the distance. Grey water from the surrounding neighborhoods feed much of the water into this system. Sighting clothing being washed in the water near these fields is common. Photo Credit: Coman (Author)

The Modern Perspective:

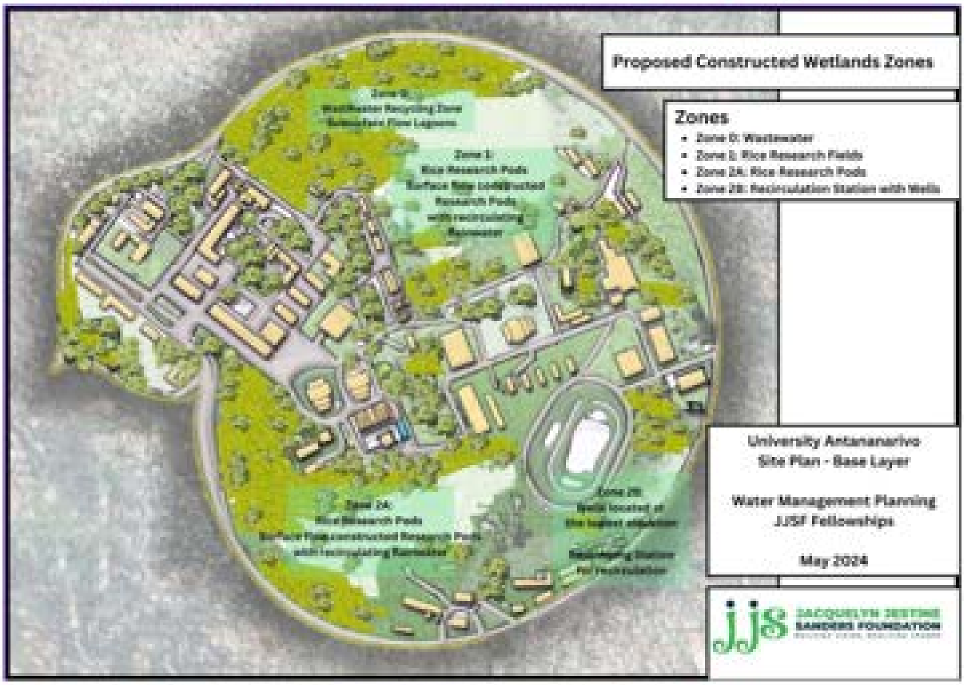
Constructed Wetlands and Water Management

Building on the traditional knowledge of rice fields, modern science has embraced constructed wetlands as a sustainable approach to water management. Constructed wetlands are engineered systems designed to mimic the natural processes of wetland ecosystems. They utilize a combination of plants, soil, and microorganisms to treat wastewater, stormwater, and even greywater from domestic sources.

By storing and treating rainwater and greywater, constructed wetlands reduce reliance on centralized water treatment facilities and provide a decentralized, eco-friendly solution. The water purification process in these wetlands involves sedimentation, filtration through plant roots, and the breakdown of pollutants by bacteria. This natural filtration system enhances water quality, making it suitable for various non-potable uses, and with additional treatment, it can even meet potable standards.



Wetlands function best when there is a combination of species working together to clean the water. Photo Credit: Canva (Pro)



Conceptual Site Plan developed as part of the 2024 Jacquelyn Sanders Foundation Fellowships. Photo Credit: JJSF

Embracing the "Garden of Eden" Concept

The "Garden of Eden" concept envisions transforming landscapes into water-saving, water-recycling havens by incorporating a diverse range of plants, including fruit trees, into the wetland system. This approach not only enhances biodiversity but also improves the efficiency of water use and purification. By strategically designing these systems to use gravity flow and extensive root networks, we can create a self-sustaining environment where water is continuously filtered and reused.

This concept is not limited to any single institution or region; it offers a universal solution that can be adapted to various climates and ecosystems. For example, the University of Antananarivo in Madagascar could adopt this approach to address its water management needs. By integrating wetlands into the campus landscape, the university could clean it's wastewater(See ARAFA Report 2020), harness rainwater and greywater, creating a sustainable water source that supports both human activities and the local ecosystem. This system would provide water for the tree conservation efforts, and it would supply a continuous supply of water for filtering for the students for showering, drinking, and even perhaps for washing their clothing as well.


Fruit trees such as Papaya and Banana are very vibrant in Madagascar. These trees would enhance greatly the rice field landscape and would multiply the food quantity and diverstiy coming out of the fields. Photo Credit: Canva (Pro)

How much land mass is dedicated worldwide to rice agriculture?

Rice production is a significant component of global agriculture, but it occupies a relatively small percentage of the total agricultural land.

Here are the details:

According to the Food and Agriculture Organization (FAO) of the United Nations, approximately 162 million hectares of land are used for rice cultivation worldwide. That represents an area the size of Mexico.

The total global agricultural land area is around 4.8 billion hectares, which includes arable land, permanent crops, and permanent pastures.

Calculating the percentage, rice cultivation accounts for about 3.4% of the total global agricultural land.

This percentage highlights the importance of rice as a staple crop for a large portion of the world's population, despite its relatively small footprint in the total agricultural land area. Rice is particularly crucial in Asia, where it is the main source of calories for billions of people.

162 million hectares of land are used for rice cultivation worldwide. That is an area roughly the size of Mexico. Photo: Canva (Pro)

Rice has been widely decribed as a "water intensive" crop. This is largely due to evaporation. But taking action to reduce evaporation may reveal that the rice field can be central to a comprehensive water storage, management and recycling strategy. Photo: Canva (Pro)

Rice as a Phytoremediation Tool

Rice plants have the ability to clean water through a process known as phytoremediation. This process involves using plants to absorb, accumulate, and degrade contaminants from water and soil. Here's how rice plants contribute to water cleaning:

Absorption and Accumulation: Rice plants can absorb pollutants, including heavy metals, nutrients, and organic compounds, from water and soil through their root systems. These contaminants are then accumulated within the plant tissues.

Root Zone Microbial Activity: The root zone of rice plants, also known as the rhizosphere, supports a diverse microbial community. These microbes can break down organic pollutants and convert them into less harmful substances.

Oxygen Release: Rice plants release oxygen into the water and soil through their roots. This oxygenation helps to promote aerobic microbial activity, which is essential for the breakdown of various contaminants, including organic matter and certain pollutants.

Nutrient Uptake: Rice plants are efficient at uptaking nutrients such as nitrogen and phosphorus from the water. This can help reduce nutrient pollution, which is a common problem in water bodies that leads to eutrophication and algal blooms.

Sediment Stabilization: The roots of rice plants help stabilize sediments in the water, reducing turbidity and preventing the resuspension of contaminants.

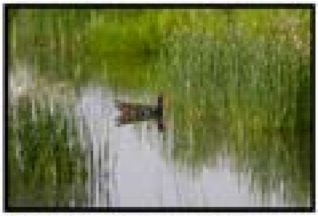
Limitations and Considerations when utilizing Rice for Phytoremediation

The Status Quo:
Be first informed that the decision has already been made broadly to use rice for phytoremediation. So many rice fields are receiving rain and grey water from all directions. Washing is being done using the water flowing into and out of rice fields. It is the Status quo. Thus - we are not asserting here that rice is the optimal phytoremediation tool. It isn't. But - since it is widely used in this context … how do we optimize that use? Since we are talking about an area globally that exceeds the amazon rain forest … it is useful to examine and propose ways to improve this land use. How effective is rice? Can the system be improved upon?

While rice plants can contribute to water cleaning, they are typically used as part of a broader system for managing water quality. They are particularly effective in rice paddies or constructed wetlands where water can be retained and treated over time. The effectiveness of rice plants in cleaning water depends on various factors, including the types and concentrations of contaminants, the characteristics of the soil and water, and the specific rice varieties used. Overall, rice plants can be an important component of comprehensive ecological engineering and sustainable water management practices, helping to improve water quality in agricultural and natural ecosystems.

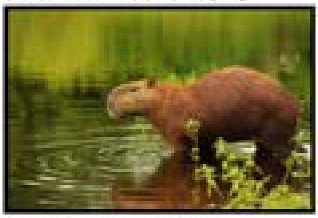
"Constructed Wetlands" as an Strategy

Using constructed wetlands as a component of a rainwater harvesting and treatment system can be a valid approach for storing and pre-treating water that will eventually meet potable standards. Here's how this can work and why it can be considered a feasible and sustainable strategy:



So many species enjoy a water environment. Photo: Canva (Pro)

Benefits of Using Constructed Wetlands for Rainwater Storage
Natural Filtration: Constructed wetlands can act as a natural filtration system. As rainwater flows through the wetland, plants and microorganisms can help remove sediments, organic matter, and some contaminants. This process can reduce the load on subsequent filtration and treatment systems needed to meet potable water standards.



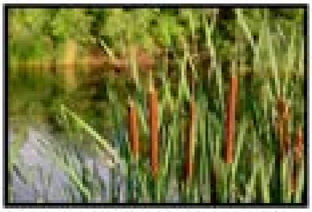
Capybara, Wetlands of Brazil. Photo: Canva (Pro)

Pollutant Reduction: Wetlands can reduce various pollutants such as nitrates, phosphates, heavy metals, and pathogens. While they may not completely purify the water to drinking standards, they can significantly lower the concentrations of these contaminants, making it easier and more cost-effective to achieve potable water quality.

Constructed wetlands of Orlando, FL, USA. Photo: Canva (Pro)

Ecosystem Services: In addition to water treatment, constructed wetlands provide habitat for wildlife, enhance biodiversity, and can be integrated into the landscape for aesthetic and educational purposes.

Water Conservation: Storing rainwater in wetlands reduces reliance on groundwater or surface water sources, contributing to overall water conservation efforts. This is especially valuable in areas facing water scarcity or drought conditions.



Constructed wetlands of Boulder, CO, USA. Photo: Canva (Pro)

Stormwater Management: Constructed wetlands help manage stormwater by reducing runoff and controlling flooding. This dual functionality allows them to serve both as water treatment facilities and as flood mitigation infrastructure.

Engineering a more Optimized Rice Phytoremeditaion Strategy

Engineering the systems and managing water quality are crucial aspects of making phytoremediation through rice cultivation a viable and safe practice. Here's a deeper dive into the salient points:

Engineering and System Management:

- **Design and Maintenance:** Properly designed and maintained phytoremediation systems are essential for effective water treatment. This includes designing the ponds to optimize the removal of contaminants and regularly maintaining the infrastructure to prevent issues.

- **Pre-Treatment:** Pre-treating grey water to remove the most harmful contaminants before it enters the phytoremediation zone can significantly reduce risks. This can involve filtering out solids, reducing heavy metal concentrations, or using chemical treatments to neutralize pollutants.

Consumer Awareness and Water Conservation:

- **Educational Initiatives:** Educating consumers about the benefits of water recycling and the role of phytoremediation can increase their respect and care for water resources. When people understand the importance of their actions, such as using environmentally friendly cleaning products, they may be more inclined to adopt practices that reduce water pollution.

- **Behavioral Changes:** Knowledge about the connection between water use, pollution, and food production can encourage consumers to make more sustainable choices. This might include opting for natural detergents and reducing waste, which in turn supports the effectiveness of phytoremediation systems.

Natural and Eco-Friendly Products:

- **Natural Detergents:** Using natural or biodegradable detergents helps minimize the introduction of harmful chemicals into grey water. These products often break down more easily and are less likely to leave behind residues that can affect the phytoremediation process.

- **Reducing Chemical Load:** Reducing the overall load of chemicals entering the wastewater system through choices like natural cleaning products and reducing personal care product waste can significantly lighten the burden on the water treatment process. This can lead to cleaner water and more effective phytoremediation.

Integration with Broader Environmental Goals:

- **Sustainability**: Phytoremediation systems, when combined with public awareness and eco-friendly practices, contribute to a broader sustainability goal. They offer a method to manage wastewater while also producing food, aligning with goals of resource conservation and environmental stewardship.

- **Community Involvement:** Engaging local communities in these practices can lead to better outcomes. By involving people in water conservation efforts and educating them about the benefits of sustainable practices, communities can collectively work towards more effective environmental management.

Effectively integrating engineering solutions with community awareness and sustainable practices creates a robust system for managing grey water through phytoremediation. Ensuring the water quality entering these systems is managed and reduced through natural detergents and other eco-friendly practices can enhance the safety and efficiency of such systems. Additionally, educating consumers and fostering a culture of respect for water resources are key to the success and sustainability of these practices.

Rice Permaculture?

Predicting food production and profitability for a hectare of land growing rice exclusively versus a mixed cropping system (rice with fruit trees and berries) involves several variables. Here's a detailed comparison, along with insights into the impact of a permaculture approach on water usage:

Rice-Only Field:

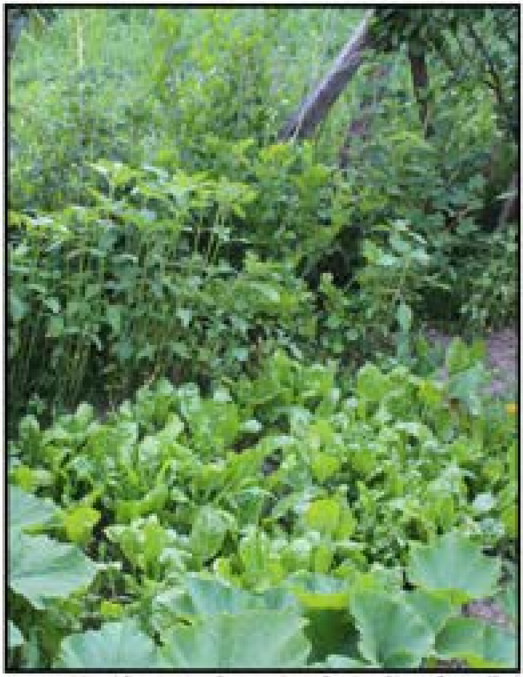
Production and Yield:

- Typical Yield: On a well-managed hectare, rice yields can range from 4 to 8 metric tons per year, depending on the variety, soil quality, and management practices.
- Income: The profitability depends on local rice prices, but assuming a yield of 6 tons per hectare and a price of $300 per ton, the gross revenue might be around $1,800 per hectare.

Water Usage:

- High Water Requirement: Rice is a water-intensive crop, often requiring around 1,500 to 2,500 cubic meters of water per hectare per season.

Rice Monoculture Photo: Canva (Pro)



Mixed Species in a Permaculture Setting. Photo: Canva (Pro)

Mixed Cropping (Rice with Fruit Trees and Berries):

Production and Yield:

- Rice: The yield might be lower due to competition for resources. A conservative estimate might be 3 to 5 metric tons per hectare.
- Fruit Trees and Berries:Yields can vary widely based on the type and age of the trees/bushes, but:
- Fruit Trees: Depending on the type (e.g., mangoes, avocados), yields might be 5 to 15 metric tons per hectare per year once the trees are mature.
- Berries: Yields can range from 5 to 10 metric tons per hectare per year.

Total Production: Combining the yields, you might expect around 8 to 20 metric tons of produce per hectare annually, depending on the mix of fruits and berries and the maturity of the plants.

Rice Permaculture Income:

- Varied Pricing: The total revenue will depend on the market prices of the fruits and berries. If you assume average prices, the mixed system could potentially generate higher gross revenue. For example, if the combined revenue of fruits and berries is around $4,000 per hectare, this could surpass the revenue from growing rice alone.

Permaculture driving higher return on investment. Photo: Canva (Pro)

Impact of Permaculture Approach on Water Usage:
Permaculture Principles:

- Diverse Planting: Incorporating fruit trees and berries into the rice field can create a more resilient ecosystem, with plants benefiting from each other (e.g., through shade or improved soil conditions).

Intercropping fruit trees brings a higher nutritional result as well. Photo: Canva (Pro)

Water Management: Permaculture techniques can significantly reduce water usage through methods like:

- Water Harvesting: Collecting and storing rainwater for irrigation.
- Mulching: Reducing evaporation and improving soil moisture.
- Swales and Contour Plowing: Directing and retaining water in the field.

Another treeless rice field. This is what gives rice a water intensive reputation - too much evaporation. Photo: Canva (Pro)

Expected Impact:
Reduced Water Demand: The permaculture approach can lead to more efficient water use compared to traditional monoculture practices. While rice still requires substantial water, the additional techniques can reduce the overall demand and improve water conservation.

Summary:

- Rice-Only: Higher yields and predictable income but higher water usage and less diversity.
- Mixed Cropping: Potentially higher overall yields and revenue with greater diversity, but initial competition for resources could reduce rice yield. Permaculture can improve water efficiency and sustainability.

Engineering the Landscape for better results is not a new concept. But let us not forget the trees! Photo: Canva (Pro)

In general, while mixed cropping with permaculture techniques might initially present challenges, it often results in higher long-term sustainability and potentially increased profitability.

Project Overview:
Kibera Slum Constructed Wetland

One noteworthy project in Africa is the Kibera Slum Constructed Wetland in Nairobi, Kenya, which is a collaboration involving Kenya's Jomo Kenyatta University of Agriculture and Technology (JKUAT) and other partners.

Kibera Slum, Nairobi, Kenya. Photo: Wikipedia

Location:
Kibera, Nairobi, Kenya

Institution Involved:
Jomo Kenyatta University of Agriculture and Technology (JKUAT)

Description:
The Kibera Slum Constructed Wetland project focuses on addressing the severe sanitation and water quality issues in one of Nairobi's largest informal settlements, Kibera. The initiative aims to improve wastewater treatment and management through the use of constructed wetlands, which are an eco-friendly and cost-effective technology for treating sewage and greywater.

University leadership in problem resolution. Photo: JKUAT

Objectives:
- Wastewater Treatment: To treat and manage wastewater from the community, reducing the contamination of local water sources.
- Environmental Impact: To create a sustainable and low-cost solution for improving water quality in the slum.
- Educational Purpose: To provide a real-world case study for students and researchers at JKUAT and other institutions, fostering practical learning and innovation in environmental management.

Moringa oleifera, an Indian Tree that has been utilized as part of the Kibera wetland solution. Photo: Canva (Pro)

Implementation:
The project involves the construction of a series of wetlands designed to mimic natural processes that filter and purify wastewater. These wetlands use plants, microorganisms, and natural filtration methods to clean the water before it is safely returned to the environment or reused.

Impact:
- Health Benefits: Improved sanitation and reduced waterborne diseases in the community.
- Educational Outcomes: Students from JKUAT and other institutions gain hands-on experience in environmental engineering and sustainable development.
- Community Engagement: The project engages local residents in maintaining and monitoring the wetlands, promoting environmental awareness and community involvement.

This project serves as an excellent example of how agroforestry constructed wetlands can be effectively utilized in challenging urban environments in Africa, combining practical solutions with educational opportunities.

Considerations for Using Constructed Wetlands in Potable Water Systems

Supplementary Treatment: While constructed wetlands can improve water quality, additional treatment steps are necessary to ensure water meets potable standards. These steps may include filtration, disinfection (e.g., chlorination, UV treatment), and possibly reverse osmosis or other advanced treatment processes.

Regulatory Compliance: Drinking water regulations can be stringent, and water sourced from constructed wetlands must comply with local and national standards. Continuous monitoring and testing are essential to ensure compliance.

Design and Maintenance: Proper design and regular maintenance of the wetland are crucial to its effectiveness. This includes selecting appropriate plant species, maintaining flow rates, and preventing clogging or stagnation.

Seasonal Variations: The effectiveness of wetlands can vary with seasons, particularly in terms of water levels, temperature, and biological activity. These factors need to be considered in the overall water management plan.

Examples and Case Studies

While specific universities using constructed wetlands directly for drinking water storage and treatment are limited, several communities and municipalities around the world use similar concepts. For instance, decentralized systems in rural areas and some urban green infrastructure projects integrate wetlands as part of the water treatment process, demonstrating the potential of this approach. Using constructed wetlands for storing and pre-treating rainwater is a valid and sustainable strategy for managing water resources, particularly in conjunction with other treatment technologies to ensure safe drinking water. This approach aligns well with integrated water management practices and the goals of sustainability and resilience in water systems.

A Call to Action: Reviving Our Lands

The "Garden of Eden" concept represents a shift towards ecological stewardship and sustainability. By returning lands to a water-rich, water-purifying state, where trees are also central, we create an environment where humans and nature coexist harmoniously. This vision extends beyond water management; it encompasses food security, biodiversity conservation, and climate resilience.

The spiritual truth embedded in this approach is the recognition that our actions have profound impacts on the environment. By embracing natural water treatment systems, we can restore balance to our ecosystems and ensure the prosperity of future generations. The answer to our water challenges lies right in front of us, in the ancient wisdom of rice fields as a central water treatment approach and the innovative potential of constructed wetlands as the modern evolution of the concept.

Constructed wetlands Simulation.
Photo: Coman / OpenArt.ai

Conclusion

In conclusion, the use of wetlands and/or rice fields as water treatment systems offers a sustainable and holistic approach to water management. The "Garden of Eden" concept encourages us to rethink our relationship with the land and to cultivate landscapes that are not only productive but also resilient and diverse. By harnessing the power of nature, we can create a world where water is abundant, clean, and accessible to all.

Introduction: ***What Are the Chances of Success for a Wetlands Project in Africa?***

The question of whether wetlands projects can succeed in Africa is one that carries both promise and challenges. Given the continent's diverse ecosystems and varying climate conditions, the potential for success is often seen as uncertain. However, in this detailed case study, our Fellow in Kenya, Mr. Samuel Kimani, provides an in-depth examination of several successful wetlands projects across Africa. Drawing on a comprehensive body of research, Mr. Kimani highlights a wide range of case studies where innovative wetlands restoration and conservation efforts have led to significant ecological, social, and economic benefits. The following pages offer a detailed exploration of these successes, providing valuable insights into the factors that contribute to the success of such projects and the lessons that can be applied to future initiatives across the continent.

JACQUELYN JESTINE SANDERS FOUNDATION
BUILDING VISION, REALIZING CHANGE

Natural and Constructed Wetlands: A Review of the Status Quo in Africa

A Report by Samuel Kimani

Jacquelyn Sanders Foundation
Summer 2024

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Natural and Constructed Wetlands: A Review of the Status Quo in Africa

Defining Wetlands: What are They?

Various definitions have been staked out amid an existential challenge among experts to accurately describe a wetland. Perhaps the most widely accepted definition is provided by the Ramsar Convention as "[an area] of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres." (Ramsar Convention on Wetlands, 2016, p. 9). A much-simplified version of this definition, and one that has become popular among scholars, is that a wetland is an ecotone, or transition zone, existing between dry land and water, such as along lakeside margins, dams, rivers, and intermittent blackwater river channels (Chomba et al., 2021).

Another suitable definition of a wetland is "an area of soil covered with water or [that] has water close to its surface all year or at some periods of the year." (Adeeyo et al, 2022, p. 1). This definition emphasizes the condition of wetlands being transition zones that are neither completely dry nor fully submerged under water — it also impresses the idea that a wetland is simply soil in a water-saturated state. A further definition by Greenway (2004) termed wetlands as "areas that are permanently or periodically inundated or saturated by surface or groundwater and support the growth of aquatic vegetation." (p. 492). Greenway's definition challenges the qualification of artificial reservoirs as wetlands since aquatic vegetation does not thrive sustainably in these catchments. Despite the varying definitions, the consensus is that wetlands are the in-between of water bodies and land. Their transitional character positions them as intermediate buffers between terrestrial and aquatic ecosystems. Some experts have even regarded wetlands as nature's "kidneys" due to their intrinsic ecosystemic filtration function which improves water quality (Mitsch & Gosselink, 2000).

Natural Wetlands in Africa

The wetlands of Africa are the most economically important ecosystem to human beings for many reasons. These ecological expanses promote the welfare of millions of people, not least because of their invaluable contribution to climate regulation, hydrological and biogeochemical cycle balancing, biodiversity protection, and livelihood sustenance (Xu et al., 2019). They also facilitate water purification, groundwater discharge and aquifer recharging in freshwater ecologies, soil erosion control, and carbon sequestration/storage (Thamaga et al., 2022). Wetlands also possess unique ecological qualities that serve as a sustainable source of food and habitat for vast species of flora and fauna (Steinbach et al., 2021). Local communities benefit from a wide variety of staple supplies, including weaving reeds, fodder for livestock, wood fuel, and downstream amenities such as nutrient retention and flood control (Mutanga et al. 2012; Thamaga et al., 2022). Hydromorphic soils and hydrophytic plant species critically contribute to the hydrological cycle, which then facilitates the supply of sustainable goods and services (Thamaga et al., 2022).

Africa's rural poor remain significantly dependent on wetland services to offset the effects of drought and crop failure. Families prefer utilizing wetland services for subsistence due to their higher agricultural productivity and aquatic affluence which facilitates fishing activities (Mitchell, 2013). Water abundance and sustainable soil fertility renders wetlands more suitable for farming activities than degraded traditional farmlands (Steinbach et al., 2021). Therefore, to the indigent African subsistence farmer, there is higher agricultural potential in farming within wetlands, a trend that has positioned these ecosystems at the heartland of agricultural development in sub- Saharan Africa (SSA).

Wetland ecosystems generate the highest global economic value per hectare, accounting for about 47% of all ecosystemic benefits available to humans (Xu et al., 2019). The Convention on Wetlands of International Importance, or the "Ramsar Convention," is the intergovernmental body responsible for the protection and conservation of wetland habitats around the world. At present, 2,518 sites are cataloged in the Ramsar List, spanning 172 territories worldwide and covering over 257 million hectares (Ramsar, 2024). These sites account for about 16-17% of the total global expanse of wetlands, which is estimated to be between 1.5 and 1.6 billion hectares (Convention on Wetlands, 2021).

Collectively, wetlands occupy about 570 million hectares, or 6% of Earth's surface, and form a habitat and breeding ground for 40% of the planet's flora and fauna (Mandishona & Knight, 2022; Sinthumule, 2021; Thamaga et al., 2022; United Nations, 2024a).

Africa's wetlands occupy 4.7% of the total sub-Saharan continental landmass (approximately 228 million hectares), a proportion which increases to about 6% with the inclusion of rivers, lakes, and reservoirs (Rebelo et al., 2010). Floodplains and freshwater marshes are the most prolific type of wetland in SSA, occupying roughly 69 million hectares (Rebelo et al., 2010). Large wetlands account for 207 million hectares (90%) while the remaining proportion comprises smaller wetlands such as riverine floodplains, seasonal salt pans, and artificial wetlands including dams, pits, reservoirs, wastewater treatment catchments, and canals (Mitchell, 2013; Ramsar Convention on Wetlands, 2016).

The Geography of Africa's Natural Wetlands

The Ramsar Convention classifies wetlands into five major types. Marine wetlands comprise coastal wetlands such as lagoons, coral reefs, and rocky shores. Estuarine wetlands comprise deltas and mangrove swamps. Lacustrine wetlands are those associated with lakes, while riverine wetlands occur along rivers and streams, and palustrine wetlands encompass marshes, bogs, and swamps. Ramsar further adopts the Ramsar Classification of Wetland Type which lists 42 distinct wetland types. In total, Ramsar lists 425 wetlands in Africa with a land coverage of 111 million hectares (see Figure 1). Of these, 367 are inland wetlands while 148 are marine or coastal wetlands. Between the two categories, there are 140 human-made wetlands, accounting for roughly 33% of all Ramsar sites.

Most of the world's wetlands are in Africa with the largest including the Okavango Delta, the basins of Lake Chad and Lake Victoria, the Sudd on River Nile, and the deltas in the Congo, Niger, and Zambezi rivers (Schuijt, 2000). Eastern Africa has an expansive reservoir of waterbodies nestled within the Rift Valley. Wetlands of the great lakes—Tanganyika, Edward, Albert, and Kivu—have steeply inclined fault lines which restrict them to the littoral zones of these lakes (Denny, 1993). Kigezi in southeastern Uganda is also home to a series of valley lacustrine wetlands such as along Lake Bunyonyi, Lake Mullehe, and Lake Mutanda.

Further, along Africa's coastlines thrives a combination of saline and brackish wetlands, including the Eastern African mangrove forests extending from Kismayu to Maputo, and the West African coastline stretching from Angola to Mauritania. North-West Africa comprises inland oases, such as wadis and chotts, and lagoons such as Sidi Moussa and the Oualidia lagoon in Morocco. Southern Africa is home to the great Limpopo River floodplain, the Mkuze River system, the Nyl River floodplain, the pans at Lake Chrissie and west of the Orange Free State, and coastal wetlands like the Lake Sibaya floodplain and the St. Lucia wetlands (Denny, 1993).

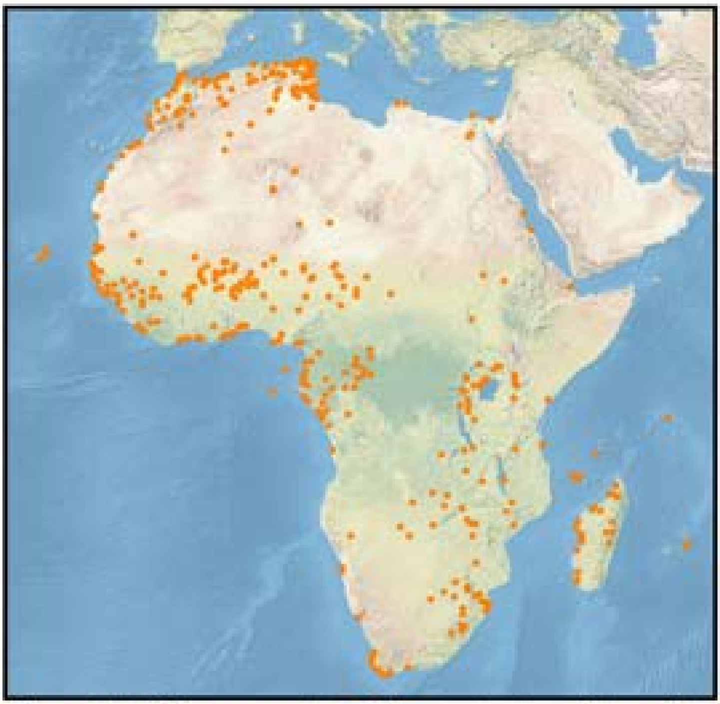


Figure 1. Ramsar sites in Africa are concentrated in three main regions – Northern Africa, West Africa, and East/Southern Africa. Image Credit: Ramsar Sites Information Service.

Why Should Anyone Care About Wetlands?

The African continent experiences arid and semi-arid climatic conditions which render freshwater bodies a rarity (Schuyt, 2005). Africa is one of two remaining regions, alongside Central and Southern Asia, which continue to experience water shortage (United Nations, 2024b). While Africa may boast an abundance of freshwater riverine and lacustrine reservoirs, these are unevenly dispersed across the continent's geophysical expanses (Papa et al., 2023). Presently, 13 African states, close to a quarter of the continent's constituents, are critically water insecure (Ighobor, 2023). This means they are either water stressed, with per-capita access of less than 1,700 cubic meters of freshwater annually, or water-scarce with an annual per-capita access of less than 1,000 cubic meters of water (United Nations, n.d.). An extra 20% of African states are expected to enter the water stress/scarcity bracket before 2030 (Schuijt, 2000). Faced with these incredible odds, a significant proportion of Africa's inhabitants has resorted to partial or full dependence on wetlands as a source of freshwater and micronutrients for sustenance and productivity. Therefore, sustainably managing wetlands is critical toward the long-term economic welfare, safety, and sustenance of many African communities.

Despite the undeniable economic and physical value of wetlands, they remain some of the most underexplored ecosystems in Africa. Similarly, existing wetlands are undergoing potentially severe modifications and reclamation. Besides wetland resource overexploitation, upstream wetland modification and development affects the volume, speed, and quality of the water feeding these wetlands (Schuyt, 2005). One important factor contributing to upstream disruptions is limited knowledge among authorities and policymakers regarding the potential ecosystemic value of wetlands. Therefore, these ecosystems suffer a deficiency of conservation efforts since their degradation is not considered a pressing issue.

Authorities have repeatedly made the error of assuming that wetlands have little to no perceived value in comparison with other farmland and hydrologic ecosystems. Other ecologies that directly support human activity are held in higher regard than wetlands due to their less immediate yield value and delayed economic benefits (Schuyt, 2005). As such, policymakers will often forego the alternative of wetland protection in favor of wetland reclamation for more tangible and immediate use. Wetlands thus end up getting drained and altered in preparation for agricultural activities and activities such as hydroelectricity generation (Schuyt, 2005). Decision- makers often perceive these opportunity costs to exceed the benefits of sustainable wetland management.

Natural Wetland Degradation and the Need for Constructed Wetlands

In recent years, a troubling trend has emerged: more wetlands have been deteriorating than have undergone improvement, with the worst affected wetlands, both globally and within the Ramsar List, being in Africa, Latin America, and the Caribbean (Convention on Wetlands, 2021). Wetlands have quickly become the most threatened ecosystem, posting a disappearance rate that is thrice as high as global deforestation (Convention on Wetlands, 2021). Even more shocking is the fact that wetlands have deteriorated by about 87% since the 1700s (Davidson, 2014). About 35% of this loss occurred between 1970 and 2015, while approximately 50% of the deterioration occurred after 1900 (Xu et al., 2019). This disturbing deterioration in the ecological character of global wetlands has posed a direct threat to the livelihood of four billion dependents who rely on the $47.4 trillion-per-year ecosystemic value created by wetland services (Convention on Wetlands, 2021).

Evolving trends in land use since 1970 have had the largest contribution to degradation across inland wetlands in Africa. Many African wetlands face the threat of economic and financial pressure, fueled by a growing demographic of dependents, shifting dynamics in land interests between private and public actors, increasing poverty levels, and worsening economic times amid the onslaught of droughts in the continent (Mandishona & Knight, 2022). At the root of these problems is the disparity in stakeholder interests in laying claims on wetland utilization. Such conflicts of interest will often result in a struggle of contrary opinions with stakeholders using policy-driven incentives as ammunition. These conflicts also result in wetland protection disincentives whereby stakeholders interested in wetland reclamation overshadow any calls to action for conservation. Other factors of degradation include urbanization and urban encroachment, pollution, species invasion, and water flow diversion (Mandishona & Knight, 2022).

Unfortunately, wetland degradation is virtually irreversible due to the sensitive nature of these ecosystems—protecting and conserving the ecological character of Africa's wetlands has thus been a key objective for conservation efforts in Africa (Sinthumule, 2021). The highest priority in wetland management and conservation efforts in Africa is to facilitate clean water provision in water-scarce countries. Green technology has been used to treat wastewater prior to reusing it or releasing it into the natural ecosystem. Perhaps the most prolific yet cost-effective green technology is an artificial or constructed wetland (CW). A CW refers to a shallow trough containing filter material like gravel, with vegetation that perseveres saturated conditions planted atop, and with wastewater flowing across the surface or within the substrate metered by a depth control assemblage (UN-HABITAT, 2008). An artificial wetland is a biological treatment system since it relies on rhizospheric soil processes and microbial activity to purify wastewater (Kappelmeyer & Aylward, 2018).

African countries with arid climates use CWs to treat wastewater and offset water stress. For instance, Algeria is the most affected North African country in terms of climatic conditions and water stress. Drastic climate change and a high population growth have aggravated the water scarcity situation. Freshwater supply is currently at 600 cubic meters per capita which borders on absolute scarcity (Bouchama, 2022; United Nations, n.d.). These statistics categorize Algeria as water-resource poor—several factors can explain this situation. First, Algeria receives a mere 200-400 mm of rainfall per annum worsened by the effects of climate change. In the Saharan region of North Africa, rainfall typically drops below 100 mm p.a. Of the 2.4 million square kilometres, over 80% of Algeria's landmass is desert land (Bouchama, 2022). The harsh arid and semi-arid conditions render Algeria highly vulnerable and prone to desertification.

Second is increased water demand due to a large inhabitant population, which has grown by a factor of four over the last 40 years. For instance, there were 43.9 million people in Algeria in January 2020, up from 41.3 million in 2017 (Office Nationale des Statistique, 2019, as cited in Bouchama, 2022). The third reason is that most dams supplying water across the country have lost their capacity due to poor maintenance. Fourth, increased industrial activity increases the release of untreated effluents which pollute surface and underground water and cause salination (Hamlat & Guidoum, 2018). Finally, Algeria is yet to widely adopt non-conventional water treatment methods for wastewater purification and desalinization (Bouchama, 2022).

Given the plethora of challenges triggering the high demand for water balance, countries like Algeria continue to espouse non-conventional water treatment methods, including desalination and wastewater reuse. Over the last few decades, countries have erected large- and small-scale systems to mimic natural hydrological processes for improved water quality. Key among these systems have been CWs which have gained considerable popularity in Africa. Wastewater reclamation using CWs has become widespread due to their low-cost, simplified design, and versatility. The preferential use of a CW over a natural wetland system is rooted in the fact that CWs offer a higher degree of control and contribute to the protection of natural wetlands.

The Working Mechanism of a Constructed Wetland

In a CW, specialized fauna, called helophytes, interact complexly with microbes within a filter matrix such as soil or gravel. Wastewater is then passed through this system and is decontaminated through processes such as precipitation, sedimentation, adsorption onto the matrix surface, microbial alterations, and root uptake by plants (Kappelmeyer & Aylward, 2018). As wastewater percolates through the wetland substrate, permanent localized transformations occur and activate contaminant degradation. The quality of wastewater treatment relies on factors such as level of contamination, light intensity, and climatic parameters. CWs provide a wastewater filtration system that handles inflow from different zones including domestic sewage, agricultural wastewater, stormwater runoff, and industrial leachate. CWs can either have a floating plant mat setup or matrix-based setup, completely submerged or with only the roots submerged while the leaves float over, with free surface flow (FSF), horizontal flow (HF) or vertical flow (VF) root system, and with surface or sub-surface flow (Kappelmeyer & Aylward, 2018).

A submerged CW is one where plants grow entirely under the water surface allowing stems and leaves to provide extra surface area for the biofilm. However, water can sometimes block out sunlight penetration which slows down photosynthetic activity. Therefore, surface water must have a shallow depth and be as clear as possible. Since submerged systems are rarely used, a rooted plant setup with either horizontal flow (HF) or vertical flow (VF) is more common. When water inflow sits over the supporting matrix surface, this is a surface flow constructed wetland (SF). However, when it is below the topmost layer of the supporting matrix surface, it is a sub-surface flow (SSF) setup. Hybrid setups combine two or more types of CWs, connected in series or parallel configurations to optimize the treatment capabilities of a system. For instance, for better wastewater denitrification, a combination of a single-stage horizontal SSF CW and a VF would be ideal.

Constructed Wetlands in Africa

This section will compile existing literature on the most important CWs in the four main subregions of SSA: Northern Africa, East Africa, West Africa and the Sahel Region, and Southern Africa. There will also be a brief description of important CWs in Central/South Asia, which is the only other water-stressed region besides Africa.

Northern Africa

The Tidili Mesfioua Hybrid Constructed Wetland

The Tidili Mesfioua HCW is a full-scale CW in Marrakesh, Morocco. Built in 2014, the CW combines a VF-CW and a HSSF-CW to treat the wastewater collected from 1,844 inhabitants (Mandi et al., 2022). The first stage in this two-stage system comprises three VSSF-CWs in parallel configuration, while the second stage comprised two smaller HSSF-CWs also in parallel (see Figure 2) (Hdidou et al., 2021). One of the VSSF-CWs is photographed in Figure 3.

Funding for this project was a collaborative effort between the U.S. Agency for International Development (USAID) and other stakeholders. The Tidili Mesfioua HCW was the first CW in Morocco to operate under the management of Tissilte Association for Development (ATD), a rural local NGO, in close collaboration with Cadi Ayyad University (Mandi et al., 2022). The removal efficiency rates for this CW average approximately 91.4% for chemical oxygen demand (COD), 93.47% for biological oxygen demand (BOD5), and 94.83% for total suspended solids (TSS) (Hdidou et al., 2021). The treated wastewater from the Tidili Mesfioua HCW complies with Moroccan and WHO standards for irrigation water quality.

Figure 2. The two-stage CW configuration comprises three VSSF-CWs in parallel in the first stage and two HSSF-CWs in the second stage. Photo Credit: El Fanssi et al., 2019, http://www.geoecotrop.be/

Figure 3. One of three VSSF-CWs constituting the first stage of the Tidili Mesfioua HCW. Screenshot Credit: YouTube, https://www.youtube.com/watch?v=a3xVM7VdoWk

The Asselda CW

The Asselda CW was established in 2015 to treat domestic wastewater from 1,260 inhabitants in Asselda village, Al-Haouz, Morocco. The project was funded by the Drosos Foundation (Zurich) in collaboration with Association Marocaine de Solidarité et de Développement (AMSED), the Asselda village NGO, and local stakeholders. The CW contains a self-priming siphon which feeds into three VF-CWs configured in parallel, vegetated using Phragmites australis, and a subsequent maturation pond (see Figures 4 and 5). The project recorded a high removal performance of 93% for TSS, 96% for BOD5, and 88% for COD with a moderate efficiency of 55% for total nitrogen (TN) removal and 55% for total phosphorus (TP) removal.

Figures 4. An aerial view of the Asselda CW. Photo Credit: Engeli, 2016, https://www.eawag.ch/en/info/portal/news/news-archive/archive-detail/bouziane-outiti-wins-energy-globe-award-for-wastewater-treatment-project/

Figures 5. One of the three VF-CWs in the Asselda CW. Photo Credit: Mandi et al., 2022, https://doi.org/10.1007/978-3-031-03600-2_1

Brézina CW

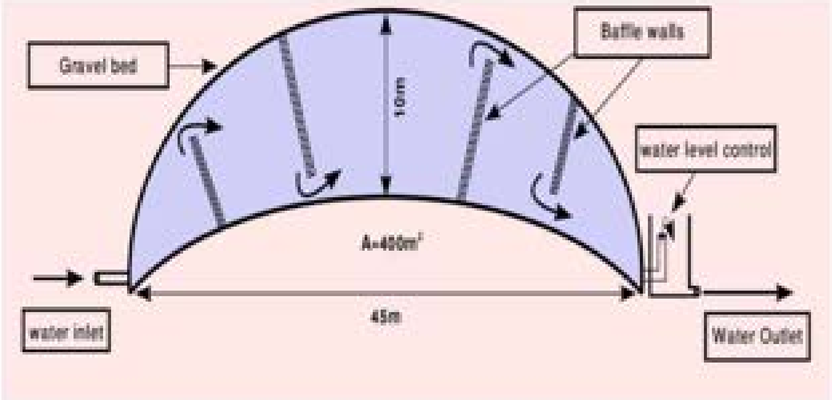
The objective of this artificial wetland is to extend preexisting wastewater treatment capacity by the natural system at the Brézina Oasis, located south of El Bayadh, Algeria (Bouchama, 2022). The project also aims at producing higher quality wastewater through the phytoremediation model which results in oasis recovery and protection. The Brézina CW project was funded by the Food and Agriculture Organization (FAO) of the United Nations (FAO, n.d.). The Brézina CW is a hybrid system combining a HSSF-CW and FSF-CW in parallel, vegetated with a mix of drought resistant and anaerobic plant species (see Figure 6). The removal efficiency for TSS and BOD5 is 82-91% and 67-84%, respectively, while total calcium (TC) and TP reduce by 99% and 80% respectively (Bouchama, 2022).

Figure 6. A wide-angle view of the hybrid system in the Brézina CW configured in parallel. Photo Credit: Bouchama, 2022, https://doi.org/10.1007/978-3-031-03600-2_2

The Temacine CW

The Temacine CW is built near the small town of Temacine, south of Touggourt city, Algeria. It was co-funded by the Algerian Government through the Ministry of Water Resources (MRE), under the Department of Sanitation and Environmental Protection (DAPE) and Temacine town. The project received support from the Belgian Technical Cooperation who facilitated research and training for the project (Nelson et al., 2008). Temacine CW treats effluent from the rural and urban localities of the Ksar Temacine village. The project adopts a two-stage crescent-shaped HSSF-CW design vegetated with palm fiber along with 23 other aridity-resistant plant species (see Figures 7 and 8). The CW can treat 15 to 22 cubic meters of wastewater per day which converts to effluent from 100 to 150 people consuming about 150 liters of water a day. The project's removal efficiency for TSS is 70-90%, COD is 80-91%, BOD5 is 75% to 96%, TP between 51% and 98%, and TN between 94 to 99%.

Figures 7. Side view showing one tip of the Temacine CW. Photo Credit: Bekkari, et al., 2022, https://doi.org/10.2166/wst.2022.242



Figures 8. An illustration of the design and working principle of the Temacine CW. Photo Credit: Bekkari, et al., 2022, https://doi.org/10.2166/wst.2022.242

The Kef el Doukhan Wastewater Stabilization System

The Algerian government funded the Mzab wastewater treatment plant as a natural lagoon treatment project designed for environmental preservation and safeguarding water resources in El Atteuf, Algeria. The natural lagoon sits on an area of 79 hectares and is designed to treat wastewater in a three-stage process followed by sludge dewatering during drying (see Figure 9). The treated water is then reused for irrigation.

Figure 9. Aerial view of the Mzab wastewater stabilization system. Photo Credit: Bouchama, 2022, https://doi.org/10.1007/978-3-031-03600-2_2

The Gravel Bed Hydroponics (GBH) CW in Ismailia

The GBH system in Egypt was established to treats sewage water through a GBH CW in the remote village of Abu-Attwa in Ismailia It is jointly overseen by the Suez Canal University and Portsmouth University (El-Serehy et al., 2014). Before the construction of this CW, wastewater from this village was discharged into Temsah Lake contaminating the aquatic ecosystem and resulting in a putrid smell. The GBH CW is a two-stage system configured in series and with six parallel channels within each stage (see Figure 10). The removal rate for BOD5, TSS, and NH4-N ranged between 70.3% and 93.2% (Abdel-Shafy et al., 2022).

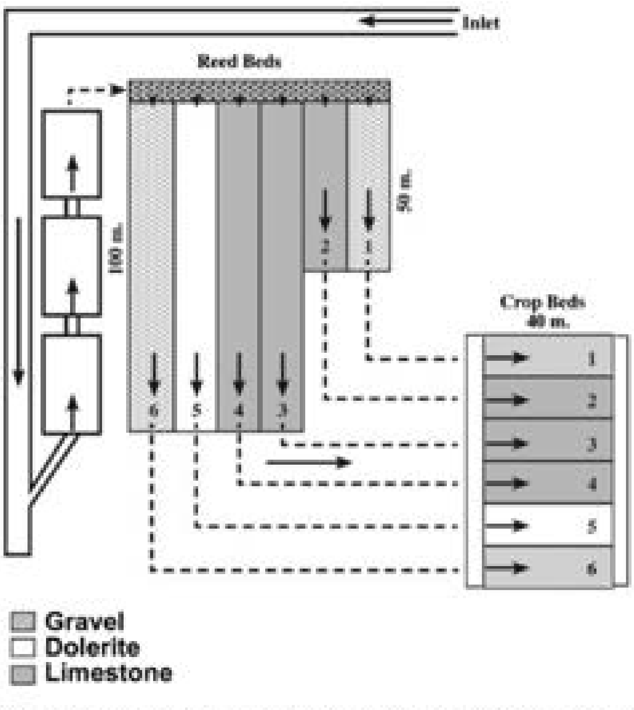


Figure 10. Structure of the GBH system in Abu-Attwa showing reed beds and crop beds in series. Photo Credit: El-Serehy et al., 2014, https://doi.org/10.1016/j.sjbs.2013.11.003

Decentralized GBH CW in Sinai

Similar to the GBH in Ismailia, the CW in the Sinai Peninsula, Egypt, was designed to serve a large village and its environs. Further, the Sinai wastewater system has six receiving basins with valves—each basin splits to form two GBHW channels. In total, the CW has 12 GBH channels. The channels have equal width and are elongated (100 meters) to increase substrate area (see Figure 11).

Figure 11. channels in the GBH CW at Sinai. Photo Credit: Abdel-Shafy et al., 2022, https://doi.org/10.1007/978-3-031-03600-2_5

The Sekem School Wastewater Treatment Program

The SEKEM CW, funded by the Sekem farm, performs wastewater treatment for reuse in fertigating agroforestry plots. The project is in the Bilbeis area, northeast of Cairo, Egypt. The objective of the project is to combine European and Egyptian agricultural practices to manage wastewater and reuse it for timber irrigation (ElZein et al., 2016). The wastewater is 100% domestic and emanates from a population of 500 students, 100 office personnel, and some residents, at 20 liters per person daily—the total discharge is about 15 cubic meters per day. The SEKEM project features an HF-CW built in 2007 occupying about 200 square meters. Filtered effluents are reused on timber plantations for product packaging.

Lake Manzala CW Project

Construction of the Lake Manzala CW began in January 2001—it was an area of 100 hectares southwest of Port Said City in Egypt. The project was co-funded by the Global Environmental Facility (GEF), the United Nations Development Program (UNDP), and the Egyptian Environmental Affairs Agency (EEAA). The rated design capacity for the CW was 25,000 to 50,000 cubic meters of wastewater per day supplied through the Bahr-El-Baqar drain. The goal of the project was to improve the quality of water in Lake Manzala (see Figure 12).

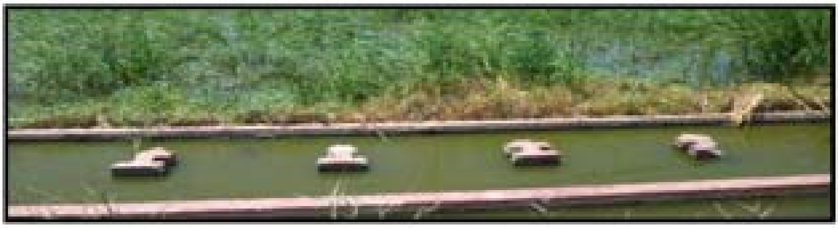


Figure 12. Treated water from the Lake Manzala CW. Photo Credit: Haroon, 2022, https://doi.org/10.1016/j.ejar.2022.02.002

The Lake Manzala CW has resulted in numerous benefits. Environmentally, it treats 25,000 cubic meters daily to help regenerate and sustain the lacustrine ecosystem, prevents lacustrine pollution, and promotes crop/fish farming. Socially, the CW has provided job opportunities to locals, facilitated workshops and training forums for raising awareness, and has led to the establishment of a dedicated research center for CW technology development in Egypt spearheaded by the National Water Research Center. Economically, the project has contributed to annual cost savings of over $700,000 in water treatment, has increased agricultural productivity, increased fishing activity, and produced biofuels (Haroon, 2022).

East Africa

The Chemelil CW

This CW was built for the management and treatment of industrial wastewater discharged from the Chemelil Sugar Company, located near the banks of a tributary pouring into the Nyando River in Kenya (Oketch, 2006). The BOD5 effluent discharge rate at the Chemelil Sugar Factory is around 2000 kg per day, the highest of any industry in the vicinity. The CW, configured in HSSF format, was built to enhance the efficiency of the 12 preexisting oxidation ponds. The CW was funded by Chemelil Sugar Company Limited.

The Mombasa CW

Constructed in 2007, the Mombasa housing estate CW was the final push toward redeeming the estate sewer system from the poorly functioning sewage soak pits and infiltration ponds. GreenWater stepped in to rehabilitate the system in compliance with the National Environment Management Authority (NEMA) discharge-to-environment standards (den Haring, 2022). For this project, GreenWater reports a waste removal efficiency of 86% for BOD5, 96% for COD, and 94% for TSS (den Haring, 2022). Funding and oversight for the project was a collaborative effort of the former municipal council, now under the County Government of Mombasa, the Water Resource Authority (WRA), Mombasa Water Supply and Sanitation Company (MOWASSCO), and NEMA.

Figure 13 is a schematic representation of the Mombasa CW illustrating the layout of flow beds, biofilter beds, and water ponds across the 10,000 square-meter residential area. The CW is in service of about 2,633 people living within the Mombasa municipality. About 80% of the water consumed by this population (about 210 of the 263 cubic meters of water supplied per day) becomes wastewater. The Mombasa CW has a hydraulic retention time of about 6.8 days. GreenWater inspects the treated water samples at three-month intervals as specified by NEMA. The sampling location is the last outlet, after which the treated water is reinjected into the seasonal watercourse (see Figure 13).

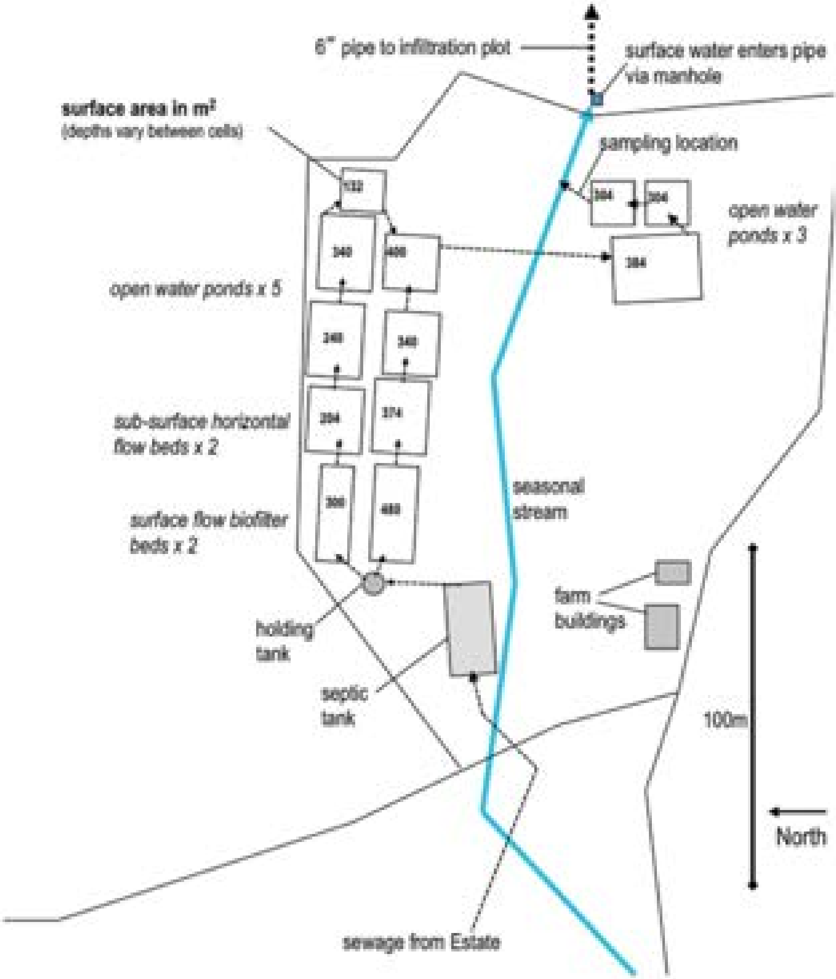


Figure 13. Aerial schematic of the Mombasa CW. Image Credit: den Haring, 2022, https://doi.org/10.1007/978-3-031-03600-2_8

The Kingfisher CW

As one of the biggest and oldest CWs in Kenya, the Kingfisher CW is arguably among the most important artificial wetlands in the country, serving as a conservational resource for Lake Naivasha. Homegrown Kenya Ltd., one of the largest growers of fresh cut roses worldwide, funded and retains ownership of this CW. The study by Kimani et al. (2012) showed that the Kingfisher CW was highly efficient at wastewater treatment and could ameliorate localized pollution sources that may affect Lake Naivasha. The CW also substantively prevents wastewater surface runoff, excessive water abstraction, and controlling invasive wetland species (Kimani et al., 2012).

The Mulji Devraj CW

This CW, situated in Kiembeni Estate, Mombasa, Kenya, treats wastewater for current and emerging housing projects in three locations around Kiembeni Estate (see Figure 14). The Mulji Devraj project combines oxidation ponds of 2,200 person-equivalent (PE), a wetland system of 2,600 PE, and designing waste stabilisation ponds of 10,000 PE. This project was done by GreenWater and funded by the Mulji Devraj Builders and Brothers company.

Figure 14. The Mulji Devraj CW in Mombasa. Photo Credit. GreenWater, https://www.green-water.org/clients/

The Kivukoni School CW

This wastewater treatment and recycling project in Kilifi County, Kenya, comprises of a CW built by GreenWater and funded by Kivukoni School. The project was implemented as part of the school's mission to build an entirely off grid solar-powered ecosystem comprising a wastewater treatment CW and an outdoor learning environment (see Figure 15). The completion of this project certified Kivukoni School as an Eco School.

Figure 15. The Kivukoni School CW in Kilifi County. Photo Credit. GreenWater, https://www.green-water.org/clients/

The Rijk Zwaan Q-Sem Seed Farm CW

GreenWater erected the Q-Sem CW in Arusha, Tanzania, to allow for the treatment of agricultural effluent for recycling. The combined CW and biofiltration system can clean about 60m^3 of wastewater per day with plans to expand this capacity to 150m^3 per day (see Figure 16). The project was funded by RZ Q-Sem Ltd., the Tanzanian branch of Dutch company Rijk Zwaan.

Figure 16. The Q-Sem Seed Farms CW with black linings laid out to prevent wastewater leakage into surrounding ground areas. Photo Credit: GreenWater, https://www.green-water.org/clients/

The Tambuzi Flower Farm CW

The Tambuzi CW in Nanyuki, Kenya, was spearheaded to treat packhouse/laundry effluents from the flower farm and utilize the treated discharge for recycling purposes. The CW comprises of a reed bed and biofiltration system with a treatment capacity of up to 50 cubic meters per day. The CW combines papyrus and water hyacinth reed beds with water ponds (see Figure 17). The flower farm currently treats 50% of its grey water and reuses it for irrigation (Tambuzi, n.d.).

Figure 17. The Tambuzi Flower Farm CW with papyrus and water hyacinth reed beds. Photo Credit: GreenWater, https://www.green-water.org/clients/

The IMCoW Project

The IMCoW Project—Improving Mtwapa Creek water quality by use of Constructed Wetland Technology—is a restorative project co-funded by the Kenya Marine and Fisheries Research Institute (KMFRI) and the Kenya Prison Service (KPS) for the Shimo La Tewa Prison (SLTP) sanitation system in Mombasa County, Kenya. Contributing partners for this project are SLTP, GreenWater, and NEMA. The objective of this CW is to improve the conservation outcomes of marine resources at Mtwapa Creek by reducing the effect of land pollutants emanating from SLTP and optimizing the operational effectiveness of the prison's CW in treating wastewater. The specific objectives of the IMCoW Project are to rehabilitate and improve the state of the preexisting SLTP CW (see Figure 18), improve sanitation at this correctional facility, and increase food security by using treated water for crop/fish farming.

Figure 18. An aerial map of SLTP and the location of each component in the prison's wastewater discharge system. Photo Credit: UNEP & Nairobi Convention, 2019, https://nairobiconvention.org/clearinghouse/node/395

The newly rehabilitated CW has an expanded capacity that handles the prison's daily wastewater discharge of between 300 and 400 cubic meters. The CW consists of two HF-CWs configured in parallel which discharge the treated water into an elevated irrigation tank (see Figure 19).

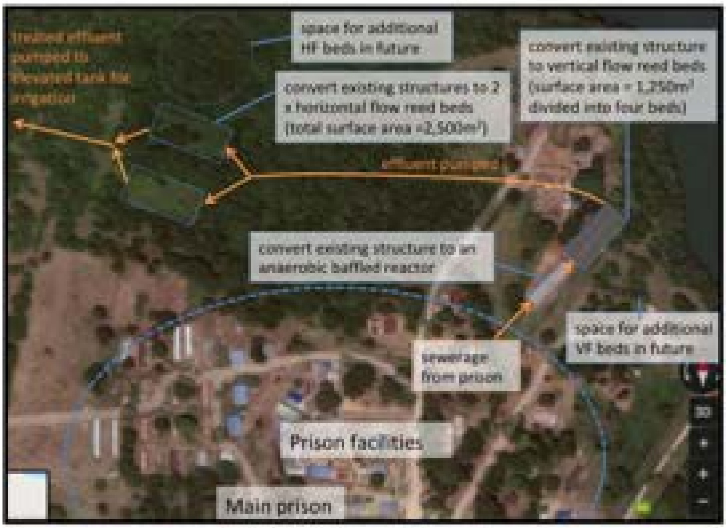


Figure 19. An aerial map of the current layout incorporating the CW and the location of the HF-CW beds. Photo Credit: UNEP & Nairobi Convention, 2019, https://nairobiconvention.org/clearinghouse/node/395

The project continues to contribute extensively to the ecosystemic welfare of Mtwapa Creek as it replaces the previously dysfunctional septic system which resulted in contamination at Mtwapa Creek and in the Indian Ocean. The wastewater posed a public health hazard, destabilized the local marine ecosystem, and compromised tourism hotspots such as coral reefs and marine parks (Okeyo, 2024). The CW's removal efficiency for TSS is an impressive 99.74%. The success of the IMCoW Project is a leap forward not only in improving ecosystemic sustainability but also by empowering local communities through a safe environment.

The Sher CWs

Sher Ethiopia PLC, the owner of the world's biggest rose nursery, funded four CWs with the objective of obtaining as much uncontaminated water through treatment as possible, and to make it dischargeable into Ziway Lake without any ecological ramifications. The project was in partnership with ECOFYT, Koppert, Wageningen University, and IDH, and was designed by the Dutch institution Wageningen University and Research Centre. Occupying a land area of 180 square meters, the CWs adopted a hybrid design comprising of a first-stage HF-CW and a second- stage VF-CW (see Figure 20).

Figure 20. CW with water ponds. Photo Credit: van Dien, 2022, https://doi.org/10.1007/978-3-031-03600-2_7

The University of Dar es Salaam CW

Before the year 2000, there were no wastewater treatment CWs in Tanzania. As such, when the University of Dar es Salaam (UDSM) commissioned a hybrid system to manage and reuse its wastewater, this was an important steppingstone for CW utilization in the country. The system combined SSF-CW and waste stabilization ponds for a removal efficiency of 80% for TSS, 66% for COD, 91% for fecal conforms (FC), and 90% for total coliforms (TC) (see Figure 21). The UDSM project proves that CWs, if well designed, managed, and operated, can have efficient outcomes and be an economical channel for improving the quality of treated wastewater to acceptable reusage standards.

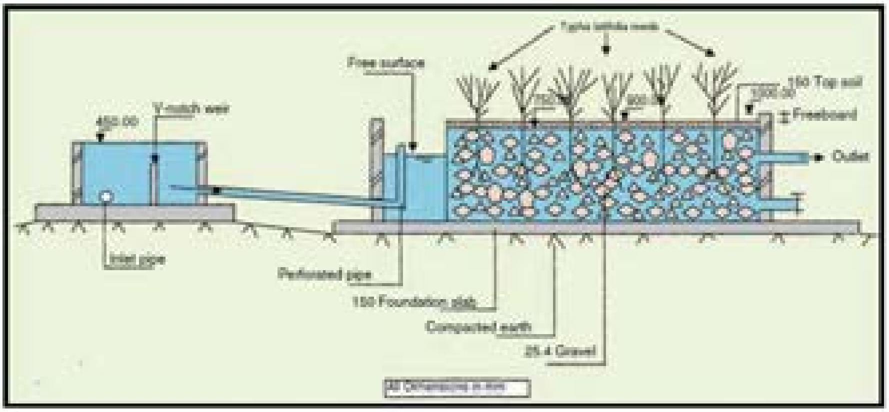


Figure 21. Schematic showing SSF-CW arrangement for the UDSM CW.

The Jinja Kirinya Sewage Treatment Plant

The Kirinya West natural wetland located in Jinja, Uganda was earmarked to receive treated water from the Jinja Kirinya Sewage Treatment Plant which is funded, owned, and operated by the National Water and Sewerage Corporation. The 320 square-meter HF-CW processes anaerobic effluent from the Jinja Kirinya Sewage Treatment Plant through eight compartments vegetated with Cyperus papyrus. The CW has resulted in water quality improvement with a removal efficiency between 61% and 98% for phosphoric and ammoniacal FC and between 80% and 98% for nitrogenous FC.

West Africa

In a recent paper by Compaoré et al. (2023), reports about the scarcity of research on artificial wastewater treatment across SSA, especially in the Sahel region, presents a challenge in investigating the benefits of CWs. Literature about CW performance in wastewater filtering among West African countries is scarce; in fact, for countries like Senegal, CW projects beyond pilot plant tests are nonexistent (Compaoré et al. 2023; Torrens et al., 2020). Therefore, this study will only cover relatively recent research on CW projects in Nigeria.

The UNILAG CW

The University of Lagos (UNILAG) funded and commissioned a CW to treat wastewater from the institution. The system contains a primary treatment inception chamber which screens off solid effluents before the wastewater is channeled into the CW. The CW contains six SF cells, each measuring 8 by 7 meters, and with the first entrapment vegetated with hyacinth. The remaining five contain gravel and ocean sharp sand as substrates vegetated with common cattail (Typha latifolia). The UNILAG CW has recorded removal efficiencies of between 76.53% and 92.86% for BOD5 and TC and thus highly efficient at treating sewage (Mustapha et al., 2015).

The Kaduna CW

Similarly, the Kaduna Refining and Petrochemical Company (Nigeria) commissioned a secondary wastewater treatment system was containing six VSSF-CWs vegetated with Cyperus alternifolius and Cynodon dactylon species to treat factory effluents. The CW recorded high removal rates ranging between 43% and 85% for TDS, BOD, COD, turbidity, ammonium, and phosphate removal using C. alternifolius, while a range of between 42% and 82% was reported for the C. dactylon species. The Kaduna CW demonstrates the effectiveness of the two plant species in treating wastewater.

Southern Africa

Botswana

Some significant CWs in Botswana include the Thuso Rehabilitation Center CW built in 1994 in Maun, the Kanye Prison CW built in 1997, the Mokolodi Nature Reserve CW, the Ramatea Vocational Training School wastewater treatment CW, and the Tonota College of Education CW. Ganesan (2001) noted that removal efficiency figures from these CWs showed "very good [results demonstrating] high efficiency." (p. A2-7). The findings reported reductions in FC and high-efficiency BOD5 (between 72% and 99%) and COD (between 61% to 99%) reductions. Removal efficiency for TN and TP averaged almost 100% with other substances like nitrate, magnesium, and iron showing minimal presence in the treated water (Ganesan, 2001).

South Africa

Among all countries in SSA, South Africa has perhaps the most comprehensive documentation of older and newer CWs. The most important CWs in the country are the Kruger National Park and Pilansburg Game Reserve, Karbochem Newcastle, the Oil Industry Wetlands, the Atlantis Groundwater Recharge Wetland, and the Sandton Urban Wetlands.

Kruger National Park

The Kruger National Park funded a CW that uses an HSF configuration to treat wastewater discharged from reserve camps, including larger camps, like Skukuza and Lethaba, which have a capacity of 3,000 people. Effluent from larger camps is treated using oxidation ponds, while smaller residential areas like Shingwedzi leverage septic tanks. Like the CW at Kruger, Pilansburg Game Reserve also funded and commissioned an HSF-CW at Bakgatla Gate to treat effluent for their 300-person reserve camp.

Industrial CWs: Karbochem Newcastle and Oil Industry Wetlands

The Karbochem Newcastle CW commissioned and funded by KarboChem (KC) Energy, is a six- channel system capable of processing up to 6,000 cubic meters of wastewater and sewage discharged from the Karbochem industrial facility. The CW receives effluent that has undergone sedimentation, oil capture, and activated sludge treatment. Similarly, two CWs were constructed oil depots at the oil depots in Pretoria and Secunda. They were designed in a VSF configuration vegetated with Typha plant genus. The surface loading rate for wastewater in both CWs is 700 and 400 liters per square meter per week.

Atlantis Groundwater Recharge Wetland (AGRW)

The AGRW is perhaps one of the largest CWs in South Africa with a capacity of up to 44,000 cubic meters of effluent treatment per day. It was funded by Atlantis Water Resource Management Scheme (AWRMS) in conjunction with the European Commission. It has an active substrate capacity of 3,000 square meters capable of processing 2,000 cubic meters of sewage every day and has a groundwater infiltration rate of up to 4,000 cubic meters daily.

The Sandton CW

The Sandton CW treats wastewater discharged from the Sandton upmarket area in Gauteng. This CW targets the Sandspruit catchment, one of the tributaries in the Berg River basin, which experiences increasing storm conditions. The vegetation and substrate in the CW reduce the velocity of the flood water and protect the Sandspruit catchment from flooding.

CW Projects in Water-Stressed Countries Outside Africa

Pakistan, Central Asia

Pakistan's warm climate is suitable for CW use in wastewater remediation since high temperatures promote CW performance (Paing et al., 2015). At the domestic level, two CW projects draw interest. The CW commissioned by NED University of Engineering & Technology (NEDUET) to treat wastewater adopted an HSF-CW design which conferred the benefit of preventing clogging (see Figure 22). While the average BOD5 and COD reduction was around 50%, much of this underperformance has been attributed to intermittent power outage in the area. Still, CW performance proved the system's buffer capacity and endurance to organic shock loads.

Figure 22. Elongated papyrus vegetation atop the NEDUET CW. Photo Credit: Mustafa & Afzal, 2022, https://doi.org/10.1007/978-3-031-03600-2_13

The second project was commissioned at Manora Island, in Karachi with the goal of erecting a HSSF-CW system for treating 120 cubic meters of sewage per day. Manora Island, being completely detached from the mainland, had come under constant threat of freshwater scarcity resulting in overreliance on vehicle-supplied water. The natural scenery in the island's environs had also been degrading due to pollution (IUCN, 2017). The artificial wetland was commissioned by the Pakistan Navy and funded by the International Union for Conservation of Nature and Natural Resources (IUCN) to restore ecological balance at the island.

Treated water from the Manora Island CW has been reused in sports turf irrigation, green belt sustenance, and tree planting at the island. The CW comprises three separate beds covering 325 square meters and vegetated using the Canna indica plant species, commonly called Indian shot (see Figures 23 and 24).

The Canna indica species has shown promising results in the extraction of organic pollutants, heavy metals, and emerging pollutants such as pesticides from aquatic environments (Karungamye, 2022).

Figure 23 (left) shows the Indian shot at its budding stages in the three-bed CW system. Figure 24 shows the plant species populating a bed of substrate in the CW. Photos Credit: Mustafa & Afzal, 2022, https://doi.org/10.1007/978-3-031-03600-2_13

At the industrial level, Toyota commissioned hybrid floating CWs at two of their carwash centers in Faisalabad — the goal was to treat and reuse the wastewater used in these centers. Elsewhere, another VF-CW was commissioned by a textile factory still in Faisalabad, vegetated with Brachiaria mutica plant species and inoculated with dye-metabolizing bacteria to remediate dyed wastewater (see Figure 25). The combination of VF-CWs and bacteria use has been effective at extracting dye from the wastewater. Similarly, bleached wastewater from this factory is inoculated with bacteria and flushed through HF-CWs vegetated with L. fusca. The CWs eliminate both organic and inorganic pollutants to a maximum removal efficiency of 86% for COD and 78% BOD5.

Figure 25. Floating CWs with bacterial inoculants to decompose dye-rich wastewater. Photos Credit: Mustafa & Afzal, 2022, https://doi.org/10.1007/978-3-031-03600-2_13

Thailand, Southeast Asia

The Royal Laem Phak Bia Environmental Research and Development Project was commissioned by King Bhumiphol of Thailand and funded by his government to remediate the mangrove forest along the Bangkok-Phetchaburi beach in Phetchaburi Province (Jitthaisong et al., 2012). The goal was to construct a mangrove CW to treat Phetchaburi Municipal wastewater and use this to restore the ecological balance of the deteriorating mangrove forest (see Figure 26). The hybrid system measured 100 by 150 meters, divided into four strips of 37.5 by 100 meters, and vegetated with the Rhizophora genus to complement the naturally occurring Avicennia marina, Ceriops tagal, and Bruguiera cylindrica species (Boonsong et al., 2002).

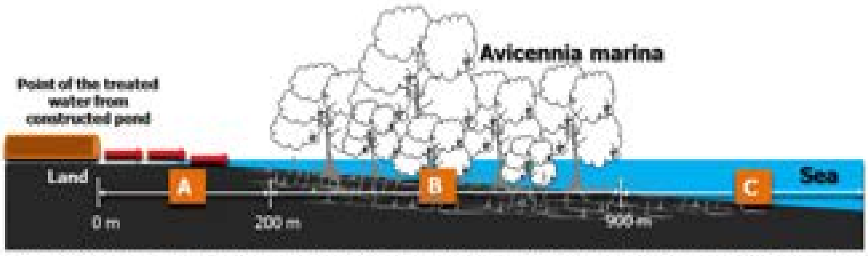


Figure 26. Illustration of the Laem Phak Bia project with marked distances representing the length of tideland between the CW and the natural mangrove system (A), the expanse of the natural system (B), and length between the mangrove forest and the Gulf of Thailand (C).

Boonsong et al. (2002) investigated the removal efficiency for the CW compared with the naturally occurring mangrove wetland. Each system performed differently across various aspects: the natural mangrove system had a lower pH due to detrital decomposition on the forest floor, while the CW had more photosynthetic activity owing to light penetration through the evenly spaced vegetation compared to the dense natural canopy. While average BOD5 remained comparatively similar, the natural mangrove system had a higher TN removal compared to the CW, and varying removal efficiencies for NH4-N and NO3-N at 3- and 7-day detention periods (Boonsong et al., 2002). Therefore, mangrove vegetated CWs have just as much potential to treat wastewater as natural mangrove systems. Systemic oxygen and soil conditions in a natural mangrove system may limit nutrient removal, especially for nitrogen, which makes a compelling case for preferring CWs.

Conclusion

Constructed wetlands are a simple and cost-effective solution to the current water shortage crisis in SSA countries, especially in Northern Africa. While countries like South Africa, Algeria, and Kenya have taken significant steps to commission CWs across different parts, most nations, especially in the Sahel region, still lag in the adoption and documentation of artificial approaches to wastewater rehabilitation. Research regarding proper wastewater rehabilitation practices in SSA is also scarce compared with the world's developed economies. All this is despite the importance of CWs as an indispensable resource for wastewater filtration and pollutant removal from domestic and industrial effluents. Future research efforts can focus more on sensitization and mobilizing policymakers and governments to espouse CWs as a necessary resource for wastewater recycling. It is more than necessary to concert all efforts toward sustainable water supply in regions like SSA and Central/South Asia where water scarcity serves as the starting point to a vicious cycle of environmental degradation and human welfare deterioration.

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Introduction to Photovoltaic Analysis - Practical Applications Sub-Project in 2024

This year, several fellows were tasked with planning photovoltaic systems, focusing on applications for pumps and integrating them with water towers to ensure pressure behind stored water. To enhance their marketability and career prospects, we expanded the research to include photovoltaic planning for residential use. This initiative aimed to encourage fellows to apply their training in practical, real-world scenarios.

As part of this fellowship, no fewer than ten residential projects were fully planned, complete with profitability analyses and system sizing tailored for residential applications. Additionally, a few commercial buildings were designed in collaboration with Planungsbüro Coman in Germany, providing invaluable experience in commercial applications.

The following reports highlight the exceptional efforts of the fellows, showcasing their ability to rise to the challenges presented. To maintain customer confidentiality in Germany, specific customer data has not been included; instead, we profile one of the practice houses developed as part of the fellowship training.

This practical training represents a significant expansion of the fellowship model, allowing students to engage in real problem-solving. We extend our gratitude to Mendrika Rahajarison for her outstanding contributions this year, as she adeptly learned the necessary software to assess the viability of photovoltaic systems for various projects in Germany.

JACQUELYN JESTINE SANDERS FOUNDATION
BUILDING VISION, REALIZING CHANGE

UPDATING THE ENERGY USAGE OF HISTORICAL BUILDINGS IN GERMANY, WITH PHOTOVOLTAIC

A Study Project

By Mendrika Handrandraina Miora RAHAJARISON

JACQUELYN JESTINE SANDERS FOUNDATION
BUILDING VISION. REALISING CHANGE

Title	UPDATING THE ENERGY USAGE OF HISTORICAL BUILDINGS IN GERMANY, WITH PHOTOVOLTAIC
Revision	
Issues	
Prepared by	Mendrika Handrandraina Miora RAHAJARISON
Reviewed by	Coman, Kenneth
Date	21.10.2024

TABLE OF CONTENTS

ABSTRACT

This paper examines the impact of adding battery storage to a photovoltaic (PV) system for a commercial building in Germany. It highlights the various customer goals that influence system design, using a case study to illustrate how different objectives—such as maximizing self- consumption, reducing grid dependency, and optimizing financial returns—shape the planning process. Recommendations are provided based on the simulations conducted, offering insights into the decision-making process for PV system planners.

INTRODUCTION

As a new planner in the field of photovoltaic (PV) systems, navigating the complexities of designing a system for a commercial building can be both challenging and rewarding. This document aims to share the thought process and methodology behind the planning and design of a PV system for a commercial building located in Hameln, Germany. The PV system is designed to meet a significant portion of the building's annual energy consumption, which amounts to approximately 65 000 kWh. This analysis aims to understand the implications of high energy consumption on the system's design and to evaluate the potential impact of adding or removing a battery. By discussing the key factors influencing the design, the challenges encountered, and the decisions made, this paper provides insights into the approach taken for this project.

I. Factors influencing the design:

Several factors must be considered when planning a PV system to ensure it aligns with the client's objectives:

I.1. Energy consumption patterns

Understanding the building's energy consumption profile is the most important task for a PV system which impacts the sizing. For the Hameln project, the building consumes approximately 65,000 kWh annually.

This information guided the size and capacity of the PV system to ensure it could offset a significant portion of this consumption.

A commercial building, with this consumption, is not usually using electricity for cooking and bathing, so this consumption can be used for lightings, heating and freezing.

I.2. Geography and site conditions

The location of the building plays a significant role in determining the system's potential energy yield. The roof's orientation, tilt, and shading from nearby structures or trees must be considered. In this case, the roof had multiple orientations, requiring careful planning to optimize panel placement.

I.3. Regulatory environment

In Germany, regulations and incentives for PV systems can impact the design. Understanding feed-in tariffs, grid connection requirements, and ensuring compliance with local regulations are a non-negotiable part of the planning process.

For this project, we took :

- Feed-in tariff : €0,07/ kWh.
- Consumption tariff : €0,38/ kWh.

I.4. System components:

The choice of PV modules, inverters, and other components plays a significant role in the overall performance and cost of the system. The system components should have as basics:

- Solar panels
- Inverters
- Optimizers
- Battery (if necessary)

II. The design process

The design process for a PV system is iterative, involving multiple stages of analysis, simulation, and optimization.

Here's how we approached the design for the Hameln building by using SolarEdge Designer as software:

II.1. Initial assessment and data collection:

The first step involved collecting detailed information about the building's energy usage, roof dimensions, and structural characteristics.

For Hameln building, we have these:

- Annual consumption: 65 000kWh/ year.

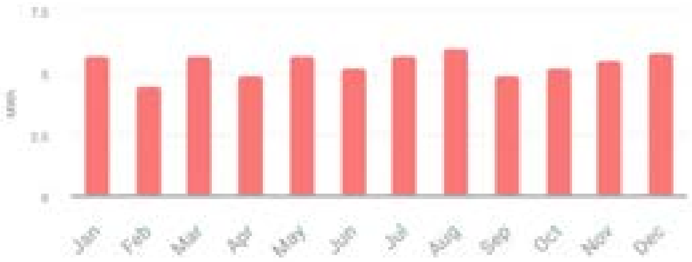

Figure 1 : Consumption profile.

This is the monthly consumption profile with a commercial consumption. It shows a high usage of energy for a commercial building in Germany, it will directly impact the financial results.

- Roof areas:

Figure 2 : Roofs dimensions.

Here, we have three available roofs with one flat roof and two tilted roofs. And we saw a shading in the first roof.

II.2. System sizing

II.2.1. PV characteristics

Figure 3 : Panels layout.

Here we have 3 roofs where we can install 82 solar panels in different ways, we choosed QCells Q.PEAK DUO L-G6-425W panels:

- 43 modules (18.3 kWp) oriented at 280° with a 31° tilt.
- 22 modules (9.4 kWp) oriented at 188° with a 41° tilt.
- 17 modules (7.2 kWp) oriented at 188° with a 45° tilt, with racks on a flat roof.

II. 2.2. Inverter and optimizers sizing

For this system, we can choose these with their characteristics:

- P850 optimizers.
- SE25kW inverter:

Figure 4 : SE25kW inverter.

Fixed voltage inverter for higher efficiency and longer strings.

Small, easy to install, and the smallest in its category.

Integrated type 2 DC surge protection (surge arrester) for better resistance to overvoltage caused by lightning or other events.

II.3. Simulation and energy yield estimation:

Using SolarEdge Designer, we modeled the PV system's performance under different configurations.

II.3.1. System configuration

The design incorporated 82 solar panels with a total installed DC capacity of 34.85 kWp.

II.3.2. System production and consumption

The simulation helped estimate the annual energy production:

Figure 5 : simulation results.

For this project, an estimated annual production of 30.98 MWh, with a self-consumption of 80% indicates that the system is designed to meet a significant portion of the building's energy needs covering about 38% of the building's annual consumption.

III. Financial Analysis

A crucial part of the design process was evaluating the financial viability of the system. We conducted a detailed financial analysis, considering the system's upfront cost, expected energy savings, and available incentives.

III.1. Initial costs

The initial investment of €40 698 for this building represents the total cost of purchasing and installing the PV system which includes:

- 1 SolarEdge inverter with a power of 25kW.
- 42 SolarEdge optimizers P850.
- 82 panels of 425W.

III.2. Estimated bill savings and return of investment

DETAILED FINANCIAL ANALYSIS

System Price	Maintenance Cost (NPV)	Returns from Incentives (NPV)	Net Payments	Lifetime Bill Savings (NPV)
€ 40,698	€ N/A	€ N/A	€ 40,698	€ 159,852

System Profit (NPV)	Internal Return Rate (IRR)	Return Of Investment (ROI)	Levelized Cost Of Energy (LCOE)	Payback Period
€ 119,155	21.66 %	292.78 %	€/kWh 0.089	4.8 years

Figure 6 : Detailed financial analysis.

Over the system's expected operational life, the estimated total savings on electricity bills amount to €159 852. This analysis revealed a payback period of 4.8 years and a return on investment (ROI) of 292.78%, making the project financially attractive.

After this period, the system will have effectively paid for itself, and any further savings will contribute directly to the financial benefit of the building owner.

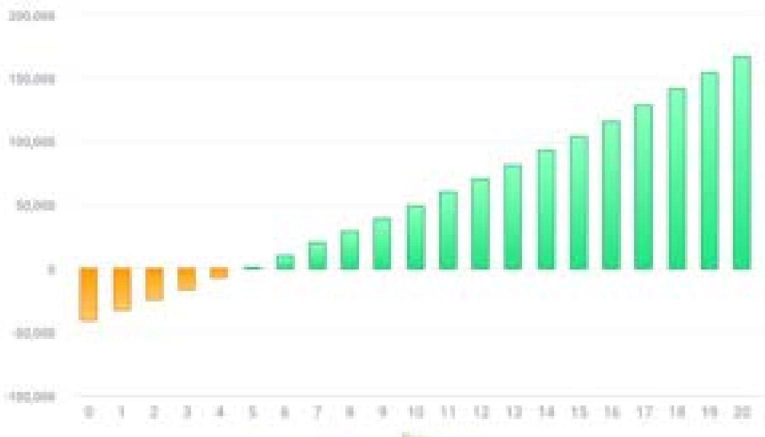

Figure 7 : Yearly cash flow.

IV. The Impact of Adding Battery Storage

Adding battery storage to a PV system can significantly enhance its functionality, particularly in terms of increasing self-consumption and reducing grid dependency.

IV.1. Battery sizing

For the Hameln project, we considered adding a 9.2 kWh SolarEdge battery. His lifetime is around 10years, which is a good investment for the system.

IV.2. Impact on Self-Consumption rates

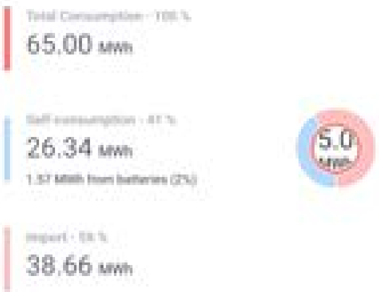

Figure 8 : Consumption with battery.

With the battery, the building's self-consumption increased from 38% to 41%. This means that more of the solar energy produced is used directly on-site, reducing the need to import electricity from the grid.

IV.3. Reduction in energy exported

The system's energy export to the grid decreased, which is beneficial in scenarios where the feed-in tariff is lower than the cost of imported electricity.

IV.4. Energy Resilience

The battery allows for better alignment between energy production and consumption, particularly during periods of low solar output or peak demand.

IV.4. Financial Considerations

We considered a price of €800/ kWh, so for this model, we had €7,360.

This should be added into the initial costs, and all components could be changed following the system configuration.

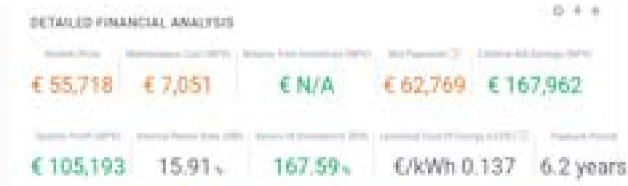

Figure 9 : Detailed financial analysis with battery.

The addition of the battery increased the system's initial cost from €40,698 to €55,718, which extended the payback period from 4.8 years to 6.2 years. The total bill savings also decreased from €159,852 to €105,193.

While the initial investment is higher, the long-term benefits of increased energy independence and potential savings during peak electricity prices may justify the cost, depending on the client's priorities.

V. Recommendations and Interpretation

Based on our findings, we offer the following recommendations for planners considering battery integration in PV systems:

V.1. Align design with client objectives

Always prioritize the client's goals when deciding on battery integration. If grid independence and energy resilience are top priorities, a battery may be justified despite the higher cost.

V.2. Iterative design process

Run multiple scenarios to understand the full impact of battery integration on both energy performance and financial outcomes. This will provide a clear picture of the trade-offs involved.

V.3. Consideration of battery storage

While batteries can enhance self-consumption and energy independence, their financial impact must be carefully evaluated. For clients with high electricity costs or those seeking to reduce grid reliance, batteries may be a worthwhile investment.

CONCLUSION

By following a structured design process and considering all potential scenarios, planners can develop PV systems that meet the unique needs of each client. This case study underscores the importance of flexibility and adaptability in PV system design, particularly when working with historical or commercial buildings.

Designing a photovoltaic system for a commercial building involves a complex interplay of technical, financial, and environmental considerations. By understanding the client's goals, analyzing the site conditions, and carefully selecting system components, a new planner can develop a PV system that meets the client's needs while providing long-term benefits. The case study of the Hameln building highlights the importance of considering battery storage or not as part of the design process and demonstrates how different design choices can impact the system's performance and financial viability.

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HOHENSTEINSTRASSE 1
Hohensteinstraße 1, Hessisch Oldendorf, 31840, Germany | Coman | Jul 10, 2024

PLANUNGSBÜRO

STORAGE

SolarEdge Home Battery 10kWh

Smart Battery Management

Self-consumption	Self-consumption from Batteries	Total Storage Capacity	Total Battery Power
39%	13%	10 kWh	5 kW

SYSTEM OVERVIEW 30 PV modules | 2 Inverters | 30 Optimizers | 1 Battery

FINANCIAL OVERVIEW

Net Payments	Lifetime Bill Savings (NPV)	System Profit (NPV)	Internal Return Rate (IRR)	Payback Period
€ 34,877	€ 66,282	€ 31,406	11.37 %	7.5 years

SIMULATION RESULTS

Installed DC Power	Max Achieved AC Power	Annual Energy Production	Reactive Energy	Apparent Energy	CO2 Emission Saved (Annually)	Equivalent Trees Planted (Annually)
12.75 kWp	6.46 kW	12.17 MWh	4.00 MVAR	12.81 MVA	5.37 t	246

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HOHENSTEINSTRASSE 1

Hohensteinstraße 1, Hessisch Oldendorf, 31840, Germany | Coman | Jul 10, 2024

PLANUNGSBÜRO

SYSTEM PRODUCTION

Total Production - 100 %
12.17 MWh

Self-consumption - 65 %
7.89 MWh

Export - 35 %
4.27 MWh

CONSUMPTION

Total Consumption - 100 %
20.00 MWh

Self-consumption - 39 %
7.89 MWh
2.53 MWh from batteries (13%)

Import - 61 %
12.11 MWh

ESTIMATED MONTHLY ENERGY

Total clipped energy: 3.08% | Clipped Energy Without Smart Battery: 5.02%

PV MODULES

# Module	Model	Peak power	Racking type	Orientation	Azimuth	Tilt
30	QCells, Q.PEAK DUO L-G6 - 425W (user-defined)	12.8 kWp			132°	20°
Total: 30		12.8 kWp				

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HOHENSTEINSTRASSE 1
Hohensteinstraße 1, Hessisch Oldendorf, 31840, Germany | Coman | Jul 10, 2024

PLANUNGSBÜRO

ESTIMATED BILL SAVINGSYEAR 1

Avg. Monthly

Current Monthly Bill	Monthly Bill with SolarEdge	Net Bill Monthly Savings	Bill Offset
€ 633.71	€ 358.83	€ 274.88	43.38 %

Estimated Net Lifetime Bill Savings

€ 66,282

Utility Provider **e.on germany** | Utility Rate **Kaufpreis (0.38 €/kWh)**

Export Rate: **Feed-in Tariff Germany (0.07 €/kWh)**

HOHENSTEINSTRASSE 1

Hohensteinstraße 1, Hessisch Oldendorf, 31840, Germany | Coman | Jul 10, 2024

PLANUNGSBÜRO

DETAILED FINANCIAL ANALYSIS

System Price	Maintenance Cost (NPV)	Returns from Incentives (NPV)	Net Payments	Lifetime Bill Savings (NPV)
€ 27,213	€ 7,664	€ N/A	€ 34,877	€ 66,282

System Profit (NPV)	Internal Return Rate (IRR)	Return Of Investment (ROI)	Levelized Cost Of Energy (LCOE)	Payback Period
€ 31,406	11.37 %	90.05 %	€/kWh 0.192	7.5 years

YEARLY CASH FLOW

# Year	System Price	Replacement Costs	Net Bill Savings	Annual Cash Flow	Cumulative Cash Flow
0	€ -27,212.50		€ 0.00	€ -27,212.50	€ -27,212.50
1			€ 3,298.55	€ 3,298.55	€ -23,913.95

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PLANUNGSBÜRO

YEARLY CASH FLOW (CONTINUED)

# Year	System Price	Replacement Costs	Net Bill Savings	Annual Cash Flow	Cumulative Cash Flow
2			€ 3,388.88	€ 3,388.88	€ -20,525.07
3			€ 3,481.71	€ 3,481.71	€ -17,043.36
4			€ 3,577.37	€ 3,577.37	€ -13,465.99
5			€ 3,675.79	€ 3,675.79	€ -9,790.19
6			€ 3,777.21	€ 3,777.21	€ -6,012.99
7			€ 3,881.12	€ 3,881.12	€ -2,131.87
8			€ 3,987.46	€ 3,987.46	€ 1,855.59
9			€ 4,097.04	€ 4,097.04	€ 5,952.63
10		€ -10,000.00	€ 4,209.51	€ -5,790.49	€ 162.14
11			€ 4,325.00	€ 4,325.00	€ 4,487.14
12			€ 4,443.57	€ 4,443.57	€ 8,930.72
13			€ 4,565.67	€ 4,565.67	€ 13,496.39
14			€ 4,690.91	€ 4,690.91	€ 18,187.29
15			€ 4,819.57	€ 4,819.57	€ 23,006.87
16			€ 4,951.67	€ 4,951.67	€ 27,958.53
17			€ 5,087.81	€ 5,087.81	€ 33,046.34
18			€ 5,227.84	€ 5,227.84	€ 38,274.18
19			€ 5,371.98	€ 5,371.98	€ 43,646.16
20			€ 5,519.74	€ 5,519.74	€ 49,165.90
Total		€ -10,000.00	€ 96,378.40	€ 49,165.90	

BILL OF MATERIALS (BOM)

Items	Part Number	Quantity	Price (€)	Total (€)
Base Price per W (DC)		12750	0.55	7,012.50
SE5000H Home Hub		1		

HOHENSTEINSTRASSE 1

Hohensteinstraße 1, Hessisch Oldendorf, 31840, Germany | Coman | Jul 10, 2024

PLANUNGSBÜRO

BILL OF MATERIALS (BOM) (CONTINUED)

Items	Part Number	Quantity	Price (€)	Total (€)
SE2200H Home Wave https://www.mg-solar-shop.com/solaredge-se2200h-hd-wave-setapp-single-phase-inverter		1	900.00	900.00
S440 https://lichtex.de/solaredge-optimizer-p300-p370-p370-p404-p405-p500-p505-p600-p650-p700-p730-p800-p850-4r-5r-p5-m4m-mdm-landscape-single-dual/a-1310_2?googlede=1&gclid=CjwKCAiAa8acBhA1EiwAgRFdw8osl3Pw33lFpMNbZ-HCRQoX1wuvD3450s9KKwGiLf5Dga_inh-RRoCULAQAvD_BwE		30	100.00	3,000.00
SolarEdge Home Battery 10kWh https://www.europe-solarstore.com/solaredge-energy-bank-10kwh-battery.html		1	7300.00	7,300.00
Q.PEAK DUO L-G6 - 425W		30	300.00	9,000.00

Total Price € 27,212.50

ELECTRICAL DESIGN

Inverters & Storage	Strings per inverter	Optimizers per string	PV modules per string
1 x SE5000H Home Hub 8.6kW | 187% Oversizing 1 x SolarEdge Home Battery 10kWh	1 x string	10 x S440	10
	1 x string	11 x S440	11
1 x SE2200H Home Wave 3.69kW | 168% Oversizing	1 x string	9 x S440	9

HOHENSTEINSTRASSE 1

Hohensteinstraße 1, Hessisch Oldendorf, 31840, Germany | Coman | Jul 10, 2024

PLANUNGSBÜRO

SYSTEM LOSS DIAGRAM

SIMULATION PARAMETERS

LOCATION & GRID

Time zone	GMT+2 (Berlin)
Weather station	Wunstorf (32.02 km away)
Station altitude	54 m
Station data source	Meteonorm 7.1
Grid	400V L-L, 230V L-N
Power factor (cos ϕ)	0.95

LOSS FACTORS

Near shading	Enabled
Albedo	0.20
Bi-Facial Albedo	0.30
Soiling/Snow	0%
Incidence angle modifier (IAM), ASHRAE b0 param.	0.05
Thermal loss factor Uc (const) Flush mount	20
Thermal loss factor Uc (const) Tilted	29
LID loss factor	0%
System unavailability	0%

Version 7.2.4

PVsyst - Simulation report

Grid-Connected System

Projet: PV Hohensteinstrasse 1

31840 Hessisch Oldendorf (Barksen)
No 3D scene defined, no shadings
System power: 12.60 kWp
Barksen - Germany

Author

Project: PV : Hohensteinstrasse 1

Variant: 31840 Hessisch Oldendorf, Barksen 8.9 years

PVsyst V7.2.4
VDK, Simulation date:
12/07/24 14:21
with v7.2.4

Project summary

Geographical Site		**Situation**		**Project settings**	
Barksen		Latitude	52.18 °N	Albedo	0.20
Germany		Longitude	9.27 °E		
		Altitude	113m		
		Time zone	UTC+1		

Meteo data
Barksen
Meteonorm 8.0 (1996-2011), Sat=100 % - Synthétique

System summary

Grid-Connected System | **No 3D scene defined, no shadings**

PV Field Orientation		**Near Shadings**		**User's needs**	
Fixed plane		No Shadings		Daily profile	
Tilt/Azimut	35 / -48°			Constant over the year	
h				Average	24.0 kWh/Day

System information

PV Array		**Inverters**		**Battery pack**	
Nb. of modules	30 units	Nb. of units	1 Unit	Storage strategy: Self-consumption	
Pnom total	12.60 kWp	Pnom total	10.00 kWac	Nb. of units	1Unit
		Pnom ratio	1.260	Voltage	51 V
				Capacity	260 Ah

Results summary

Produced Energy	12.78 MWh/year	Specific production	1014 kWh/kWp/year	Perf. Ratio PR	86.30 %
				Solar Fraction SF	69.72 %

Table of contents

Project: PV : Hohensteinstrasse 1

Variant: 31840 Hessisch Oldendorf, Barksen 8.9 years

PVsyst V7.2.4
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General parameters

Grid-Connected System

No 3D scene defined, no shadings

PV Field Orientation

Orientation
Fixed plane
Tilt/Azimuth 35 / -48°

Sheds configuration
No 3D scene defined

Models used
Transposition Perez
Diffuse Perez, Meteonorm
Circumsolar separate

Horizon
Free Horizon

Near Shadings
No Shadings

User's needs
Daily profile
Constant over the year
Average 24.0 kWh/Day

Storage
Kind Self-consumption

Charging strategy
When excess solar power is available

Discharging strategy
As soon as power is needed

Hourly load	0 h 1000	1 h 1000	2 h 1000	3 h 1000	4 h 1000	5 h 1000	6 h 1000	7 h 1000	8 h 1000	9 h 1000	10 h 1000	11 h 1000	W
	12 h 1000	13 h 1000	14 h 1000	15 h 1000	16 h 1000	17 h 1000	18 h 1000	19 h 1000	20 h 1000	21 h 1000	22 h 1000	23 h 1000	W

PV Array Characteristics

PV module
Manufacturer Hanwha Q Cells
Model Q Peak Duo L-G8-420
(Original PVsyst database)
Unit Nom. Power 420 Wp
Number of PV modules 30 units
Nominal (STC) 12.60 kWp
Modules 2 Strings x 15In series

At operating cond. (50°C)
Pmpp 11.49 kWp
U mpp 559V
I mpp 21A

Total PV power
Nominal (STC) 13 kWp
Total 30 modules
Module area 64.3 m²

Inverter
Manufacturer Platinum GmbH (Diehl)
Model Platinum 11000 R3-MDX-10 752660
(Original PVsyst database)
Unit Nom. Power 10.00kWac
Number of inverters 1units
Total power 10.0kWac
Operating voltage 350-720V
Pnom ratio (DC:AC) 1.26

Total inverter power
Total power 10 kWac
Nb. of inverters 1 Unit
Pnom ratio 1.26

Battery Storage

Battery
Manufacturer BYD
Model B-Box PRO 13.8

Battery pack
Nb. of units 1 Unit
Discharging min. SOC 20.0 %
Stored energy 10.6 kWh

Battery Pack Characteristics
Voltage 51V
Nominal Capacity 260Ah (C10)
Temperature Fixed 20°C

Project: PV : Hohensteinstrasse 1

Variant: 31840 Hessisch Oldendorf, Barksen 8.9 years

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PV Array Characteristics

Battery Storage

Battery input charger

Model	Generic
Max. charg. power	3.6 kWdc
Max./Euro effic.	97.0/95.0 %

Battery to Grid inverter

Model	Generic
Max. disch. power	1.0 kWac
Max./Euro effic.	97.0/95.0 %

Project: PV : Hohensteinstrasse 1

Variant: 31840 Hessisch Oldendorf, Barksen 8.9 years

PVsyst V7.2.4
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Array losses

Thermal Loss factor
Module temperature according to irradiance
Uc (const) 20.0W/m²K
Uv (wind) 0.0W/m²K/m/s

Module mismatch losses
Loss Fraction 2.0% at MPP

DC wiring losses
Global array res. 450 mΩ
Loss Fraction 1.5% at STC

Strings Mismatch loss
Loss Fraction 0.1%

Module Quality Loss
Loss Fraction -0.8 %

IAM loss factor

Incidence effect (IAM): Fresnel AR coating, n(glass)=1.526, n(AR)=1.290

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.999	0.987	0.962	0.892	0.816	0.681	0.440	0.000

Project: PV : Hohensteinstrasse 1

Variant: 31840 Hessisch Oldendorf, Barksen 8.9 years

PVsyst V7.2.4
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Main results

System Production

Produced Energy	12.78 MWh/year	Specific production	1014 kWh/kWp/year
		Performance Ratio PR	86.30 %
		Solar Fraction SF	69.72 %

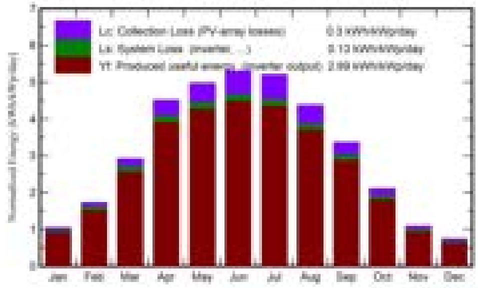
Battery aging (State of Wear)

Cycles SOW	96.4 %
Static SOW	90.0 %
Battery lifetime	10.0 years

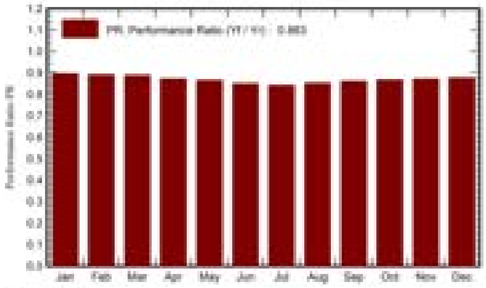
Economic evaluation

Investment		**Yearly cost**		**LCOE**	
Global	20'990.00 EUR	Annuities	0.00 EUR/yr	Energy cost	0.10 EUR/kWh
Specific	1.67 EUR/Wp	Run. costs	200.00 EUR/yr		
		Payback period	8.8 years		

Normalized productions (per installed kWp)



Performance Ratio PR



Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_User MWh	E_Solar MWh	E_Grid MWh	EFrGrid MWh
January	20.8	12.13	2.28	32.4	31.1	0.386	0.744	0.277	0.088	0.467
February	36.2	21.43	2.80	48.5	47.0	0.584	0.672	0.358	0.187	0.314
March	77.4	43.58	5.50	90.4	88.1	1.068	0.744	0.557	0.455	0.187
April	123.1	56.01	9.75	135.5	132.4	1.557	0.720	0.626	0.863	0.094
May	150.3	81.46	13.89	154.1	150.6	1.750	0.744	0.701	0.979	0.043
June	157.9	78.94	16.80	159.3	156.0	1.774	0.720	0.678	1.028	0.042
July	156.9	80.32	19.31	161.2	157.6	1.782	0.744	0.714	0.997	0.030
August	131.9	70.16	18.94	135.7	132.5	1.522	0.744	0.666	0.791	0.078
September	89.2	45.41	14.83	100.9	98.5	1.150	0.720	0.557	0.538	0.163
October	53.4	32.12	10.77	65.3	63.2	0.760	0.744	0.484	0.230	0.260
November	23.7	14.15	6.39	32.8	31.3	0.383	0.720	0.272	0.087	0.448
December	15.6	11.14	3.53	22.8	21.9	0.271	0.744	0.217	0.035	0.527
Year	1036.3	546.85	10.44	1139.1	1110.3	12.987	8.760	6.107	6.278	2.653

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_User	Energy supplied to the user
T_Amb	Ambient Temperature	E_Solar	Energy from the sun
GlobInc	Global incident in coll. plane	E_Grid	Energy injected into grid
GlobEff	Effective Global, corr. for IAM and shadings	EFrGrid	Energy from the grid

12/07/24 PVsyst Licensed to Page 6/12

Project: PV : Hohensteinstrasse 1

Variant: 31840 Hessisch Oldendorf, Barksen 8.9 years

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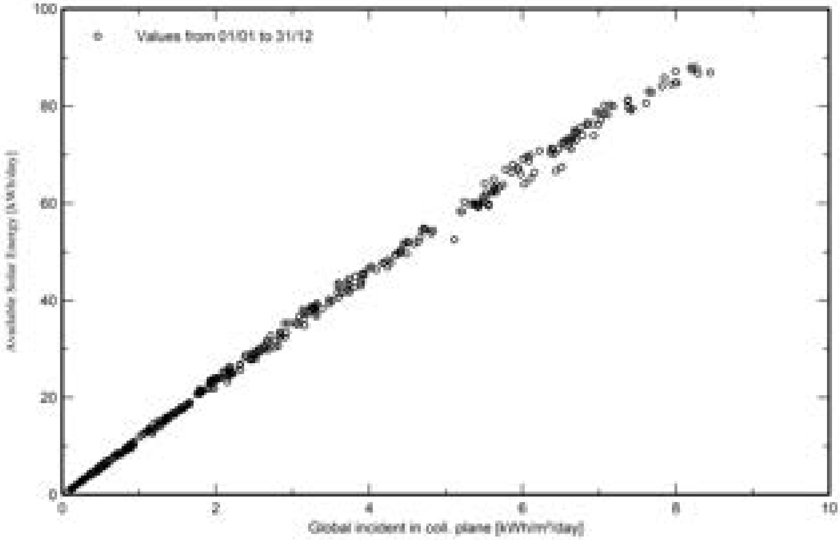
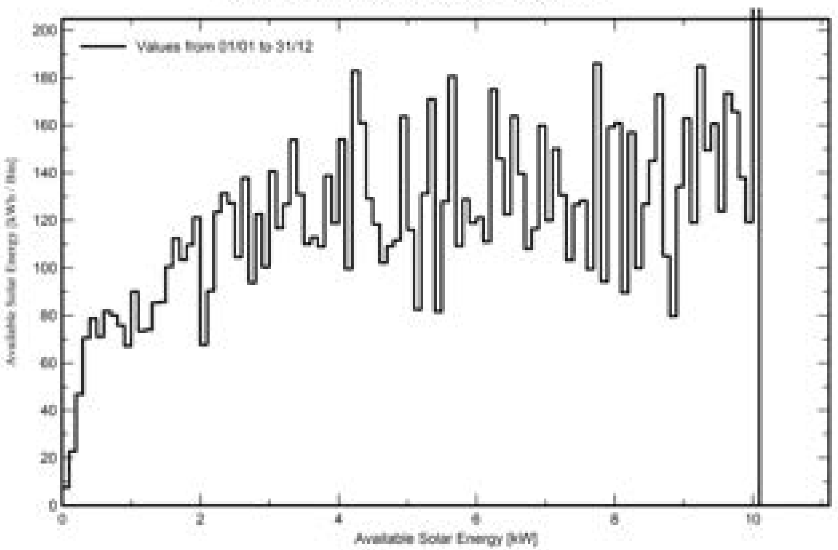
Special graphs

Diagramme d'entrée/sortie journalier



Distribution de la puissance de sortie système



Project: PV : Hohensteinstrasse 1

Variant: 31840 Hessisch Oldendorf, Barksen 8.9 years

PVsyst V7.2.4
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Cost of the system

Installation costs

Item	Quantity units	Cost EUR	Total EUR
PV modules			
Q Peak Duo L-G8-420	3	300.0	9'000.0
Supports for modules	0	0	0
Inverters	3	100.0	3'000.0
Platinum 11000 R3-MDX-10 752660	01	990.00	0'990.00
Batteries			8'000.00
Total			20'990.00
Depreciable asset			20'990.00

Operating costs

Item	Total EUR/year
Maintenance	
Provision for battery replacement	200.0
Total (OPEX)	0 200.0 0

System summary

Total installation cost	20'990.00 EUR
Operating costs	200.00 EUR/year
Unused energy	6107 kWh/year
Energy sold to the grid	6278 kWh/year
Cost of produced energy (LCOE)	0.101 EUR/kWh

Project: PV : Hohensteinstrasse 1

Variant: 31840 Hessisch Oldendorf, Barksen 8.9 years

PVsyst V7.2.4
VDK, Simulation date:
12/07/24 14:21
with v7.2.4

Financial analysis

Simulation period

Project lifetime	20 years	Start year	2025

Income variation over time

Inflation	0.00 %/year
Production variation (aging)	0.00 %/year
Discount rate	0.00 %/year

Income dependent expenses

Income tax rate	0.00 %/year
Other income tax	0.00 %/year
Dividends	0.00 %/year

Financing

Own funds	20'990.00 EUR

Electricity sale

Feed-in tariff	0.07 EUR/kWh
Duration of tariff warranty	20 years
Annual connection tax	0.00 EUR/kWh
Annual tariff variation	0.0 %/year
Feed-in tariff decrease after warranty	50.00 %

Self-consumption

Consumption tariff	0.35 EUR/kWh
Tariff evolution	0.0 %/year

Return on investment

Payback period	8.8 years
Net present value (NPV)	26'549.47 EUR
Return on investment (ROI)	126.5 %

Detailed economic results (EUR)

	Electricity sale	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Self-cons. saving	Cumul. profit	% amorti.
2025	439	200	0	239	0	239	2'138	-18'613	11.3%
2026	439	200	0	239	0	239	2'138	-16'236	22.6%
2027	439	200	0	239	0	239	2'138	-13'859	34.0%
2028	439	200	0	239	0	239	2'138	-11'482	45.3%
2029	439	200	0	239	0	239	2'138	-9'105	56.6%
2030	439	200	0	239	0	239	2'138	-6'728	67.9%
2031	439	200	0	239	0	239	2'138	-4'351	79.3%
2032	439	200	0	239	0	239	2'138	-1'974	90.6%
2033	439	200	0	239	0	239	2'138	403	101.9%
2034	439	200	0	239	0	239	2'138	2'780	113.2%
2035	439	200	0	239	0	239	2'138	5'157	124.6%
2036	439	200	0	239	0	239	2'138	7'534	135.9%
2037	439	200	0	239	0	239	2'138	9'911	147.2%
2038	439	200	0	239	0	239	2'138	12'288	158.5%
2039	439	200	0	239	0	239	2'138	14'665	169.9%
2040	439	200	0	239	0	239	2'138	17'042	181.2%
2041	439	200	0	239	0	239	2'138	19'419	192.5%
2042	439	200	0	239	0	239	2'138	21'796	203.8%
2043	439	200	0	239	0	239	2'138	24'173	215.2%
2044	439	200	0	239	0	239	2'138	26'549	226.5%
Total	**8'789**	**4'000**	**0**	**4'789**	**0**	**4'789**	**42'750**	**26'549**	**226.5%**

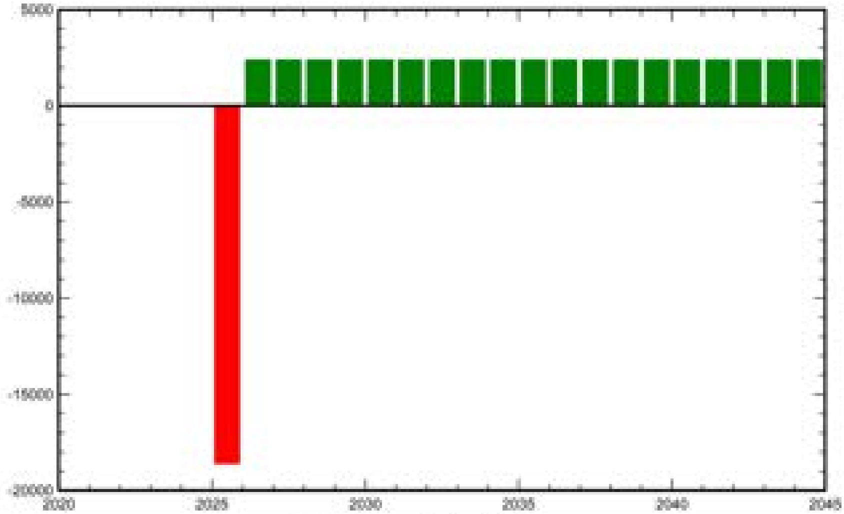
Project: PV : Hohensteinstrasse 1

Variant: 31840 Hessisch Oldendorf, Barksen 8.9 years

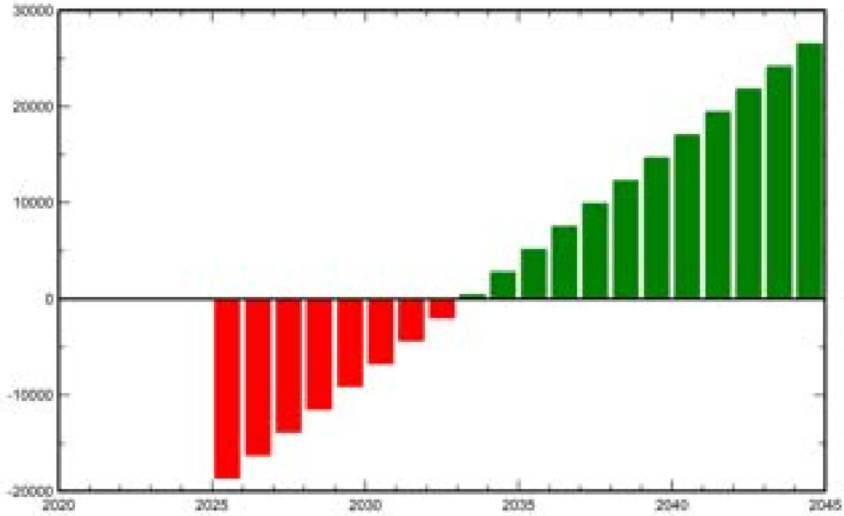
PVsyst V7.2.4
VDK, Simulation date:
12/07/24 14:21
with v7.2.4

Financial analysis

Yearly net profit (EUR)



Cumulative cashflow (EUR)



Project: PV : Hohensteinstrasse 1

Variant: 31840 Hessisch Oldendorf, Barksen 8.9 years

PVsyst V7.2.4
VDK, Simulation date:
12/07/24 14:21
with v7.2.4

CO_2 Emission Balance

Total: -19.2 tCO_2

Generated emissions

Total: 19.18 tCO_2

Source: Detailed calculation from table below:

Replaced Emissions

Total: 0.0 tCO_2

System production: 12.78 MWh/yr

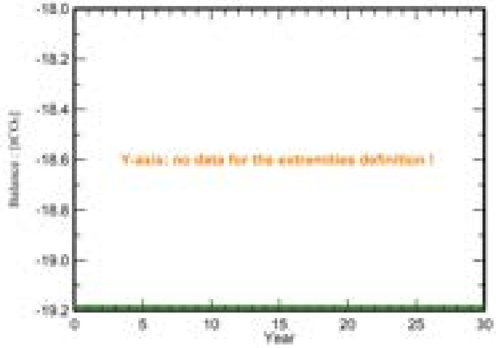
Grid Lifecycle Emissions: 0 gCO_2/kWh

Source: Custom value supplied by user

Lifetime: 30 years

Annual degradation: 1.0%

Saved CO_2 Emission vs. Time



System Lifecycle Emissions Details

Item	LCE	Quantity	Subtotal
			[$kgCO_2$]
Modules	1631 kgCO2/kWp	11.8 kWp	19182
Supports	0.01 kgCO2/kg	280 kg	1.87
Inverters	0.66 kgCO2/units	1.00 units	0.66

JJSF Contributor & Fellow Emeritus
Williams, Barrett
Graduate, Systems Engineering

Introduction to the APA-Compliant Report and Rice Permaculture Research

The next report is authored by a professional engineer from the United States, Mr. Barrett, who generously contributed his time to assist the foundation. His nearly volunteer work was instrumental in developing an APA-compliant template for the fellows, ensuring that all reports maintain a consistent, professional standard for publication. The process of formatting and achieving consistency across all submissions was a substantial task, and Mr. Barrett William's contributions significantly streamlined this effort.

In addition to his work on the template, Mr. William's research on rice permaculture in America provided a strong foundation for subsequent planning within the fellowship. His research has served as a valuable reference point, enhancing the understanding of sustainable agricultural practices and their integration with renewable energy solutions.

JACQUELYN JESTINE SANDERS FOUNDATION
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Exploring the Potential of Rice Permaculture (Intercropping):

A Review of Research Projects

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Abstract

Rice cultivation is a cornerstone of global food security, yet traditional monoculture practices often lead to environmental degradation and limited resource utilization. Intercropping rice with various plant species has emerged as a promising approach within the realm of permaculture, offering opportunities for enhanced soil fertility, water conservation, and diversified agricultural outputs. This paper presents a review of research projects investigating the integration of rice cultivation with diverse vegetation as a sustainable strategy to redefine water usage and land productivity.

Drawing from a range of academic sources, this review encompasses diverse methodologies and outcomes. The selected projects highlight the efficacy of intercropping systems in mitigating crop yield reductions, improving nutrient cycling, and enhancing overall agroecosystem resilience.

One such study, conducted in the Upper Amazon Basin, evaluated the impact of alley cropping with leguminous species on upland rice production. Results demonstrated varying effects on crop yield and nutrient budgets, emphasizing the importance of species selection and mulch application rates. Similarly, a bibliometric analysis spanning four decades revealed the global landscape of rice intercropping research, identifying key geographical regions and research priorities for future investigation.

Furthermore, a global analysis explored the yield benefits and risks associated with integrating trees into rice production systems. Findings indicated significant improvements in rice yield across various agroforestry practices, with notable benefits observed in biomass transfer and pre-rice green manuring approaches. Moreover, innovative models, such as intercropping rice with phytoremediation plants like alligator flag and Solanum nigrum, showcased potential solutions for reducing soil contaminants while maintaining crop productivity.

Through a synthesis of these research endeavors, this paper expounds the multifaceted advantages of rice intercropping within permaculture frameworks. By harnessing the complementary interactions between rice and diverse vegetation, such as trees and hyperaccumulators, these projects offer actionable insights for sustainable agricultural practices. The implications extend beyond mere crop diversification, encompassing broader goals of environmental stewardship, community resilience, and food sovereignty.

Keywords: Rice intercropping, permaculture, agroforestry, sustainable agriculture, water usage, crop diversification, soil fertility, phytoremediation.

Introduction

Rice cultivation stands as a cornerstone of global food security, feeding billions of people worldwide. However, conventional monoculture practices often lead to environmental degradation, water scarcity, and diminished soil fertility. In response to these challenges, the integration of permaculture principles with rice production has gained momentum, offering sustainable solutions for enhancing agricultural resilience and productivity. Permaculture emphasizes holistic approaches to farming, incorporating principles of diversity, synergy, and ecological harmony. One promising strategy within this framework is rice intercropping, whereby rice is cultivated alongside complementary plant species, including trees and hyperaccumulators. This approach holds the potential to mitigate yield losses, conserve water, and improve soil health while diversifying agricultural outputs. In this paper, we embark on a comprehensive review of research projects investigating rice intercropping within permaculture systems. Through a synthesis of empirical findings and scholarly insights, we aim to explain the multifaceted benefits and challenges of integrating rice cultivation with diverse vegetation, with implications for sustainable agriculture and food security.

Literature Review

Using Eucalyptus Intercropped with Rice and Beans

Methodology and Results

This investigation into sustainable farming practices involved a two-year agroforestry trial where Eucalyptus urophylla was intercropped with rice (Oryza sativa) and common beans (Phaseolus vulgaris) (Ceccon, 2007). Conducted in a humid subtropical region, the experimental design incorporated randomized block setups combining these three species in varying spatial arrangements (Ceccon, 2007). The objective was to evaluate the effect of Eucalyptus urophylla on the growth and yield of intercropped rice and beans, examining the potential for optimized land use and increased bioenergy resources (Ceccon, 2007).

Data collected included growth rates, yield measurements, and soil nutrient profiles, analyzed through a mixture of ANOVA and multivariate regression techniques to determine inter-species interactions and their impacts on agroforestry productivity. Initial results indicated that rice yields were slightly lower in intercropping setups than in monocultures, attributed to partial shading by Eucalyptus trees (Ceccon, 2007). However, bean yields showed significant improvement, likely due to the nitrogen-fixing capability of the legumes which benefitted from the altered soil nitrogen profile caused by leaf litter decay from the Eucalyptus (Ceccon, 2007).

Furthermore, the growth rate of Eucalyptus urophylla was found to increase in the presence of rice and beans, suggesting a beneficial below-ground interaction (Ceccon, 2007). Wood volume and biomass were measured at the end of the second year, showing that the Eucalyptus trees had higher bioenergy potential when grown in this intercropping system compared to traditional forestry practices (Ceccon, 2007).

Implications for the Production of Bioenergy on Small Farms

The integration of Eucalyptus urophylla in rice and bean cropping systems presents a compelling strategy for small-scale farms to enhance their sustainability and economic viability. The increased biomass production of Eucalyptus offers a dual-purpose solution: it provides potential bioenergy resources while improving crop yields through ecological interactions. Small farms can utilize the wood for local energy needs or as a supplementary income source through the sale of bioenergy feedstock (Ceccon, 2007).

Moreover, this system promotes a more efficient use of land, reducing the need for separate areas dedicated to energy crops, thus fostering a holistic model of agriculture that aligns with permacultural and agroforestry principles (Ceccon, 2007). The shade provided by Eucalyptus can reduce water evaporation from the soil, conserving water and potentially reducing the need for irrigation – a critical factor in sustainable agriculture (Ceccon, 2007).

The broader adoption of such intercropping systems could significantly impact bioenergy production on a regional scale, contributing to rural electrification and energy security (Ceccon, 2007). These systems also play a role in carbon sequestration, an essential factor in climate change mitigation strategies. By diversifying crop production and integrating bioenergy crops, small farms can hedge against economic and environmental shocks, enhancing both their resilience and contribution to global sustainability goals (Ceccon, 2007).

The findings from this study underscore the importance of designing intercropping systems based on local environmental conditions and crop characteristics. Future research should explore the long-term ecological impacts and economic feasibility of scaling up these systems, including detailed lifecycle assessments and market analysis to better understand their role in sustainable agriculture and rural development.

Crop-Tree Interactions in Alley Cropping Systems

The integration of trees within rice cropping systems, often termed alley cropping, has been identified as a favorable strategy to address both agricultural productivity and environmental sustainability. This research has emphasized the importance of studying crop-tree interactions to optimize the benefits of intercropping systems tailored specifically for rice cultivation (Salazar et al., 1993b). The methodology of such research predominantly involves longitudinal studies where rice crops are interplanted with various tree species to observe different growth parameters and soil health indicators over multiple growing seasons (Salazar et al., 1993b). Figure 1 shows a traditional alley crop system.

Figure 1
Traditional Alley Crop System

Photo Credit: Naresh Tevathasan, University of Guelph, Canada. CC-BY-NC (https://creativecommons.org/licenses/by/2.0/)

Methodology and Findings

Findings from these investigations reveal significant insights into how trees influence the microclimatic conditions favorable for rice growth. Trees in alley cropping systems have been shown to improve soil moisture retention, which is critical for rice, a crop notoriously dependent on substantial water resources (Salazar et al., 1993b). The shade provided by strategically planted tree species can decrease soil temperature and reduce the evaporation of precious water resources, creating a more favorable growth environment for rice particularly in regions prone to drought (Salazar et al., 1993b).

Furthermore, the literature highlights that the presence of trees contributes to enhanced nutrient cycling within the ecosystem (Salazar et al., 1993b). Decaying leaves and other organic matter from trees add essential nutrients back into the soil, which can reduce the need for synthetic fertilizers, thus lowering the ecological footprint of rice cultivation (Salazar et al., 1993b). This natural input of organic matter enhances soil structure and fertility, fostering a robust environment for rice growth (Salazar et al., 1993b).

Implications for Rice Intercropping

The implications of these research findings are manifold. Firstly, crop yields have been observed to improve due to better soil health and reduced stress on the rice plants due to moderated microclimate conditions (Salazar et al., 1993b). Secondly, the environmental impact of rice cultivation can be mitigated by reducing the input of chemical fertilizers and the amount of irrigation water required (Salazar et al., 1993b). The enhanced biodiversity from incorporating trees not only supports a healthier ecosystem but also promotes resilience against pests and diseases through natural ecological processes such as pest predation and habitat diversification (Salazar et al., 1993b).

In specific cases, the studies pinpointed the types of trees that are particularly beneficial when intercropped with rice. Leguminous tree species, for example, were found to be advantageous due to their ability to fix atmospheric nitrogen, a vital nutrient for rice (Salazar et al., 1993b). The role of tree root systems in breaking hardpan soil layers also emerged as a crucial function, facilitating deeper penetration of rice roots and better access to nutrients and water (Salazar et al., 1993b).

These positive interactions, however, are not without challenges. The competition for light, space, and nutrients between the trees and the rice crop can be significant if not correctly managed (Salazar et al., 1993b). The selection of appropriate tree species and their spatial arrangement requires careful consideration to avoid detrimental effects on rice yields (Salazar et al., 1993b). Additionally, management practices such as pruning and the timing of tree planting relative to the rice planting season are critical factors that influence the success of these intercropping systems.

Overall, the advancement in understanding crop-tree interactions within alley cropping systems provides a promising avenue for enhancing the sustainability and productivity of rice cultivation. These insights not only help in formulating better agricultural practices but also in paving the way for more research aimed at fine- tuning these interactions to leverage the maximum benefit for both crop yields and environmental health.

Bibliometric Analysis of Rice Intercropping Research

A comprehensive bibliometric analysis was conducted to unravel the evolution and trends in the research of rice intercropping systems (Shahidullah et al., 2024). The review spanned over four decades, harnessing data extracted from major databases including Web of Science, Scopus, and Google Scholar. By employing tools such as VOSviewer and CiteSpace, pivotal publications, citation networks, and keyword frequencies were meticulously analyzed.

Key Findings and Trends

The analysis revealed a noticeable increase in publications from the early 2000s, correlating with a growing recognition of sustainable agricultural practices globally (Shahidullah et al., 2024). Initial studies were predominantly concentrated in Asia, particularly in China, India, and Indonesia, where rice is a staple food crop. The focus of early research was primarily on understanding the basic benefits of intercropping rice with various legumes and non-legume crops.

Over the years, the scope of research expanded, reflecting a shift towards more complex systems incorporating trees and other perennials (Shahidullah et al., 2024). This transition is evidenced by the emergence of new keywords and research foci, such as 'agroforestry,' 'sustainable yield,' and 'ecosystem services' (Shahidullah et al., 2024). The citations within this field suggest a strong linkage between rice intercropping research and broader themes of ecological agriculture and resilience in food systems (Shahidullah et al., 2024).

Geographical Distribution of Research

The geographical distribution of the studies also broadened with significant contributions coming from sub-Saharan Africa and South America, regions where sustainable practices are crucial to agriculture due to the vulnerability to climate change (Shahidullah et al., 2024). These studies contribute to a richer understanding of the localized benefits and adaptations necessary for successful intercropping practices in diverse ecological and socio-economic contexts.

Interestingly, a cluster analysis of the research network highlighted several highly cited cornerstone studies that have shaped current understanding and practices. These foundational papers often explore the physiological interactions between rice and companion plants, demonstrating how specific plant combinations can optimize light capture, improve water use efficiency, and enhance nutrient cycling.

Additionally, the analysis has pointed out a growing trend towards interdisciplinary research involving soil scientists, agronomists, and ecologists (Shahidullah et al., 2024). This collaboration is pivotal for developing holistic rice intercropping systems that are not only productive but also promote biodiversity, soil health, and ecological balance (Shahidullah et al., 2024).

The bibliometric analysis has underscored the necessity for further empirical and theoretical studies to address gaps in knowledge, particularly in the mechanisms underlying the observed benefits of intercropping. Furthermore, it highlights the need for innovation in policy making and local farming practice adaptations to support the scalability of successful intercropping models.

The findings from this bibliometric review serve as a crucial component in understanding the past trajectories and future directions of rice intercropping research. By recognizing influential regions, key players, and pivotal research themes, this analysis provides a valuable roadmap for upcoming research ventures and for the formulation of strategies aimed at enhancing the sustainability and productivity of rice cultivation systems worldwide.

Global Analysis of Yield Benefits and Risks from Integrating Trees with Rice

The integration of trees with rice cultivation presents a compelling solution to numerous agricultural challenges, particularly in enhancing yield stability while mitigating environmental risks (Rodenburg, Mollee, Coe, & Sinclair, 2022). A diverse array of agroforestry practices has been explored globally, with varying implications on both yields and ecological balance. These practices, predominantly utilized in regions susceptible to adverse climatic conditions and poor soil fertility, underscore the necessity of rethinking traditional farming methodologies towards more sustainable approaches (Rodenburg, Mollee, Coe, & Sinclair, 2022).

Overview of Agroforestry Practices

The concept of integrating trees in rice paddies – known as rice agroforestry systems – provides multifunctional benefits, not only increasing the productivity of rice but also contributing to a more dynamic agroecosystem (Rodenburg, Mollee, Coe, & Sinclair, 2022). Trees play a vital role in these systems by improving microclimatic conditions, which in turn enhances water retention and moderates temperatures around rice crops. Furthermore, tree roots help in stabilizing soil structure and increasing organic matter content, which are critical for rice growth under fluctuating environmental conditions (Rodenburg, Mollee, Coe, & Sinclair, 2022).

Implications for Sustainable Rice Production

Empirical data from several studies across Asia and parts of Africa indicate that the incorporation of nitrogen-fixing trees, such as species from the genus Faidherbia, significantly boosts rice yields (Rodenburg, Mollee, Coe, & Sinclair, 2022). These trees exhibit reverse leaf phenology, shedding their leaves during the rainy season, which coincides with the rice growing period, thus reducing competition for light while contributing organic material directly to the rice crops below (Rodenburg, Mollee, Coe, & Sinclair, 2022). This symbiosis not only improves soil nitrogen content but also offers a practical solution to the labor and cost- intensive application of synthetic fertilizers (Rodenburg, Mollee, Coe, & Sinclair, 2022).

However, the practice of integrating trees with rice does not come without its challenges and risks. One of the primary concerns lies in the selection of appropriate strategy for managing agricultural lands that have been compromised by industrial pollutants or mismanagement (Yang et al., 2021). The potential for scaling up these systems exists and could result in widespread adoption if the economic costs are balanced by the long-term benefits of restored land and increased agricultural output (Yang et al., 2021).

In conclusion, the coupling of upland rice cultivation with Solanum nigrum for phytoremediation represents a promising development in the pursuit of sustainable agricultural practices. This innovative approach harnesses the synergistic potentials of both species, addressing critical environmental challenges while fostering a productive and sustainable agricultural ecosystem. Further research into optimizing these interactions and understanding the long-term implications on soil health and crop safety is necessary to fully harness the benefits of such intercropping systems.

Biodiversity Conservation in Tropical Agroecosystems

The intricate relationship between agricultural practices and biodiversity conservation is particularly evident in tropical agroecosystems, where high biodiversity can be leveraged to enhance ecosystem services and sustainability (Perfecto et al., 2008). Integrating agricultural landscapes into broader conservation strategies is not only a pressing necessity but also a strategic opportunity to promote biodiversity throughout cultivated areas (Perfecto et al., 2008).

Argument for Integrating Agricultural Landscapes into Conservation Strategies

The argument for integrating agricultural landscapes into conservation strategies is grounded in the recognition that traditional separate zoning approaches, where conservation and agricultural areas are distinctly apart, are becoming increasingly untenable in the face of expanding human populations and the resultant pressure on land resources (Perfecto et al., 2008). Agricultural landscapes that incorporate elements of natural ecosystems not only support wild flora and fauna but also contribute significantly to the conservation of biodiversity at large (Perfecto et al., 2008). Such landscapes act as buffers and corridors, connecting protected areas and allowing for species migration and gene flow, which is critical in the context of climate change and habitat fragmentation (Perfecto et al., 2008).

Reviewing literature on the role of biodiversity in tropical agricultural landscapes underscores the myriad benefits that diversified farming systems offer. These benefits range from pollination, pest control, and nutrient cycling to cultural and aesthetic values (Perfecto et al., 2008). Research highlights that these systems, by mimicking natural ecosystems, can sustain a wide array of organisms, thus maintaining ecological functions and resilience. For example, studies have shown that birds and pollinators are notably more abundant and diverse in agroforests and mixed cropping systems than in monocultures (Perfecto et al., 2008). These findings showcase the potential of such systems to support conservation while maintaining productive agriculture.

Importance of Diverse, Low Input Agroecological Systems for Biodiversity Conservation

Moreover, the importance of diverse, low input agroecological systems cannot be overstated. These systems utilize practices that maintain ecological balance and reduce dependence on chemical inputs, thereby not only supporting biodiversity but also enhancing soil health and reducing ecological footprints (Perfecto et al., 2008). Their adaptability to local conditions, reliance on traditional knowledge and practices, and their capacity to sustainably manage natural resources render them invaluable in tropical regions where conservation and food production must coexist (Perfecto et al., 2008).

Role of Small Farmers and Grassroots Social Movements

Finally, the role of small farmers and grassroots social movements in creating sustainable landscape matrices for conservation highlights an often-overlooked aspect of biodiversity conservation (Perfecto et al., 2008). These stakeholders are vital in implementing and maintaining biodiversity-friendly practices due to their local knowledge and vested interest in ecological sustainability (Perfecto et al., 2008). Their practices often emphasize polyculture and agroforestry, which enhance both crop and non-crop biodiversity (Perfecto et al., 2008). Grassroots movements, advocating for sustainable and equitable resource management, play a crucial role in pushing for policies that integrate conservation objectives into agricultural development plans (Perfecto et al., 2008).

Through these discussions, the critical interplay between agriculture and conservation emerges vividly, illustrating that sustainable management of tropical agroecosystems is not only about enhancing agricultural yield but is intrinsically linked to preserving biodiversity. This synthesis offers a robust framework for understanding and improving the coexistence of agriculture and conservation, providing a pathway towards sustainable land use that supports both food security and ecological health.

Discussion

Synthesis of Findings from Reviewed Research Projects

The comprehensive review of research into rice intercropping systems highlights a series of promising outcomes for sustainable agricultural practices. Studies demonstrate that integrating different plant species with rice can lead to benefits such as improved soil health, increased biodiversity, enhanced resilience to environmental stressors, and improved yields. The analysis of alley cropping systems particularly underscores the symbiotic relationships between rice and leguminous tree species, which contribute significantly to nutrient cycling and soil fertility—vital for low-input farming systems. However, the variability in results across different geographical locations and species emphasizes the need for localized research to optimize intercropping strategies to specific ecological and socio- economic contexts.

Advantages and Challenges of Rice Intercropping in Permaculture

Intercropping rice within a permaculture framework offers multiple advantages, including reduced reliance on chemical inputs, diversification of produce, and higher overall productivity per unit area. This translates to better food security and economic stability for smallholder farmers. Additionally, such systems contribute significantly to ecosystem services like soil retention and carbon sequestration, thus aiding in the mitigation of climate change effects. Despite these advantages, challenges remain. The main issues revolve around the complexity of managing multiple species in a single plot, the need for detailed knowledge about specific plant interactions, and the initial transition period required for farmers to adapt to new agricultural methods. Addressing these challenges is crucial for the wider adoption of rice intercropping practices.

Potential Implications for Agricultural Practices

Locations with unique biodiversity and existing extensive rice cultivation stand to benefit significantly from the adoption of rice intercropping strategies. The potential for enhancing soil fertility through organic means is vital where soil erosion and degradation are prevalent. Introducing tree species known for their nitrogen- fixing capabilities could reduce dependency on synthetic fertilizers, improve water retention, and increase yield stability. Additionally, integrating native flora could help preserve biodiversity while providing additional food and medicinal resources to local farmers. However, the success of such programs would depend heavily on robust local outreach and effective training programs to ensure that farmers can implement and maintain these complex systems.

Future Research Directions and Priorities

Given the promising yet varied results of rice intercropping studies, future research should prioritize establishing clear guidelines for the implementation of such systems in diverse environmental and socio-economic settings. Longitudinal studies examining the long-term impacts of intercropping on soil health, crop yields, and ecosystem services are particularly needed. Research should also focus on the development of models to predict the outcomes of complex crop interactions, which could significantly aid in the planning and optimization of intercropping systems. Finally, there is a pressing need for participatory research that involves local farming communities, ensuring that scientific advancements are accessible and adapted to the needs of those most impacted by agricultural innovation.

Conclusion

Importance of Rice Intercropping for Sustainable Agriculture

The synthesis of the reviewed studies firmly establishes rice intercropping as a cornerstone for sustainable agriculture. By diversifying planting strategies, rice intercropping systems not only optimize land use but also contribute to a myriad of ecological benefits. These include enhanced biomass production, improved nutrient cycling, and reduction in the need for chemical inputs through natural pest control and weed suppression strategies. Such ecological intensification is pivotal in sustainably increasing agricultural productivity and resilience in the face of climate change and growing global food demands.

Call to Action for Implementing Permaculture Principles in Rice Cultivation

Given the compelling evidence presented, there is a critical need for stakeholders in the agricultural sector—from policymakers to practitioners—to embrace and actively implement permaculture principles in rice cultivation. This approach not only sustains food production but also promotes ecological health. Specific actions can include the adoption of guidelines for species selection in intercropping systems, investment in community-based training programs to spread knowledge on sustainable practices, and fostering policy incentives that encourage small-scale farmers to adopt agroforestry practices. Additionally, agricultural research institutions should continue to explore innovative intercropping systems, underscoring the importance of local environmental conditions and cultural practices in shaping successful integration of permaculture into traditional farming systems.

Closing Remarks: Significance for Global Food Security

This review has underlined how integrating permaculture principles, particularly rice intercropping, into mainstream agricultural practices is not merely a theoretical ideal but a practical solution to pressing global challenges. The potential of such practices to improve food security is immense, particularly in regions that are most vulnerable to food scarcity and the impacts of climate change. By fostering more resilient food systems through rice intercropping, the global community can move towards a more sustainable and food-secure future. Ultimately, the adoption of these practices represents a critical step towards achieving global food sovereignty and environmental sustainability, ensuring that future generations inherit a healthier planet. Implementing permaculture rice cultivation is indeed complex. However, nature itself is also complex. The crucial approach lies in comprehending this complexity, showing respect towards it, and collaborating with it rather than opposing it.

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"I have a dream to contribute to the development of Madagascar through the study that I have done. I came to the university because one of my favorite things was chemistry, so I wanted to continue and deepen it more."

JJSF Fellow
Boris Tsitonirina RAHARIJAONA
Masters Graduate, Water & Environmental Engineering
University of Antananarivo
Fellowship 2024

Mr. Raharijaona, an environmental engineering graduate student at the University of Antananarivo, has undertaken a significant project focused on earthwork planning to support the construction of freshwater ponds and the stabilization of surrounding berms. Building on the foundational research conducted by ARAFA, Raharijaona's work is pivotal in addressing the challenges of sustainable water management in Madagascar. His systematic approach provides practical guidelines for effectively building ponds while ensuring environmental integrity and structural stability.

In his research, Raharijaona emphasizes the importance of thorough earthwork planning as a precursor to successful pond construction. He begins with a comprehensive site assessment that includes soil analysis, topographical surveys, and hydrological evaluations. By understanding the specific characteristics of the site, including soil type and drainage patterns, Raharijaona can design ponds that are not only effective in water retention but also resilient to erosion and sedimentation.

Mr. Raharijaona's earthwork planning provides a comprehensive framework for the effective construction of freshwater ponds and the stabilization of berms in Madagascar. By building upon ARAFA's research and incorporating innovative strategies, his work sets the stage for sustainable water management practices that will benefit local communities and ecosystems. Through meticulous planning and community engagement, Raharijaona is paving the way for resilient and efficient water resource solutions in a region facing increasing environmental challenges.

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University of Antananarivo
Faculty of Science

Process Engineering and Environmental Engineering Research Unit (URGPGE)

URGPGE

Water Engineering and Environmental Engineering Courses

Planning Of Earthworks For A Rainwater Retention Basin And Stabilisation By Planting (Horticultural Planning): Lagooning

Presented by: Boris Tsitonirina RAHARIJAONA

Supervisor: Elando Fréda ZAMANILEHA

June 2024

LIST OF ILLUSTRATIONS

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- Glossary

PE (population equivalent)Unit of measurement used to assess the capacity of a treatment plant. This unit of measurement is based on the amount of pollution emitted per person per day.

- 1 EH = 60 g of DBO5/day at the station entrance, i.e. 21.6 kg of DBO5/year.

The European directive of May 21, 1991 defines the population equivalent as the biodegradable organic load having a biochemical oxygen demand in five days (BOD5) of 60 grams of oxygen per day.

SUMMARY

INTRODUCTION

As a reminder, water plays a particularly important role in daily life; it is found in all the activities that punctuate our daily lives: cooking, washing, various washing, waste disposal (toilet, sink, bathtub). In addition, during the rainy season, rainwater is lost everywhere due to the lack of planning for rainwater recovery and also the lack of will.

And the overall objective of this study is to master the supply of potable and sufficient water to the population of the University of Antananarivo. It is managed by collecting rainwater, transporting it to a large storage basin and treating it. By integrating modern infrastructure, sustainable management practices and continuing education in water conservation, the university can not only meet its current needs, but also prepare for a resilient and sustainable future in water management.

So, we have seen in the last book all the preliminary study of this project that starts with the geographical study of the study site up to the soil analysis and the planning of earthworks. The study of plants that can be used during the biological treatment in the treatment center or lagoon basin is already proposed. And we have already proposed three different plants that can be used as Phragmites australis ; Juncus effusus ; Cyperus papyrus.

But, when we talk about planning the earthworks of the stormwater retention basin and stabilization by planting, we will explore the different stages of the process, from the initial design of the earthworks to the implementation of adapted planting strategies. Thus, this document clearly addresses the design as well as the dimensioning of this lagoon.

Chapter 1: OPERATING PRINCIPLE OF NATURAL LAGOONING

I: DESIGN

Natural lagooning is based on a bacterial culture that is mainly aerobic. This is then separated by a sedimentation mechanism. The principle is to recreate "buffer" environments or basins through which wastewater or polluted water will pass, before being released into the natural environment.

I.1. PRETREATMENTS

1. Screening

Screening must be provided. If the installation includes a lift, a screening basket will ensure the protection of the pumping devices. As in any other use, the operating means must be available: jib crane and hoist if necessary, pressurized water, storage containers, waterproofed washing and draining area.

If the arrival is gravity-fed, manual screening, oversized to allow spaced visits (once a week in dry weather and additional cleaning in the event of a storm on unitary networks), is the minimum solution. Mechanized screening is desirable and easily amortizable if the treatment plant is not too far from the electrical connection points.

2. Desanding

Except in very special cases, sand removal is not necessary. It may be planned when the network is likely to transport particularly large quantities of sand.

3. Degreasing

In general, since the lagoon must be reserved for domestic effluents, a separate degreaser is not necessary. A simplified degreaser (a siphon partition may suffice) will be installed at the head of the first basin to avoid the presence of various floats.

The surface must allow a peak ascent speed of between 10 and 20 m/h. Maintenance will be particularly facilitated by good accessibility. A footbridge also allowing access for emptying the sedimentation cone at the entrance to the first lagoon is of definite interest.

I.2. THE LAGOONS

1. Number of lagoons

Operating reliability comparable to that of other processes with a comparable hardiness (bacterial beds, etc.) is only achieved by planning the installation of three lagoons in series. The respective role of these basins can be summarized as follows:

- the first lagoon is the main site of the reduction of the carbon pollutant load, the limit of the treatment being relative to the concentration of microscopic algae in the effluent leaving this basin;
- the second lagoon reduces nitrogen and phosphorus and allows on average a reduction in the concentration of algae;
- the third lagoon significantly improves these treatments. The additional reduction is however relatively low at the beginning of the life of the installations and in the case where all the basins have significant sludge deposits (average height greater than 15 - 20 cm);

Furthermore, the presence of three basins allows, during the cleaning of the sludge from the first, to maintain a good quality of treatment.

2. Implementation of the lagoons

Lagoon basins can be created in several ways: either by digging and removing the spoil, or by digging and building embankments, or by creating dikes surrounding the land which has simply been stripped, not dug or even raised.

The shape of the basins must be regular. Angular shapes are the site of significant deposits and promote dead zones. The depth of the three basins is variable. For microphyte basins it is often around 1.2 meters, at a minimum, it must be around 1 meter to prevent the growth of higher plants, allow light penetration and therefore oxygenation and limit the effects of possible thermal stratification of the basins.

The slope of naturally sealed dikes must respect a height/length ratio of 1 / 2.5 to limit the erosive action of the wave, facilitate routine maintenance and allow access for cleaning equipment. In the case of laying a geomembrane, for the dikes, the height/length ratio will only be 1 / 1.5. The dikes must be erected by successive compaction of 15 to 20 cm slices.

Siphon connections must be provided between the basins to block duckweed or other floaters. It is necessary to provide a bypass for each basin to facilitate emptying and cleaning operations and to have an overflow per basin.

To prevent erosion by sloshing and rodent damage, it is advisable to grass the banks before flooding or to use self-locking slabs, geogrids or any other bank protection material.

The structures must be filled with water quickly to ensure permeability (prevent the risk of cracks and the development of vegetation in the soil), check the watertightness and promote the establishment of the ecosystem. Poor watertightness may lead to pollution of the water table by percolation of wastewater. To maintain a good hydraulic regime inside the lagoon, the flow rate of the inputs (wastewater + rain) must generally compensate for losses (infiltration + evaporation).

3. Flow measurement works and macrophyte planting

On the one hand, on all installations, a flow meter channel hydraulically independent of the water level of the last basin will be installed at the outlet of the lagoon. When the feed is gravity, a second flow meter channel will be installed upstream of the first lagoon, preferably with a lateral contraction threshold. In the event of a backflow, the operating time of the pumps will provide the flow.

On the other hand, the tertiary lagoon can be planted with macrophytes which are intended to be supports for bacteria, algae and zooplankton and especially for daphnia (small crustaceans) which play an essential role in the filtration of algae. They are made up of reeds, chair rushes, bulrushes or marsh irises.

The presence of macrophytes increases the performance of the lagoon, particularly for nitrogen and mineral phosphorus. However, they need to be mown once a year. The cutting must be done above the water surface to allow normal plant recovery and the cutting products must be removed from the basins.

I.3. ADAPTED PLANTING

To get the best results from your lagoon, it's time to discover the ideal plants to create a thriving lagoon. Here is our selection of the three most suitable plants to purify and beautify your aquatic space. They are Phragmites australis ; Juncus effusus ; Cyperus papyrus.

Each plant has specific characteristics that contribute to water purification, such as nutrient absorption, mechanical filtration, decomposition of organic matter, etc. We also provide you with practical advice for planting and maintaining these plants, to ensure their full effectiveness in your lagoon system.

II. LAGOON SIZING

Table 1: Sizing of all units studied by natural lagooning

Settings	Unit	Standard values	Recommended values
Pre-treatment			
Spacing of screening bars	Cm	3	3
Degreaser Ascent Speed	m3/m2/h	10 to 20	10 to 20
Submerged height of the siphon wall of the grease trap	Cm	40 to 60	40 to 60
On depth of sedimentation cone	Cm	70	70
Lagooning			
Maximum permissible permeability	m/s	10-8	5. 10-8
Dwell time	Days	60	80
Unsealed lagoon slope	H/L ratio	1/2.5	1/2.5
Waterproofed lagoon slope	H/L ratio	1/1.5	1/1.5
Primary lagoon			
Sizing	m2/EH	6	9
Depth	M	1.2 to 1.8	1.2 to 1.8
Dwell time	Days	30 to 40	50 to 55
Secondary lagoon			
Sizing	m2/EH	2.5	4.5
Depth	M	1.0 to 1.4	1.0 to 1.4
Dwell time	Days	7 to 10	15 to 20
Tertiary lagoon			
Sizing	m2/EH	2.5	4.5
Depth	M	1.0 to 1.2	1.0 to 1.2 (without macrophytes), 0.3 to 0.4 (with macrophytes)
Dwell time	Days	7 to 10	5 to 15

Source: Author, July 2024

III. BLOCK DIAGRAM

The water to be purified is directed to lagoon basins, which are divided into different zones, each fulfilling a specific role in the purification process. The first zone, called the " pretreatment zone ", allows large particles to be retained and the organic load to be reduced.

Then the water passes through the " clarification zone ", where sediments settle at the bottom of the basin.

Finally, the water reaches the " lagoon zone ," where plants play a vital role in purification. The roots of the plants act as biological filters, absorbing nutrients and pollutants from the water, while beneficial microorganisms break down organic matter. As the water passes through these different zones, it becomes increasingly cleaner and purer. So, the following figures show the schematics of this lagoon.

III.1. TOP VIEW

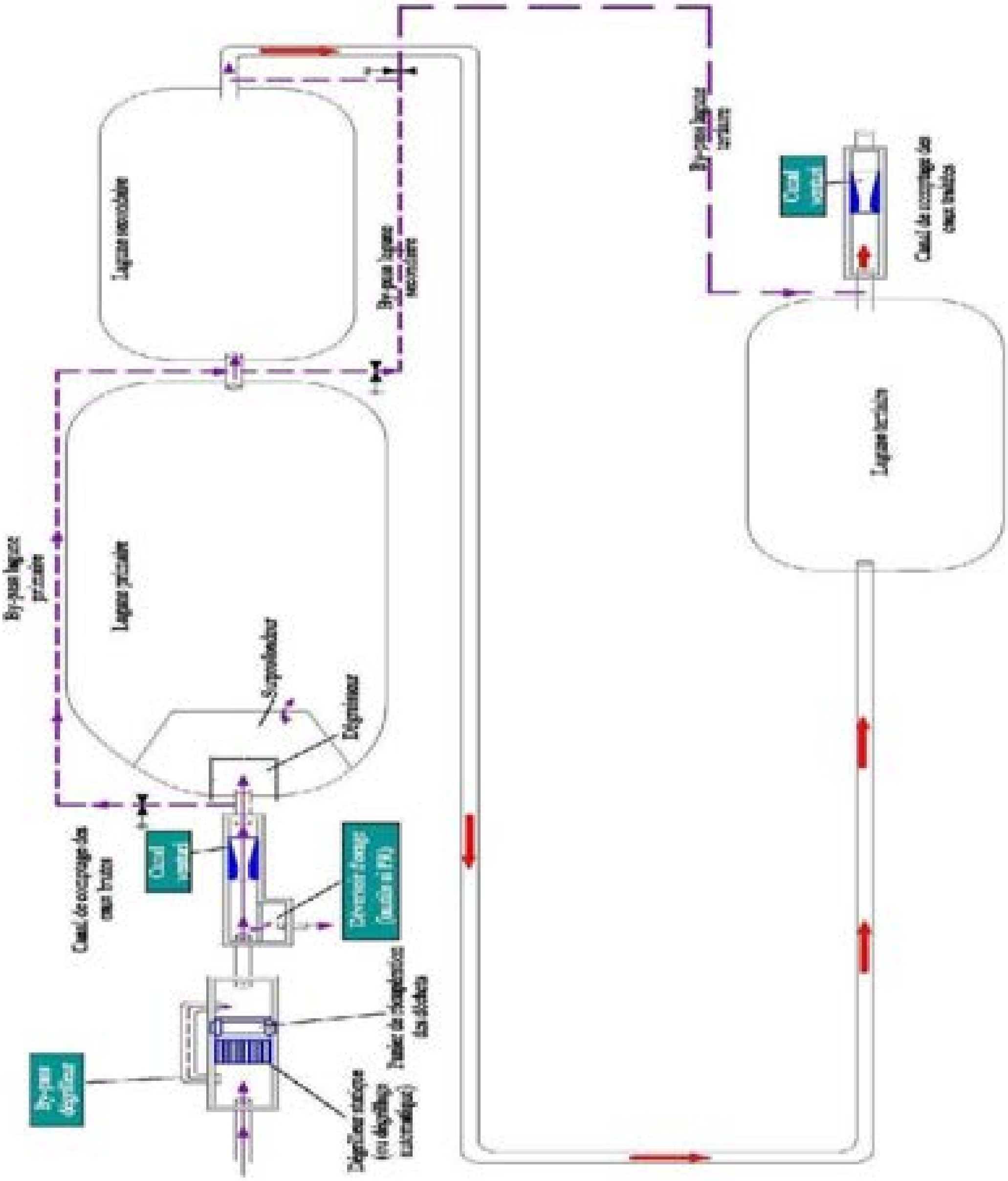

Figure 01 : Vue au-dessus de point de lagunage

III.2. SECTIONAL VIEW

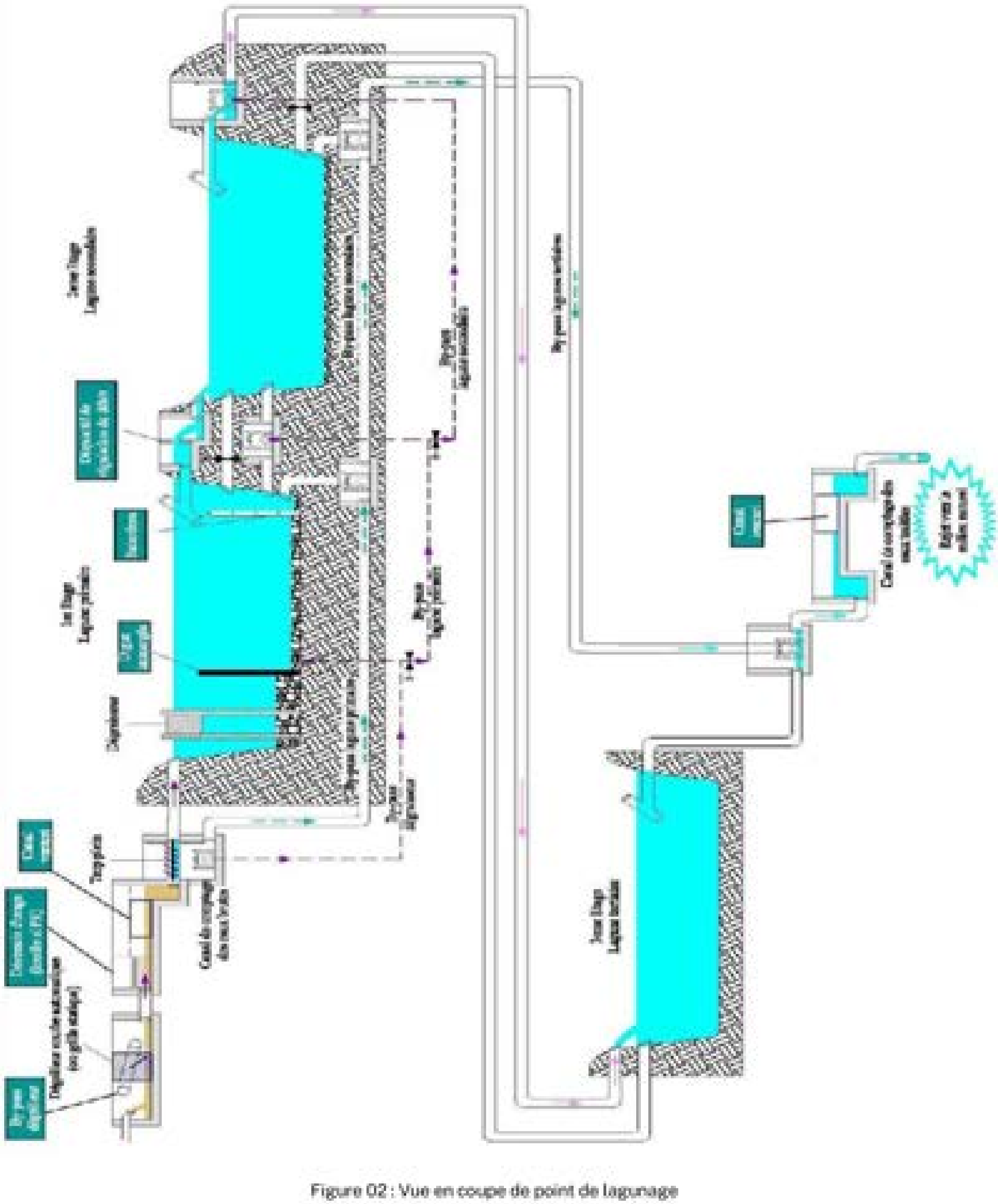

Figure 02 : Vue en coupe de point de lagunage

Chapter II: MONITORING AND EVALUATION OF LAGOONING

II.1. DETECTION OF MALFUNCTIONS

Two closely related indicators signal that the head basin is undergoing a dystrophic crisis:

- The appearance of foul odors and
- The change in color (or turn) of the body of water.

- The disappearance of algae and the predominance of bacteria cause the appearance of a brown, gray color. The pool becomes completely anaerobic, favoring reducing metabolisms with the release of H 2 S in particular, and therefore odors.
- When the H2S concentration is high, the development of sulfur photosynthetic bacteria predominates and the pool takes on a red, pink, ochre or brown color. At this stage, there is a decrease in odors since the sulfur is consumed.
- Green coloring indicates a return to a normal situation.
- The phenomenon can stabilize at the first stage which is the most annoying for the neighborhood. The quality of the discharge however frequently remains correct.
- The red color can lead to a reduction in the overall efficiency of the installation, with purification then being carried out more by the following basins.

From the survey cited above, it emerged that approximately 30% of the lagoons had at least once presented a malfunction problem attributed to various causes (overload, nature of the effluents, duckweed, lack of maintenance, etc.). This concept of malfunction deserves to be clarified and this chapter is devoted to it.

Table 02: Main possible malfunctions

Dysfunction	Cause	Solution
- Empty pools - Difficult filling - No output flow - Significant drop in level during dry periods	- Infiltrations due to insufficient sealing - Interaction with the water table - Presence recovered from an old drainage - Hydraulically loaded installation	- Carry out a serious soil study (drilling, excavation, permeability measurement) - Respect a margin of at least 20 cm between the lowest level of the earthworks and the high level of the water table in the basement (capillary fringe) - Waterproof the bottom of the pools (clay, geomembrane, etc.) - Add a supply of clear water - Biological control: settling of ducks - Do not use weedkiller or other chemical product (toxic to fish) - Manual or mechanical elimination after concentrations at one
- Proliferation of duckweed resulting in a plant cover preventing	- Low load - Secondary or tertiary basin under organic load	
oxygenation and the development of algae (rotting of the water).	- Temperature rise - High concentration of nitrogen, phosphorus, calcium or magnesium	point in the basin (by wind)
- Degradation of the banks	- Erosion due to the absence of grass	- Do not use weedkillers for river bank maintenance
	- Rodent activity	- Rodent control
- Rising water level during flood periods	- Discharge pipe submerged by the receiving environment (principle of communicating vessels)	- Position the pipeline so as to limit the introduction of clear water into the lagoon (possibility of non-return valves)
	- Flooding of the system by the river	- Build dikes at least 50 cm higher than the flood level
	- Communication with the water table (poor sealing)	- Waterproofing of the bottom of the pools (clay and bentonite, avoid installing geomembrane)
- Odors	- Poor maintenance of pre-treatment	- Increase the frequency of visits for maintenance of the installation
	- Silting up of the first lagoon	- Ensure regular monitoring of sludge and clean if necessary, even partially
	- Anaerobiosis of effluents	- Recirculation of water from the last basin or supply of clear water
	- Fermentable septic effluents	- Eliminate sedimentation cones
	- Presence of slurry or other non-domestic wastewater (milk, etc.)	- Prohibit the discharge of slurry and other non-domestic discharges
- Red turn of the lagoon - Odors - Decrease in quality	- Septic effluents (development of photosynthetic sulfur bacteria)	- Prohibit the connection of septic tanks
	- Limitation of light penetration (floaters)	- Limit the residence time in the networks or set up systems to combat H_2S ($FeSO_4$, aeration)
-Degradation of macrophytes	- Omnipresence of rodents	- Rodent control
	- Introduction of ducks	- Provide food supplements to sedentary ducks
	- Presence of hunters	- Exclude the lagoon from the hunting perimeter
- Excessive presence of green algae in the treated effluent (discharge level not respected, alteration of the quality of the natural environment)	- Temperature rise (summer) - Installation in organic overload	- Seeding of the station with daphnia - Dense planting of the lagoons with macrophytes - Tertiary treatment by filtration (sands) - Extension of the primary lagoon

Source: Author, July 2024

II.2. MONITORING AND MAINTENANCE OF LAGOONS

It should be noted that natural lagooning is a purification system in its own right. Therefore, it is very important to keep an operating log. All the measurements and maintenance operations useful for this lagooning must therefore be kept regularly.

1. General surveillance

General monitoring is essential to detect any anomalies in the installation such as erosion of dikes, the presence of rodents, obstruction of communication structures, development of water lenses.

The operator must in particular check the following points:

- Good water flow;
- the color of the water;
- the condition of the dikes;
- absence of floaters;
- the absence of odors.

To do this, it is essential to go through all the dikes (this passage also creates a "disturbance" which can dissuade rodents from settling). Self-monitoring is done once a week for at least 30 minutes to 1 hour.

2. Maintenance

Pretreatment Maintenance

Maintenance of pre-treatment works is necessary for:

- prevent the network from being loaded or the effluent bypassed ;
- avoid bad odors or disturbances on the first lagoon;
- reduce the risk of turning this place into a "feeding trough" for rodents.

The waste removed from the pre-treatment must not constitute a new source of nuisance. It must be evacuated to a class 2 technical landfill site in the case of the largest installations. Burying the waste on site is an unsatisfactory palliative, and in any case the addition of lime is necessary to stabilize it.

Maintenance of the surroundings

- Mowing vegetation on dikes and banks

This operation is an important part of the operation of a lagoon. In addition to the objectives of making access to the body of water easy and preserving the aesthetic appearance of the station, mowing must limit the installation of rodents and control the condition of the banks. During mowing, the introduction of cut plants into the basins should be avoided as much as possible.

Vegetation control using weedkillers should be avoided due to the risks of toxicity and increased erosion phenomena (except on rock dikes where a "systemic weedkiller" is the only means of controlling vegetation).

- Mowing the plant belt around the body of water

This operation is as important as the previous one because it influences the functioning of the lagoon. The objectives are:

- avoid the progressive invasion of the basins;
- limit the development of insect larvae (mosquitoes in particular);
- limit the installation of rodents.

The presence of this plant belt is very important to reduce the harmful effects of the wave when there is no rockfill; it also serves to retain the cut grass during mowing at the banks. However, under no circumstances should the plants encroach on the basin.

3. Rodent control

The presence of rodents is common in a lagoon installation. Preventing their proliferation aims to:

- to prevent erosion of the dikes
- prevent hydraulic short circuits;
- to avoid altering the watertightness of the basins;
- where appropriate to prevent the destruction of macrophytes.

The products to be used are different depending on whether they are water rats (dicoumarin), muskrats (chlorophacinone) or nutria (bromadiolone). To be effective, this operation must not be limited to the immediate surroundings of the structures.

4. Cleaning the sludge at the head of the first basin

Regular cleaning of the sedimentation cone at the entrance to the first basin must be integrated into the current operation. Other points of the lagoons where the deposits are the most significant (in particular: the corners, the peripheral zones and the "inlets-outlets" of each basin) can also be subject to partial cleaning.

5. Fight against duckweed

Lentils disrupt purification due to the interruption of light penetration and the resulting anaerobiosis. In addition, in the absence of extraction, they contribute to a significant increase in the volume of sediment and their degradation increases the organic load to be treated. Preventive treatment methods are preferable to curative methods.

6. Mowing macrophytes

In the case of macrophyte lagoons, mowing is absolutely necessary to prevent the rotting of plants in the water that recharges the basins with organic matter and nutrients. This operation also limits preferential water flows that reduce residence time.

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Table 03: Lagoon point maintenance program

Type of monitoring and maintenance	Frequency	Time needed
General surveillance	once a week at least	1/2 hour to 1 hour
Pretreatment Maintenance	once or several times a week depending on needs	1/4 hour to 1/2 hour
Mowing vegetation on dikes and banks	two to four times a year, to be adapted according to climatic conditions	One to five days depending on the size of the station and the equipment used
Mowing the plant belt around the body of water	two to four times a year	one to five days depending on the case
Rodent control	once a year, poisoning campaign (autumn or winter)	
Cleaning the sludge at the head of the first basin	once a year on average (to be adapted according to deposits observed by sampling)	pumping with or without lowering the water level
Mowing macrophytes	once a year at the end of summer (August-September)	1 to 5 days depending on the surface

Source: Author, July 2024

CONCLUSION

In conclusion, lagooning is a natural and ecological solution to purify the water in your pond or natural swimming pool. Thanks to the power of plants, you can preserve the beauty of your aquatic space while considerably improving the quality of the water. By creating a balanced ecosystem, lagooning offers a sustainable and aesthetically pleasing alternative to traditional purification systems.

The stability of the operation of a lagoon system depends largely on the design of the first basin. Consequently, to limit the risks of total anaerobiosis of the first basin resulting from an excessive organic load, an increase in its surface area of 20% is necessary compared to the previous size (Inter-Agency Study, 1979), i.e. now 6 m2 /PE. The shape and depth recommended for this basin must be respected. For the next two basins, the general design remains unchanged, i.e. a cumulative surface area of 5 m2 /PE.

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"My highest priority in life is to address the water issues in Madagascar and contribute to achievin the objectives of sustainable development."

JJSF Fellow
El-Banou, Charles
Masters Graduate, Chemistry
University of Antananarivo
Fellowship 2024

Introduction to the Research of Mr. Charles El-Banou ANDRIAMAHENINTSOA

We are honored to present the findings of Mr. Charles El-Banou, whose extensive research on the existing water infrastructure around our campus has provided critical insights into our water management strategies. Through a comprehensive assessment of the current state of water tanks and other storage facilities, Charles's work revealed that most onsite water tanks are empty and, consequently, that relying on tanks alone is not a viable solution for achieving our rainwater capture goals.

Mr. El-Banou's research has been instrumental in guiding our understanding of the limitations of traditional water storage systems. His thorough analysis highlighted the inefficiencies associated with current practices, paving the way for a re-evaluation of our approach to water management.

Thanks to Charles's diligent efforts, we have concluded that constructed wetlands represent a more effective and sustainable option for rainwater capture and management. By integrating his findings into our planning, we can develop innovative solutions that align with our goals for sustainable water use.

We extend our heartfelt gratitude to Mr. El-Banou for his invaluable contributions to this project. His research not only enhances our knowledge of the existing infrastructure but also sets the foundation for implementing more effective and eco-friendly water management practices on campus.

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UNIVERSITY OF ANTANANARIVO
FACULTY OF SCIENCES
WATER-ENVIRONMENT ENGINEERING

JACQUELYN JESTINE SANDERS FOUNDATION

FELLOWSHIP 3A :

RAINWATER COLLECTION AND STORAGE

By ANDRIAMAHENINTSOA Charles El-Banou

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INTRODUCTION

In Madagasikara, during the stormy season and the rainy season; the rainwater submerges certain surfaces. However, they are underexploited, thus creating problematic factors at the societal level, especially in the University site.

Can we exploit rainwater to reduce the water shortages in the campus ? we can store them followed by various processes (capture, filtration,) before using it. To be able to satisfy the needs of the university from ANTANANARIVO, the tanks can be introduced inside the site to store rainwater which can be used in most cases as source of water use laboratory, elements which all need water. It will therefore be a question in this research as an essentially technical object and more generally, our ambition is to contribute to awareness of the important of treatment and to the management especially of rainwater at the end in a holistic and integrated manner in thinking about water and sanitation.We need to have the information for the tanks which exist on the site of University.

AREAS OF SUBJECT

I. SOME DEFINITION:

THE IMPLUVIUM is a rainwater collection system made up of a surface, gutters, pipes circulating rainwater to the tank, and a storage tank. (1)

STORAGE TANK is a equipment of various volumes and different shapes to store water to be consumed or used. (2)

II. RAINWATER BACKGROUND:

The rainwater that is going to be stored must first be intercepted on a surface called IMPLUVIUM which can be judged according to two criteria : healthiness and the coefficient of runoff. The protection of impluvium must therefore be a primary concern, including the installation of a fence, to prevent the approach of animals and the passage of people is essential. It will have a twist slope of 10%

The quality of the atmosphere through which rainwater passes must be considered depending on the context project location. Indeed, before even arriving on a roof surface, rainwater presents an acidic character and may contain traces of pesticides, hydrocarbons, organisms pathogens, or certain heavy metals. (3)

Local rainfall and weather conditions can also cause strong variations in the quality of collected rainwater depending on the intensity and frequency of rain. Thus, a regime of heavy precipitation with alternation of long periods of dry weather will cause great variation in rainwater quality recovered.

In a rainwater harvesting system which consists of a collection system (the roof), recovery (gutters and pipes) and storage (tank). (4)

The quality of rainwater runoff downstream from roofs varies greatly. She depends on both from the receiving environment, roof materials, design and nature recovery system,tank materials, and storage conditions. (4)

III. THE STORAGE TANKS ONSITE-QUALITATIVE LOGISTICAL ANALYSIS:

Location of storage tanks near a heat source (solar exposure, proximity to the boiler room system) should be avoided, because it is likely to promote the development of microorganism. Polyvinyl chloride recovery tanks (PVC) or high density polyethylene (HDPE) must be analyzed for the rainwater recovery, inert concerning water, subject to atmospheric pressure. (5)

Currently, at the UNIVERSITY OF ANTANANARIVO, different tanks are installed near buildings, some are placed in the garden and they are powered by JIRAMA industry (JIro sy RAno MAlagasy).

FIGURE 1 : Three tanks near the science department

They can stored 50 000 liters of water. Before we use it for cleaning the toilets and now, they are no longer functional.

FIGURE 2 : MAP of the University of Antananarivo « the science departement » which exist the three tanks

FIGURE 3 : Tank in the garden of the economic department

According to the information, this tank can stored 10 000 liters of water and it is powered with the water from IKOPA by a local company. The latter is transported by trucks.

The stored water is pumped in order to water the gardens, the flowers and even to minimize JIRAMA water.

FIGURE 4 : MAP of the University of Antananarivo : « the garden of economics department» which exist an tanks

FIGURE 5 : An areal blue tank and the horizontal tank in the building of the « Madagascar Institute for Vaccine »

An aerial blue tank of 3000 liters localeted near the research of vaccine building, also have a horizontal tank for 3500 litres.There is a solar panel to provide energy and to pump the water stored in the horizontal tank to the overhead tank.

The water store is using for watering too the little garden and for cleaning equipment.

FIGURE 6 : MAP of the University of Antananarivo : « the building of the Madagascar Institute for Vaccine » which exist theirs tanks

Near from the economic department, an underground cistern made manually by digging 3 successives cubes linked to each other by a pipe with a volume of 8 meter3 , this storage can help the tanks in the garden with rainwater.

FIGURE 7 cistern undergroung « near of the economics department »

FIGURE 8 MAP of the University of Antananarivo : « near of the economics department » which exist an underground cistern

FIGURE 8 : An tank near the swimming pool with the volumes : 5000 liters

This tanks is needed for storage the water to wash the toilet near the swimming pool and it is too powered by JIRAMA

FIGURE 9 : MAP of the University of Antananarivo : « near of the swimming pool » which exist a blue tank

FIGURE 10 : An tank above « the AMPHI building » with the volumes : 2500 liters

This tank of 2500 liters is used for the buildings « AMPHI and the BIG AMPHI » in the toilets and it help too the underground strorage to store the water for the department.JIRAMA powered this tanks.

FIGURE 12 : MAP of the University of Antananarivo : « AMPHI DEGS » which exist a blue tank

FIGURE 10 : MAP of the University of Antananarivo : An tank in « the presidency building » with the volumes : 15000 liters

The storage at the presidency has a capacity of 15000 liters and supplies water to several faculty.

It is price vary depending on the storage volumes,for 10m3 or 10 000 liters, they cost **12,588, 000 Ariary or 62,942,000 Francs** and for volumes of 7,5m3 therefore **9,840,000 Ariary or 49,200,000 Francs.** Indeed, cistern for 3000 liters cost **7,248,000 Ariary or 36,240,000 Francs** and **8,028,000 Ariary or 40,140,000 Francs** for the volumes of HORIZONTAL containers. (6) Considering the diameters of the lids. We can enter the tanks. Furthermore we can clean these tanks on the outside but it is a bit difficult on the inside. (6)

CONCLUSION:

On the ANTANANARIVO university, there is an underground storage near the economics department with the volumes : 24000 liters and in its garden,a tank of 10000 liters ; In the building of Madagascar institute of vaccine ,there is 3000 liters an 3500 liters. It exist 3 large tanks of 50000 liters near the science department. An tanks in the presidency building with 15000 liters. There is too an tanks near the swimming pool with 5000 liters of volumes and above the AMPHI building,a blue tank of 2500 liters. The total volume of existing tanks on the university site is 213000 liters.

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UNIVERSITY OF ANTANANRIVO
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Fellowship 3A:

UNIVERSITY RAINWATER STORAGE RECOMMENDATIONS

By ANDRIAMAHENINTSOA Charles El-Banou

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I. INTRODUCTION:

Today, drinking water is used for all kinds of purposes (domestic, agricultural, industrial), including those for which this quality does not seem essential. Nowadays, rainwater can be used for certain purposes that are in line with this logic. In particular, if it is impossible to infiltrate rainwater in situ, reclaiming it for use is a way of preserving the resource quantitatively. Moreover, rainwater has long been perceived as a source of nuisance to be disposed of (1). The installation of water reservoirs and underground drainage networks at the University of Antananarivo was essential for certain uses; we can promote and improve water storage systems to guarantee the next year or perhaps years to come.

II. MODELS AND RECOMMENDATIONS:

1.Water collection system:

Near the Faculty of Science, there are three (3) non-functional water storage tanks (50,000 liters). During the rainy season, they can be used to store as much rainwater as possible. The length of the gutter depends on the surface area of the roof catchment within the faculty, which is related to the storage volume and the annual rainfall.

According to the simplified design, we recommend an agglo basin to evacuate the water not stored by these three existing tanks to the drain and a single water intake with taps for use. (2) We can store rainwater without waiting for the water distributed by JIRAMA, the volumes of tanks are necessary and we can have large volumes of water but. At the same time, existing cisterns of the same volume can be installed to receive water from JIRAMA.

Design :

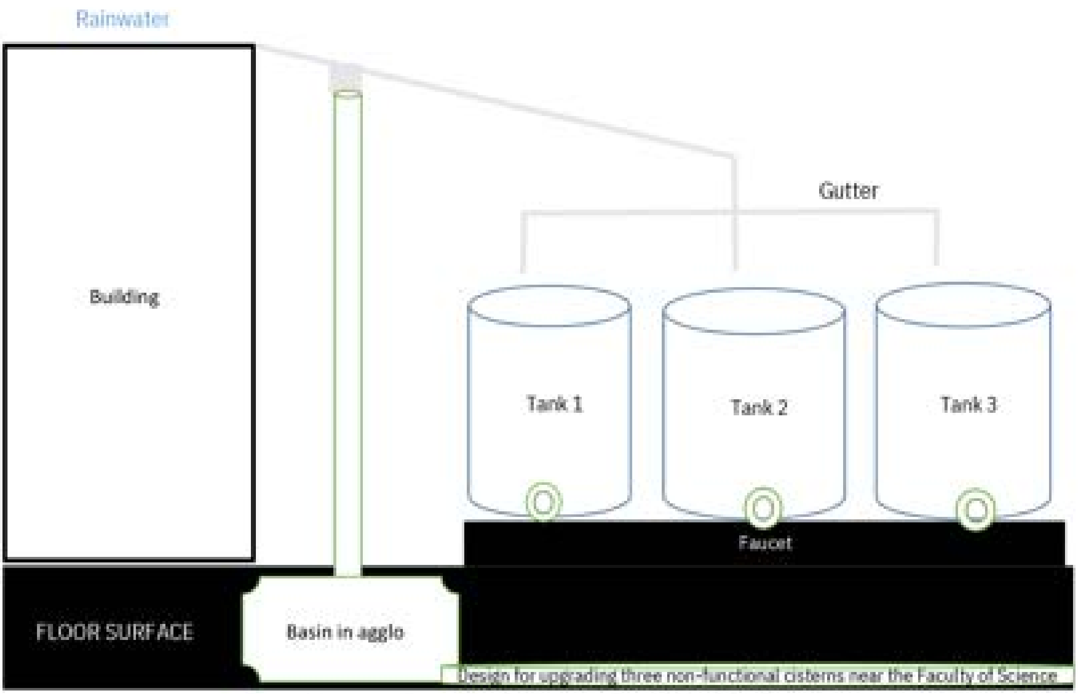

Figure 1: Rainwater harvesting design near the Faculty of Science

The optimization of the water collection system is useful given the non-functionality of the tanks, so its use is favored for years to come and to act as a model. Below is the location of the tanks.

MAP 1: Location of the three non-functional cisterns near the Faculty of Science

2.A dry open-air basin:

It is useful for increasing the volume of water stored at the university site during rainy events. In dry weather, they can be used for other purposes (pedestrian zone, garden or play area). Drainage is often required to keep the basin dry during wet weather, and the slopes of the structure must be gentle (3 m long by 1 m high). Maintenance is so important that muddy areas can form at the bottom of the pond. In this case, a drainage system is required. (4)

Infiltration basins allow water to be temporarily stored before infiltration, and positioned at a low point to ensure gravity operation. Easier to implement, but the aim is to avoid infiltration, so the use of cement liners to capture rainwater is fundamental. (5)

We can recommend several large underground storage volumes on a sloping site (university hill) with a volume of 8 cubic meters, for maximum water storage and other uses such as watering.

Design :

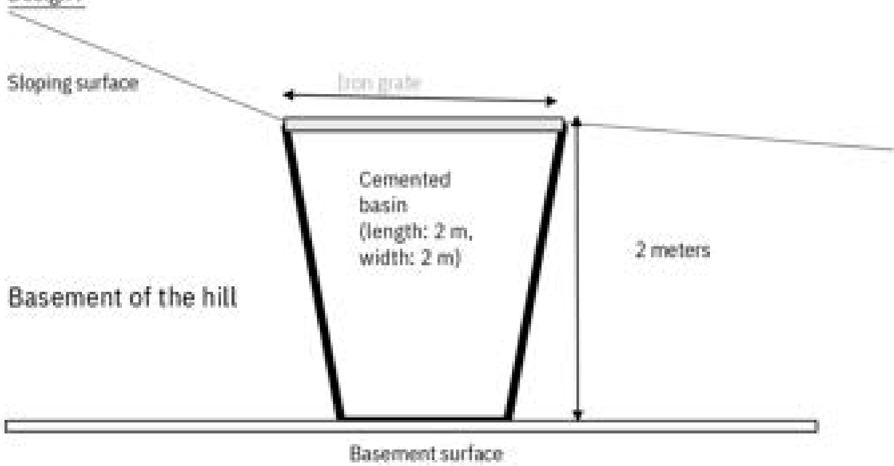

Figure 2: Rainwater harvesting design for the university hill basin

Sloping land is the most recommended for maximum possible water flow from basins of precise volumes. The MAP below shows the location of the hill.

MAP 2: Inclined site for a dry open basin at the University of Antananarivo

3.An infiltration trench:

Trenches are perfectly suited to urban areas and similar to dry open ponds, and can meet the needs of different types of space, such as near a rolling road downhill within a pipe, provided the latter's foundations or any subsoil are well protected from excess moisture. Surface materials can be a waterproof coating, or grates (when vehicles drive over them) for maintenance purposes. (5)

Water supply can be provided by infiltration of run-off water through the porous pavement, but the 4-cubic-meter volume basin is fundamentally built up by multiplying the water at pipe level. Advantages include good landscape integration, easy maintenance and simple installation. (6)

<u>Design :</u>

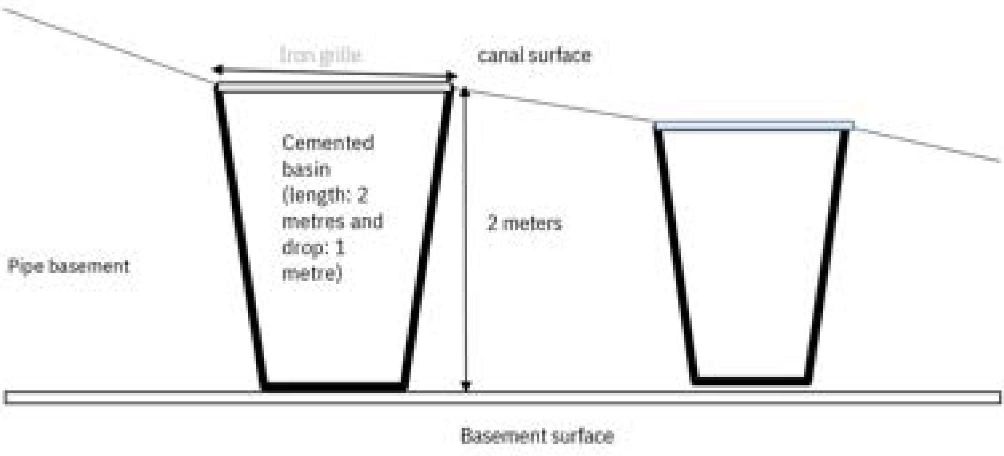

Figure 3: Rainwater harvesting design for pipe sites

Along the University's piping circuits, various devices can be placed one beside the other with a difference of around 1 meter to obtain rainwater whose purpose is to optimize exciting reserves for building, watering or gardening.

MAP 3: Possible canalization for an infiltration trench at the University of Antananarivo

4.Increase in the number of overhead tanks in all départements:

Within the site, the various buildings have the capacity to install overhead tanks on or off their roofs. This system can capture and optimize the volume of rainwater collected within the university grounds.

Close to the vaccine research building, the overhead storage model is necessary if there is to be space to place the tanks and pillars. The system's power supply depends on the voltage provided by the solar panels to bring the stored water up from the terrestrial tank to the aerial

tanks via wires and pipes; the design below can give some of the details and shows that the storage is twice as good as the existing tank because there are

another 3000-litre tank in the middle of the pillars. (7)

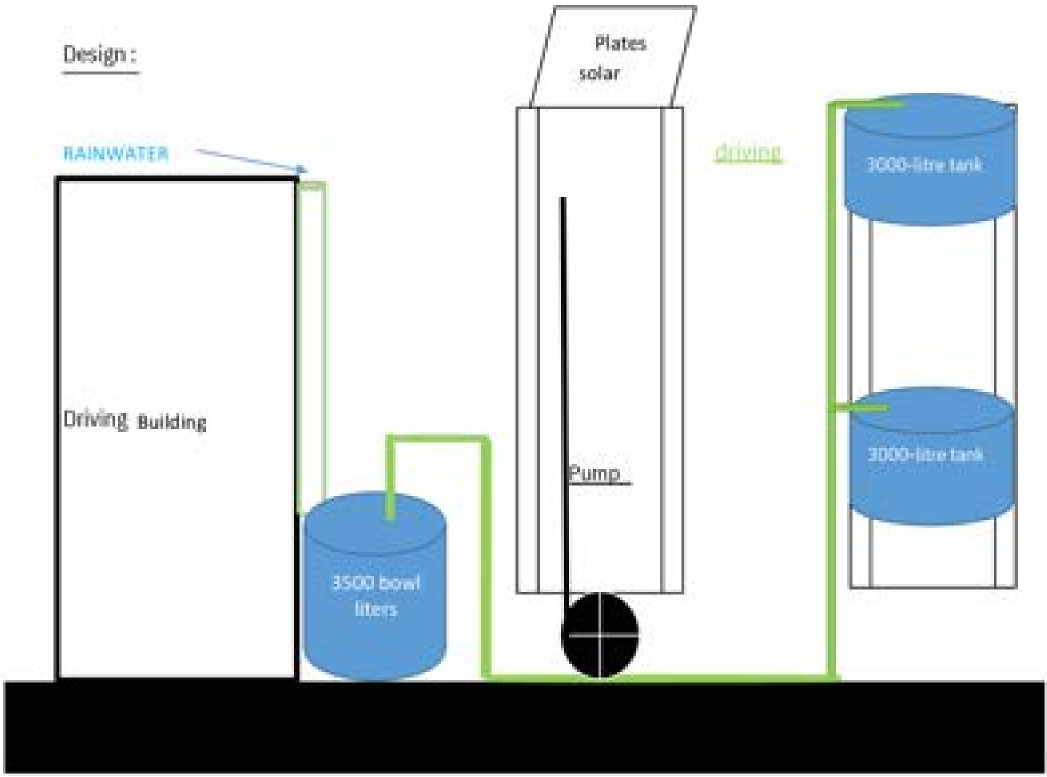

Figure 4: Rainwater harvesting design for overhead tanks

This model is acceptable to the site, especially to the various faculties or university buildings, if there is space for the tanks and solar panels. Almost all university buildings have collector roofs.

MAP 4: Buildings for aerial tanks at the University of Antananarivo

III. SUMMARY:

Given the total volume of existing tanks within the university site: 213,000 liters, tank optimization is fundamental by building rainwater catchment models based on these volumes. To increase the volume of water stored in the coming year, the functionality of the tanks near the Faculty of Science, the installation of open-air basins of varying volumes, infiltration trenches at pipe level, and overhead tanks on buildings.

IV. CONCLUSION:

In a nutshell, the purpose of rainwater tanks is to relieve us of the expense of connecting to the regular water supply network. Our existing tanks may not be able to cover all our on-site needs due to prolonged dry spells. Underground networks are required in addition to water collection systems through roofs, infiltration basins on sloping surfaces and infiltration trenches.

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5. https://www.siavos.fr

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Introduction to the research by Mr. Stenny Randriamaherininaina: Assessing the Aging Infrastructure of the University of Antananarivo

This report, authored by Mr. Stenny Randriamaherininaina, provides a critical examination of the aging infrastructure at the University of Antananarivo, with a particular focus on the buildings constructed during the 1950s and 1960s. These structures, once symbols of academic progress and innovation, are now showing signs of significant deterioration. The report highlights both the potential opportunities and the risks associated with this failing infrastructure, emphasizing the urgent need for comprehensive improvements.

The University stands as a beacon of learning for the next generation of leaders, scientists, and innovators in Madagascar, yet students and faculty alike are increasingly preoccupied with basic water needs rather than the pursuit of knowledge. This situation underscores a broader challenge — while these historic buildings hold immense potential, they also present substantial risks to the health and safety of those who rely on them daily. It is imperative that we act now to address these critical infrastructure challenges, ensuring that the University can continue to provide a conducive environment for learning and growth. By prioritizing these improvements, we can offer the next generation a future built on hope, security, and the promise of academic excellence.

JACQUELYN JESTINE SANDERS FOUNDATION
BUILDING VISION, REALIZING CHANGE

UNIVERSITE D'ANTANANARIVO

UNIVERSITY OF ANTANANARIVO
FACULTY OF SCIENCES
MENTION PEI
COURSE: WATER AND ENVIRONMENTAL ENGINEERING

THE BUILDINGS OF THE UNIVERSITY OF ANTANANARIVO

BY: RANDRIAMAHERINIAINA Manohisoa Stenny

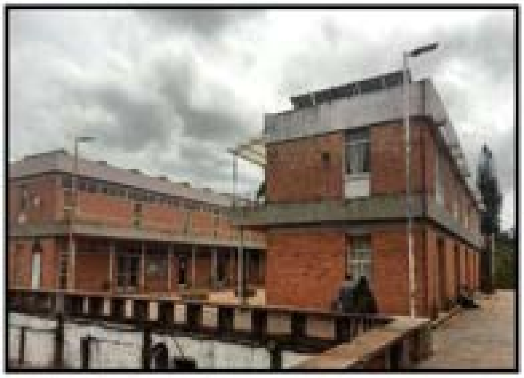
Table of contents

I. PRESIDENTIAL BUILDINGS

Roof characteristics:

	Roof type	Roof perimeter (m)	Roof area (m²)
Star-shaped roof	Dalles	72.5	321.42
Roof of the two buildings	Dalles	[64-66]	[178-180]

Pictures:

II. UNIVERSITY LIBRARY

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m^2)
Sheet metal	165	1702

Pictures:

III. GYMNAGE

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet metal	185.03	1995.18

Pictures:




Rainwater drain pipes

IV. MADAGASCAR INSTITUTE FOR VACCINE RESEARCH

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet metal	96,82	449,77

Pictures:

V. EGS FACULTY BUILDING (ECONOMY; GESTION; SOCIOLOGY)

1.Building A

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet metal	110,68	615,15

Pictures:

2. Building B

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m^2)
Sheet metal	111	629,96

Pictures

3. Conaco:

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet metal	204,61	2560,57

Pictures:

4. Cathédral:

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet metal	173,44	1623,79

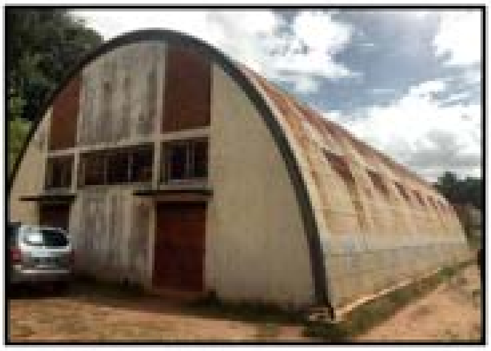
Pictures:

5. Bloc 3:

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet metal	91,97	489,94

Pictures:



VI. BUILDING OF THE FACULTY OF SCIENCES

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m^2)
Sheet metal	280,27	2006,53

Pictures:

1. Q Building

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m^2)
Sheet metal	126,81	1004,79

Pictures:

2. P Building

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet metal	116,96	678,57

Pictures:

3. O Building:

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet metal	115,95	657,05

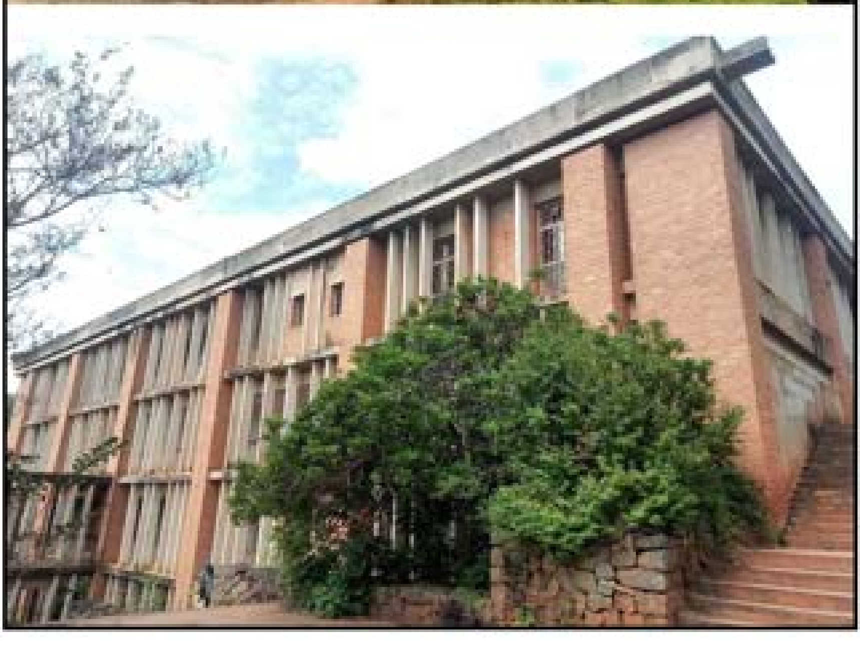
Pictures:

4. J Building:

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet metal	116,36	672,87

Pictures:



5. NAS:

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet metal	153,54	1281,38

Pictures:

6. Conaco:

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet metal	179,09	1834,79

Pictures:



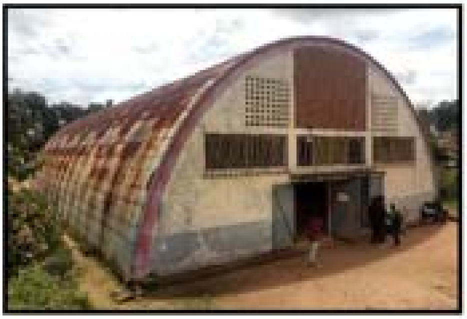


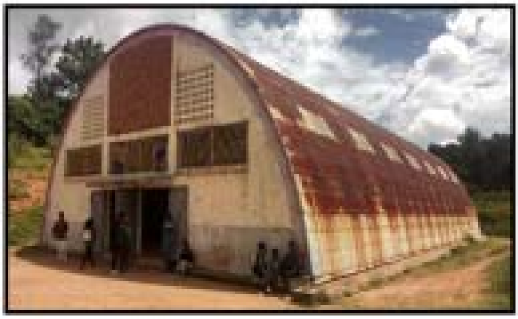
7. Q3

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m^2)
Sheet metal	93,09	497,3

Pictures:





VII. BUILDING ON THE HILL

1.Dicos:

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet metal	62,4	194,65

Pictures:




2. Mineral chemistry laboratory:

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet metal	63,51	201,79

Pictures:

3. Géology:

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet metal	63,43	199,51

Pictures:

4. Général Pharmacology Cosmétology Pharmacokinetics Laboratory:

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet metal	55,09	153,06

Pictures:

VIII. BUILDING OF THE FACULTY OF LETTERS AND HUMAN SCIENCES:

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m^2)
Sheet metal	254,83	1772,94

Pictures:

1. APF2:

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m^2)
Sheet metal	203.46	2530.07

Pictures:

2. Demi-tonneau:

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet metal	92,36	485,38

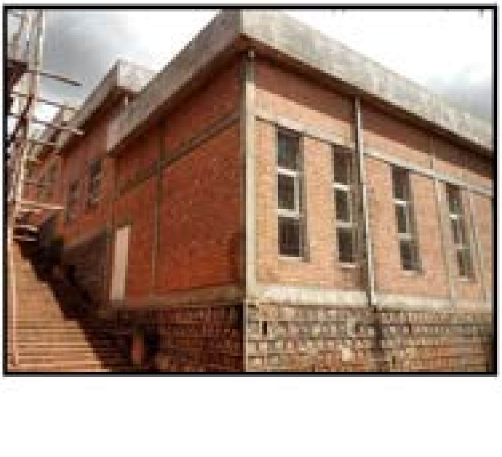
Pictures:

3. Japanese language laboratory:

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet metal	83,44	441,22

Pictures:



IX. BUILDING OF THE FACULTY OF MEDECIN:

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet metal	128,4	739,36

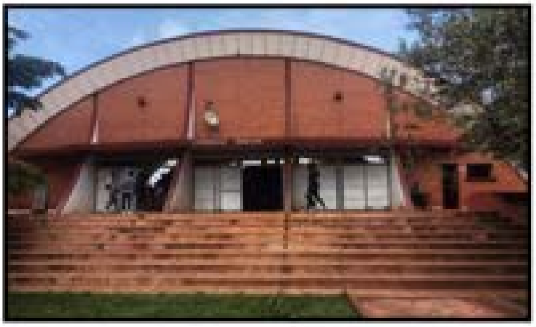
Pictures

1. Cathédral:

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet metal	152,04	1294,27

Pictures:



2. Conaco:

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet metal	179,02	1823,75

Pictures:

X. INSTITUTE CONFESIUS OF THE UNIVERSITY OF ANTANANARIVO

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet metal	142,22	866,53

Pictures:

XI. BUILDING OF THE XYLOTHEQUE

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet métal	52.11	143.79

Pictures:

XII. IMGP BUILDING :

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet métal	109,85	646,92

Pictures:

XIII. Thesis room Ankatso

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet métal	84,7	388,96

Pictures:

XIV. BUILDING OF THE POLYTHECNIC

1. Préfa 1:

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet métal	72,38	286,13

Pictures:

2. Préfa 2:

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet métal	72,98	291,23

Pictures:

3. Demi-tonneau:

Roof characteristics:

Roof type	Roof perimeter (m)	Roof area (m²)
Sheet métal	89,5	439,18

Pictures:

We are pleased to recognize the significant contributions of Mr. Jeff Kibe, a distinguished GIS expert based in Kenya, whose expertise has been indispensable to our work over the past year. Operating remotely, Mr. Kibe provided critical technical support and spatial analysis as we explored the University of Antananarivo's landscape in search of viable solutions to the region's water crisis. His proficiency in geographic information systems has been central to interpreting complex spatial data and generating the visual representations featured in the following pages. These images, which offer both clarity and depth to our understanding of the landscape, are a testament to his meticulous approach and dedication. Mr. Kibe's involvement underscores the value of interdisciplinary and cross-regional collaboration in addressing pressing environmental challenges.

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GIS Analysis by our International Correspondent in Kenya!

By Jeffrey Kibe
International Correspondent, Kenya

Reprinted from the Sustainable Vision Journal Quasrterly Magazine 2024

Reprinted from the Sustainable Vision Journal Quasrterly Magazine 2024

THE SOUTHERN RICE LAGOONS (ZONE 2A)

Zoom in on The University Rice Field - South

Reprinted from the Sustainable Vision Journal Quarterly Magazine 2024

THE NORTHERN VALLEY OF THE UNIVERSITY

Zoom in on The University Northern Valley

Reprinted from the Sustainable Vision Journal Quarterly
Magazine 2024

BIRD'S EYE VIEW OF THE LAGOONS

Zoom in on the Rice Fields Today

Reprinted from the Sustainable Vision Journal Quarterly
Magazine 2024

The Garden of Eden Model: A Pathway to Water Autarchy and Sustainable Solutions

The Garden of Eden Model represents a holistic approach to environmental sustainability, drawing inspiration from the idea of a self-sustaining ecosystem that harmonizes the natural world with human innovation. This model seeks to integrate ecological principles into the design and management of urban spaces, offering a framework for creating resilient environments capable of thriving with minimal external input. At its core, the Garden of Eden Model emphasizes biodiversity, water conservation, and ecosystem restoration, providing a blueprint for sustainable living that aligns closely with the goals of the Foundation in promoting natural, nachhaltig (sustainable) solutions to global environmental challenges.

The model's significance extends far beyond its conceptual design. It serves as a cornerstone of the Foundation's broader mission to foster environments where human development and ecological health are not in opposition, but rather in a mutually reinforcing relationship. By reimagining how we interact with natural systems, the Garden of Eden Model lays the groundwork for solutions that address critical issues such as water scarcity, land degradation, and resource depletion. Through the implementation of this model, the Foundation aims to demonstrate that it is possible to reverse the damage done by unsustainable practices, while simultaneously promoting innovative strategies for future generations to live in harmony with the planet.

In the context of the University of Antananarivo, the Garden of Eden Model is central to the proposal for achieving 100% water autarchy on campus. By harnessing advanced water management techniques, including rainwater harvesting, wastewater recycling, and sustainable landscaping, this model envisions a university that is not only self-sufficient in its water needs but also a model for sustainable resource use and ecological stewardship. The integration of green spaces, urban agriculture, and regenerative design principles ensures that water management becomes a dynamic and ongoing process, rooted in ecological principles rather than external dependencies.

This approach is not merely a theoretical exercise but a practical solution to a very real challenge. The Garden of Eden Model encapsulates the Foundation's vision for creating resilient ecosystems capable of sustaining both human and ecological needs in the face of increasing global pressures. As the pages that follow illustrate, the proposed model is not just a solution for the University of Antananarivo; it is a replicable framework that can inspire similar efforts in other institutions and communities worldwide, contributing to the larger global movement towards sustainability.

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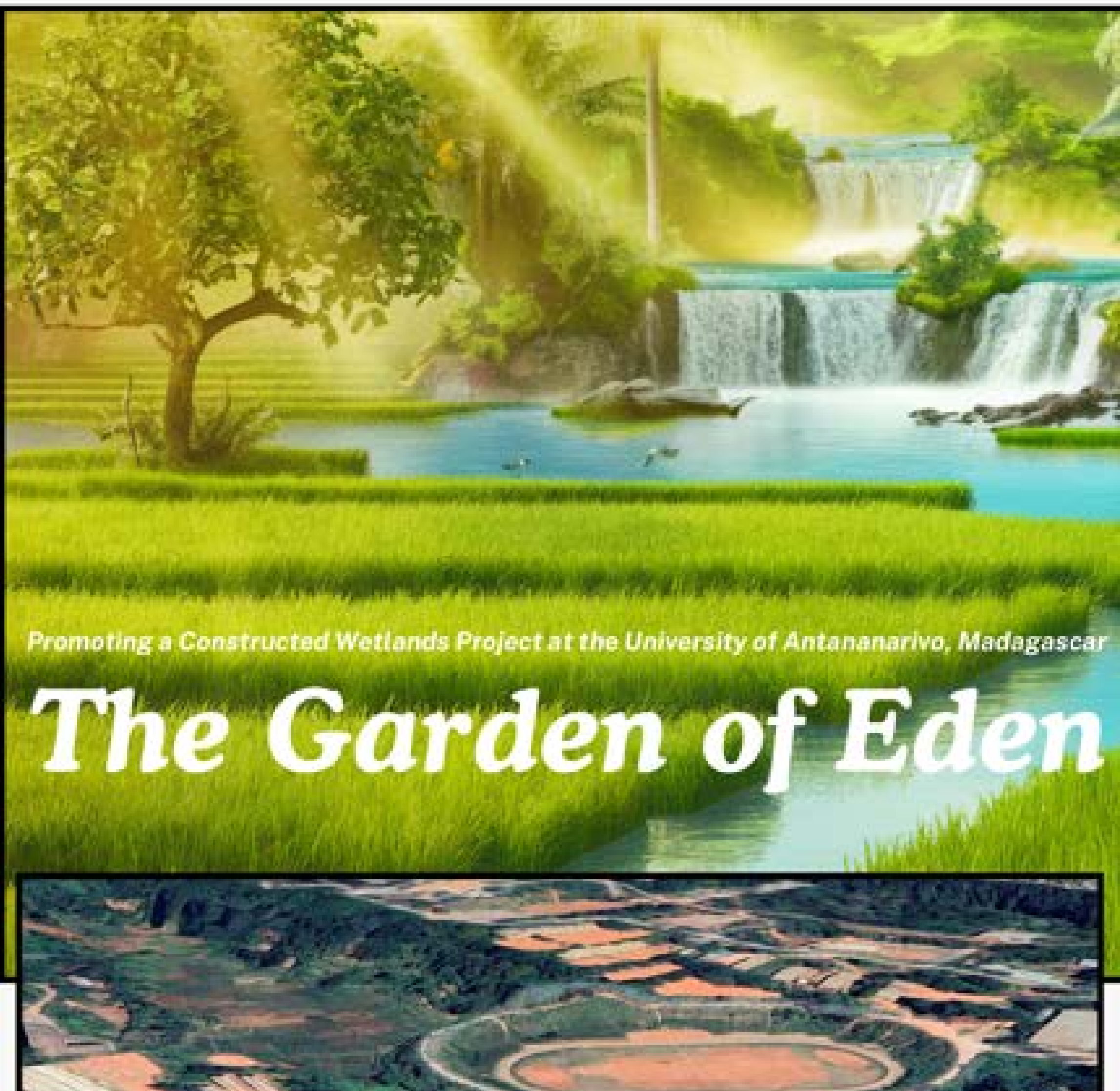


Promoting a Constructed Wetlands Project at the University of Antananarivo, Madagascar

The Garden of Eden

Introduction

The University of Antananarivo, nestled in the vibrant capital city of Madagascar, is home to acres of lush rice research fields. These fields, which receive abundant stormwater from the expansive 50-hectare university grounds, present a unique opportunity to transform the campus and address critical infrastructure challenges.

By converting these rice fields into constructed wetlands, the university could create a stunning ecological feature that not only enhances the local environment but also provides a sustainable solution to water scarcity. This ambitious "Garden of Eden" project holds the potential to make the university a beacon of ecological innovation and a magnet for eco-tourism.

Fruit Tree Shaded Lagoon Storage & Biological Water Treatment

***[Drinking] Water Management and Storage**: Constructed wetlands can effectively capture and store stormwater, reducing the risk of flooding and ensuring a steady supply of water throughout the year. This is particularly crucial for the university, which currently struggles with water infrastructure challenges.*

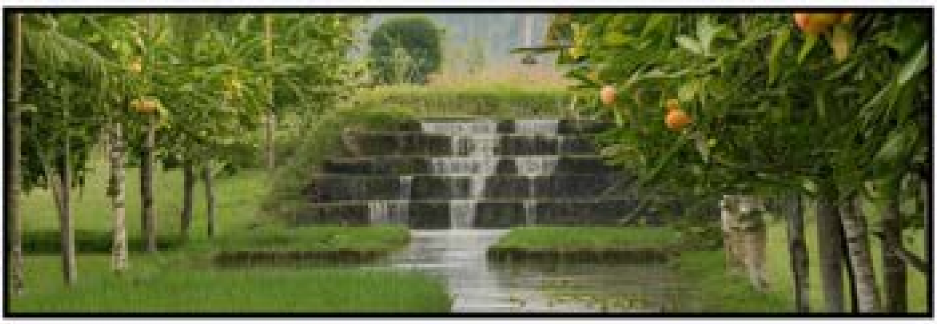
***Biodiversity and Habitat Creation**: Wetlands are known for their rich biodiversity. By creating these ecosystems, the university would support a variety of plant and animal species, contributing to conservation efforts and enhancing the local environment.*

***Educational and Research Opportunities**: The constructed wetlands would serve as a living laboratory for students and researchers, providing hands-on learning experiences in ecology, environmental science, and sustainable water management.*

***Aesthetic and Recreational Value**: A beautifully designed wetland area would offer serene landscapes for relaxation and recreation, enhancing the campus's appeal to students, staff, and visitors.*

Vision for the Constructed Wetlands

The concept of transforming the rice research fields into constructed wetlands involves designing a series of interconnected water bodies that mimic natural wetland ecosystems. These wetlands would serve multiple purposes:



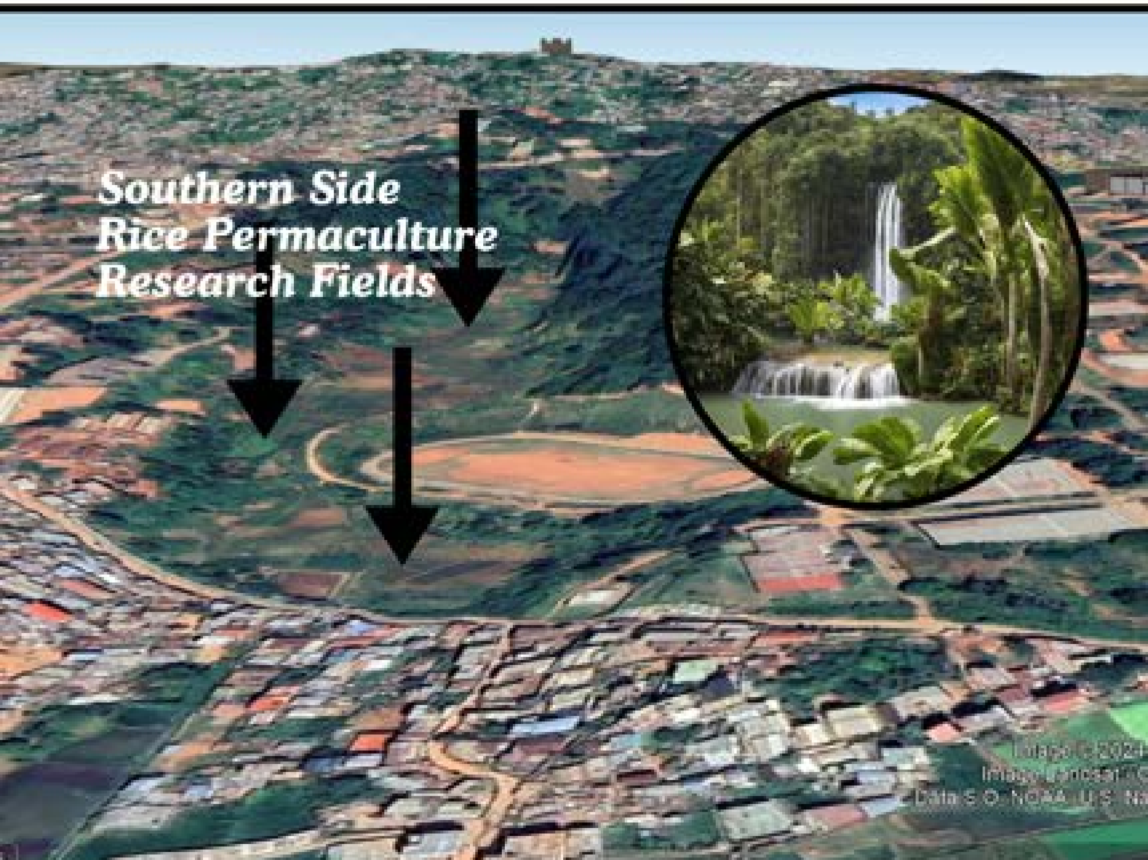
The Garden of Eden Solution

Addressing Water Infrastructure Challenges
One of the most pressing issues facing the University of Antananarivo is the lack of reliable water infrastructure. Students and staff often face water shortages, which can disrupt daily activities and academic work. The "Garden of Eden" project aims to tackle this problem head-on by:

Rainwater Harvesting: The constructed wetlands would act as a massive rainwater harvesting system, capturing runoff from the university grounds and storing it for future use.

Groundwater Recharge: *By facilitating the infiltration of stormwater into the ground, the wetlands would help recharge local aquifers, improving the overall water availability in the region.*

Water Quality Improvement: *Wetlands are natural filters, capable of removing pollutants from water through physical, chemical, and biological processes. This means that the water stored in the wetlands would be cleaner and safer for use.*



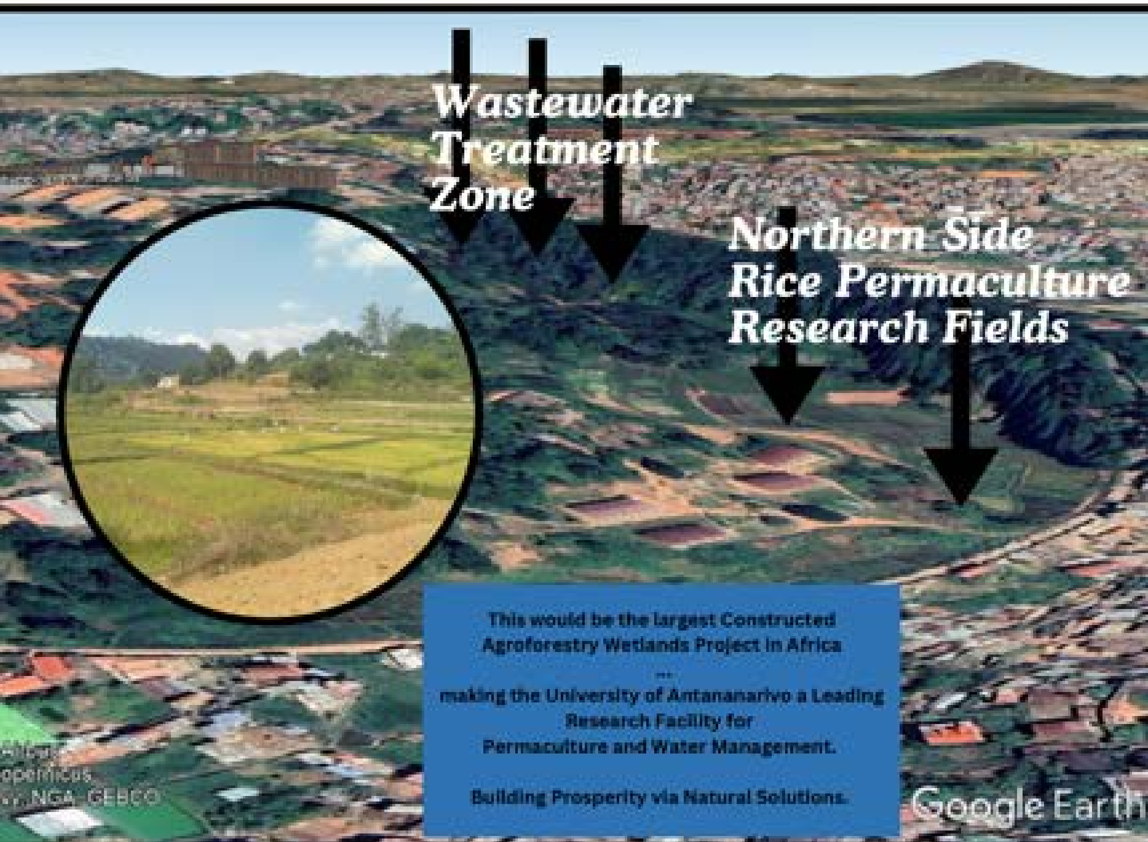
Constructed Wetlands for Stormwater Management

Academic Research and Foundation Support

In 2024, the Jacquelyn Jestine Sanders Foundation generously funded a pivotal academic research initiative at the University of Antananarivo.

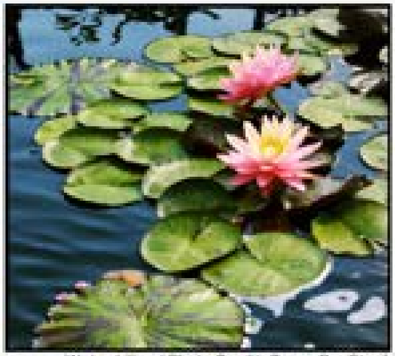
This research, encapsulated in the Sustainable Vision Academic Journal, has provided a comprehensive analysis of the university's water infrastructure challenges. The findings from this study have led to the development of the "Garden of Eden" proposal as the optimal solution.

The research highlighted the critical need for innovative water management strategies to address the university's ongoing water shortages. The proposed constructed wetlands emerged as a core component of this solution, offering a multifaceted approach to sustainable water management. This project represents the heart of the proposed water management strategy, promising to transform the university into a water-rich, ecologically vibrant campus.



Predicted Flora

Madagascar is renowned for its unique and diverse ecosystems, home to many species found nowhere else on Earth. By converting the rice research fields at the University of Antananarivo into constructed wetlands, this "Garden of Eden" project could attract a vibrant range of plant and animal species, enhancing biodiversity and ecological value. Here's a prediction of the flora and fauna that might flourish in this new wetland habitat.


Water Lilies / Photo Credit: Canva Pro Stock

Aquatic Plants:

- **Water Lilies (Nymphaeaceae)**: *Known for their beautiful, floating flowers, these plants will thrive in the still waters of the constructed wetlands.*
- **Papyrus (Cyperus papyrus)**: *Common in wetland areas, this plant can create dense, green stands that provide habitat and protection for wildlife.*
- **Duckweed (Lemna spp.)**: *Small, floating plants that can quickly cover the surface of the water, providing food for various aquatic creatures.*

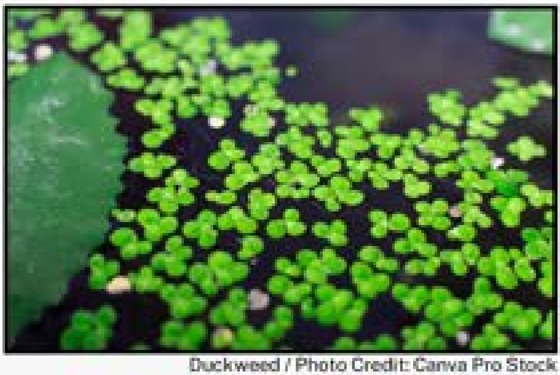
Emergent Vegetation:

- **Cattails (Typha spp.)**: *These tall plants with distinctive brown flower spikes will establish along the water's edge, helping with filtration and erosion control.*
- **Bulrushes (Schoenoplectus spp.)**: *Found in shallow water, these plants offer nesting material and shelter for birds and other wildlife.*


Cattails / Photo Credit: Canva Pro Stock

Wetland Trees and Shrubs:

- **Willows** *(Salix spp.): These trees thrive in wet conditions and can help stabilize the soil along the wetland margins.*


Duckweed / Photo Credit: Canva Pro Stock


Papyrus / Photo Credit: Canva Pro Stock

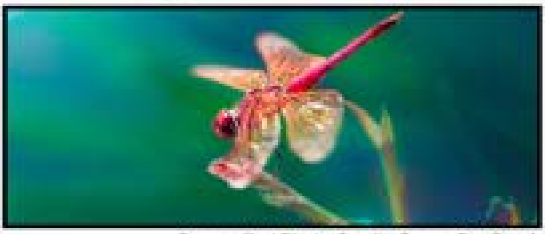
and Fauna for the "Garden of Eden" Wetlands

Birds:

- Madagascar Pond Heron (Ardeola idae): An endangered species that could find a new habitat in the wetlands, benefiting from the abundant food supply.
- Madagascar Jacana (Actophilornis albinucha): These birds, with their striking appearance, would thrive in the wetland environment.
- Kingfishers (Alcedinidae): Various kingfisher species would be attracted to the wetland for hunting fish and insects.

Amphibians and Reptiles:

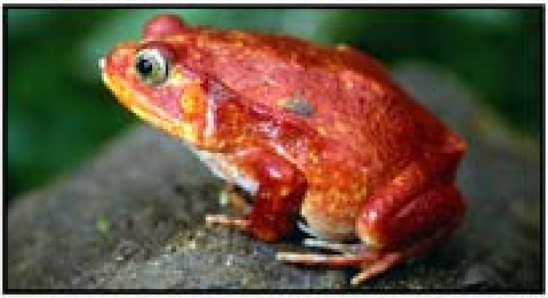
- Tomato Frog (Dyscophus antongilii): This brightly colored frog species is native to Madagascar and would find the wetlands a suitable habitat.
- Madagascar Tree Boa (Sanzinia madagascariensis): These boas could inhabit the riparian zones, preying on small mammals and birds.



Dragonfly / Photo Credit: Canva Pro Stock

Invertebrates:

- Dragonflies and Damselflies (Odonata): These insects are vital indicators of a healthy wetland ecosystem and would flourish in the new habitat.
- Butterflies (Lepidoptera): Species such as the Madagascar Giant Swallowtail (Papilio antenor) would be attracted to the diverse plant life.



Tomato Frog / Photo Credit: Canva Pro Stock

Fish and Aquatic Species:

- *Cichlids (Cichlidae): Diverse species of cichlids, native to Madagascar's waters, could inhabit the constructed wetlands, contributing to the aquatic biodiversity.*
- *Freshwater Crabs (Potamonautidae): These crabs play a crucial role in the wetland ecosystem, helping to decompose plant material.*

Madagascar Jacana / Photo Credit: Canva Pro Stock

Freshwater Crab / Photo Credit: Canva Pro Stock

Wetlands Agroforestry Agricultural Research Center - Leading Africa in Rice Permaculture

Ecotourism Potential

The "Garden of Eden" project is not only about solving water problems; it also has the potential to position the University of Antananarivo as a prime research and ecotourism destination. Madagascar is already renowned for its unique biodiversity and natural beauty, attracting tourists from around the world. By creating an exemplary ecological feature within the capital city, the university can:

- ***Attract Visitors**: The constructed wetlands, with their diverse flora and fauna, could become a major attraction for eco-tourists, nature enthusiasts, and researchers.*
- ***Boost Local Economy**: Increased tourism would bring economic benefits to the local community, creating job opportunities and supporting local businesses.*
- ***Promote Environmental Awareness**: The project would serve as a model for sustainable development, inspiring visitors and local residents to engage in conservation efforts and adopt eco-friendly practices.*

Wetlands Agroforestry Research Center, Antananarivo. Photo Credit: Coman/OpenArt.ai

Wetlands Agroforestry Research Center, Antananarivo. Photo Credit: Coman/OpenArt.ai

Research Collaboration & Ecotourism

Madagascar is renowned for its extraordinary biodiversity, with a high percentage of flora and fauna that are found nowhere else on Earth. A wetlands agroforestry agricultural research center would highlight the island's unique ecosystems and offer visitors a chance to observe rare species in their natural habitat. This center would serve as a living museum of biodiversity, attracting ecotourists keen to experience Madagascar's rich natural heritage.

Benefits for Other Universities and Agricultural Research Centers - Collaborative Research

Involving other universities and agricultural research centers in this project would foster collaborative research and knowledge exchange. Institutions could share expertise, resources, and data, leading to more robust research outcomes and innovations in sustainable agriculture and conservation.

Educational Opportunities

The research center could offer guided tours, workshops, and educational programs that engage visitors in hands-on learning experiences. These programs could cover topics such as wetland restoration, agroforestry techniques, and sustainable farming practices. By integrating education with tourism, the center would foster a deeper understanding and appreciation of ecological and agricultural research among tourists.

Wetlands Agroforestry Research Center, Antananarivo.
Photo Credit: Coman/OpenArt.ai

Global Impact

The involvement of multiple institutions could elevate the project's profile, attracting international attention and funding. This global collaboration could lead to the development of best practices that can be applied in other parts of the world, enhancing the global impact of the research conducted at the center.

Enhanced Research Outputs

By collaborating with a diverse group of researchers, the center could produce comprehensive and interdisciplinary research outputs. These publications could address a wide range of topics, from ecological restoration and biodiversity conservation to sustainable agriculture and climate resilience, contributing significantly to the scientific community.

Community Engagement

Such a center would likely involve local communities in its operations, providing them with employment opportunities and involving them in conservation and research activities. This engagement would enhance the ecotourism experience by allowing visitors to interact with local people and learn about their culture, traditions, and sustainable living practices. This kind of community-based tourism can help uplift local economies and ensure that the benefits of tourism are shared widely.

In summary, a wetlands agroforestry agricultural research center in Madagascar would not only serve as an excellent ecotourism destination but also provide substantial benefits through collaborative research, educational opportunities, and community engagement. By involving other universities and research centers, the project could achieve a broader impact, fostering global solutions to environmental and agricultural challenges.

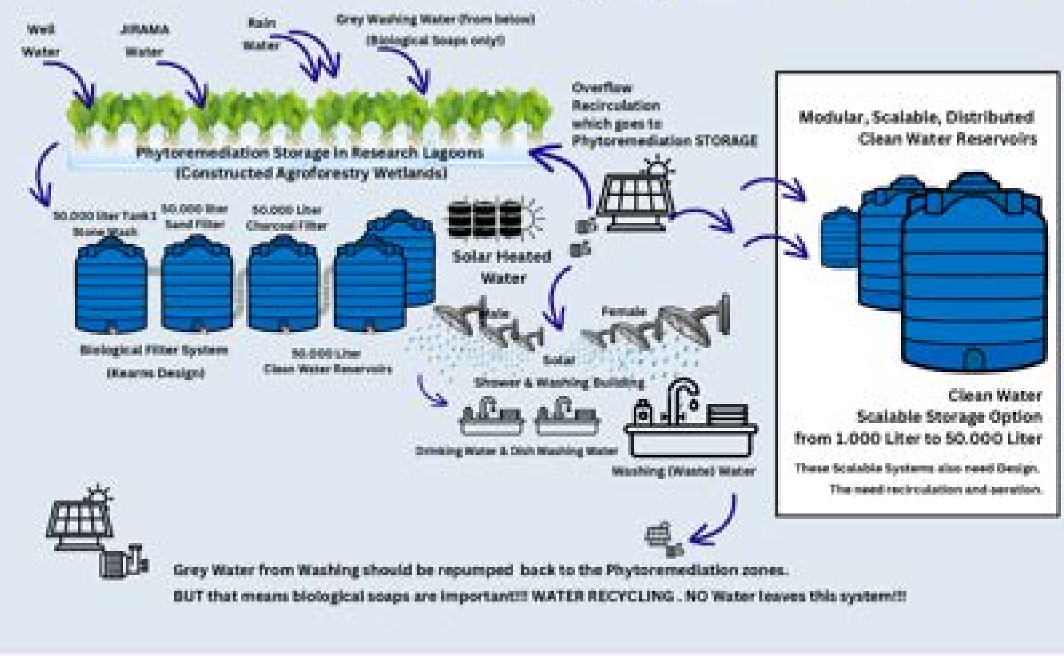
Constructed Wetlands as part of the Central Water Infrastructure

The proposal to incorporate constructed wetlands as a central element of the university's water infrastructure marks a significant advancement in sustainable water management. The primary objective is to establish an extensive water storage system capable of effectively managing stormwater, which currently is not being utilized to its full potential. The plan involves directing stormwater into the university's Research Facility Lagoons, which have been engineered to accommodate up to 10 million liters of water. Preliminary assessments suggest that these lagoons could potentially store as much as 25 million liters, far exceeding the university's current water demand.

To maximize the utility of this stored water, the project aims to develop 100 defined research pads. These pads are designed for easy access and optimal testing conditions, providing a controlled environment for various research activities. By slowing down and storing stormwater, the constructed wetlands will not only enhance water conservation efforts but also support diverse research opportunities within the university, thereby aligning with both environmental sustainability and academic excellence.

This initiative not only addresses the immediate need for improved stormwater management but also sets a precedent for innovative water conservation practices in academic institutions. The integration of such a large-scale water storage system within the university's infrastructure highlights a commitment to sustainable development and resource efficiency, potentially serving as a model for other universities and organizations aiming to enhance their environmental stewardship.

Central Water Infrastructure in Technical Planning by the JJSF Fellowship



Constructed Wetlands: returning to the Garden of Eden to address Water Needs

Conclusion

The "Garden of Eden" project at the University of Antananarivo represents a visionary approach to addressing water infrastructure challenges while enhancing the ecological and aesthetic value of the campus. By converting the rice research fields into constructed wetlands research facility, the university can create a sustainable water management system, support biodiversity, and attract ecotourism. This initiative, backed by the Jacquelyn Jestine Sanders Foundation and grounded in rigorous academic research, has the potential to transform the university into a leading example of ecological innovation and sustainability. It is an opportunity to create a lasting legacy that combines environmental stewardship with practical solutions, truly embodying the spirit of a modern-day Garden of Eden.

Lagoons at the University of Antananarivo / Photo Credit: FINARCH

Rice Research at the University of Antananarivo / Photo Credit: FINARCH

JACQUELYN JESTINE SANDERS FOUNDATION
BUILDING VISION, REALIZING CHANGE

Kenneth Dale Coman
Sustainable Vision Journal Editor

Fazit: Sustainable Vision Academic Journal, 2024 Edition

The Sustainable Vision Academic Journal, published by the Jacquelyn Jestine Sanders Foundation, presents a comprehensive narrative of the Foundation's 2024 efforts to advance sustainability through research, collaboration, and actionable change. This edition weaves together the diverse projects undertaken by the Foundation and its Fellows, showcasing the tangible impact of their work in Madagascar, Kenya, Germany, and the Philippines. Through perseverance, innovation, and an unwavering commitment to environmental stewardship, these efforts are already rippling outward, promising to inspire new initiatives in other communities in the years ahead.

The 2024 Fellowship Project was a dynamic journey—a true rollercoaster of challenges and breakthroughs. Graduate students, serving both as researchers and solution-builders, proved to be invaluable in tackling pressing issues such as water scarcity, sustainable energy, and ecological restoration. This model of engagement underscores the potential of investing in the next generation of leaders to address real-world problems while fostering a more sustainable future.

Looking forward, the Foundation envisions expanding its Fellowship model in 2025 and 2026, fortified by the lessons learned in 2024. By refining and building upon this year's experiences, the Foundation aims to continue shaping a future where innovation, collaboration, and a vision for sustainability drive meaningful change for communities worldwide.

JACQUELYN JESTINE SANDERS FOUNDATION
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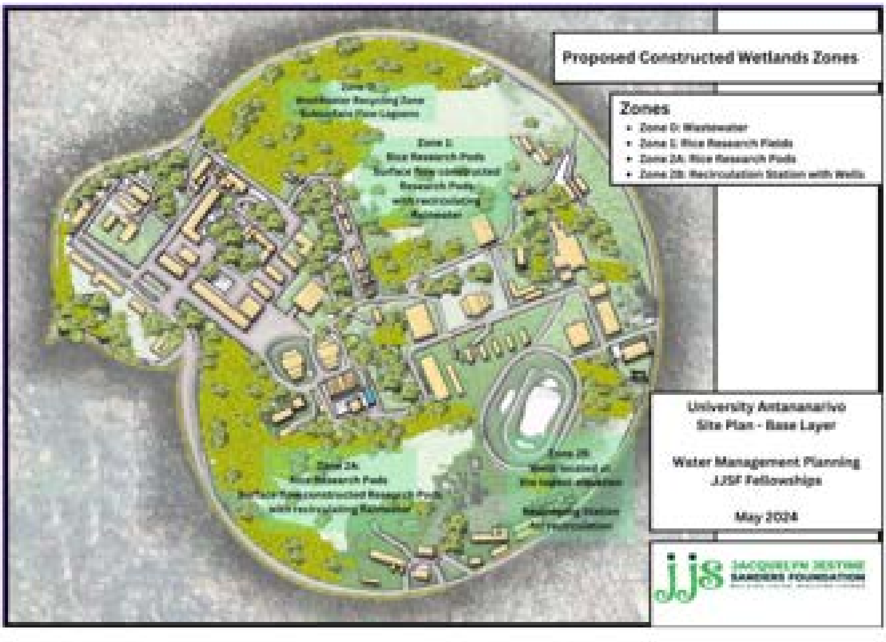
Celebrating Our Achievements

As we reach the conclusion of the inaugural year of the Sustainable Vision Academic Journal in 2024, we celebrate the significant strides we have made. This year has been marked by a profound commitment to addressing pressing social and environmental challenges, paving the way for innovative solutions. A pivotal moment in our journey was identifying a serious real-world challenge in Madagascar, which is emblematic of a larger global issue—communities grappling with basic infrastructure. At the University of Antananarivo, a thriving hub for over 40,000 residents, the daily threat of water scarcity starkly contrasts with the city's vibrant academic life, highlighting the urgent need for foundational support and collaborative action. This dire situation illustrates not only our moral obligation to lend a helping hand but also a fundamental belief that we are part of a global family, interconnected and collectively responsible for each other's well-being.

A few of the Easter Workshop Graduate Students (April 2024, Antananarivo, Madagascar)

Understanding the Water Paradox

Within this context, the fluctuating availability of water emerges as a striking paradox. Seasonal rains inundate the region, yet access to potable water remains precariously low for much of the year. The local practice of diverting rainwater to low-lying agricultural lands—while beneficial for food crops like rice—exacerbates the community's ongoing water crisis. This year's comprehensive investigation into the circumstances faced by those at the university has yielded critical insights: the rainwater that falls on the grounds is sufficient to meet the community's needs if managed effectively. This realization speaks to the importance of capturing, purifying, and circulating this precious resource to provide for drinking, sanitation, and agricultural uses. Such efforts not only highlight the innovative engineering solutions needed but also the necessity of systems thinking in addressing complex challenges.



Embracing Engineering Solutions

Embracing this multifaceted challenge, the Jacquelyn Sanders Foundation has fully committed to exploring sustainable answers for Antananarivo while considering how these solutions can be adapted for other communities, such as our partners at the Ayni Bahay Community in the Philippines. Our overarching goal is to develop modular solutions that enable communities to aspire toward water autonomy, thus reducing their dependency on external aid. Testing our strategies in Germany, we adapted to the colder climate while pursuing the creation of a freestanding water storage and filtration system powered by photovoltaic energy. This approach presented unique challenges, including accounting for reduced winter daylight affecting photovoltaic panel efficiency, yet we persevered. Moreover, the construction of our prototype, reliant on simple yet effective materials—pond liners, sandbags, and IBC containers—demonstrated the technical feasibility of our concept.

Prototyping Easy Water Filtration via the Kearns bilogical Filter design (2024, Niedersachsen, Germany)

The Jacquelyn Jestine Sanders Foundation (JJSF) demonstrates strong alignment with the United Nations Sustainable Development Goals (SDGs) through its initiatives that emphasize sustainability, education, and community empowerment.

Alignment with Key SDGs:

Clean Water and Sanitation (Goal 6)
JJSF's Garden of Eden project tackles water infrastructure challenges by implementing systems such as constructed wetlands and rainwater harvesting. These efforts aim to provide clean and reliable water sources, critical for both community health and environmental sustainability.

Zero Hunger (Goal 2)
Early in 2024, JJSF provided food aid to families in Madagascar. This was followed by initiatives promoting agricultural sustainability, including research into permaculture practices like integrating rice fields with water management systems, ensuring long-term food security.

Quality Education (Goal 4)
Through its fellowship programs, JJSF supports graduate students in developing regions. These fellowships provide financial support and opportunities to engage in research that addresses local and global challenges, enhancing access to and quality of higher education.

Climate Action (Goal 13)
The foundation's focus on water recycling, rainwater management, and sustainable agricultural practices directly addresses climate adaptation needs, particularly in drought-prone regions such as Madagascar.

Partnerships for the Goals (Goal 17)
JJSF's collaborative approach involves partnerships with academic institutions and international researchers. These alliances ensure that projects are scalable and impactful, benefiting multiple communities and advancing shared sustainability objectives.

By fostering systemic solutions to pressing global issues, the foundation embodies the spirit of the SDGs, addressing both immediate needs and long-term challenges. Its integrated approach to education, sustainability, and community development serves as a model for impactful change.

6 CLEAN WATER AND SANITATION

2 ZERO HUNGER

4 QUALITY EDUCATION

13 CLIMATE ACTION

17 PARTNERSHIPS FOR THE GOALS

JACQUELYN JESTINE SANDERS FOUNDATION
BUILDING VISION, REALIZING CHANGE

SUSTAINABLE DEVELOPMENT GOALS

The Jacquelyn Jestine Sanders Foundation

The Jacquelyn Jestine Sanders Foundation is a 501c3 nonprofit focused on addressing critical global challenges, particularly in sustainable development, education, and environmental solutions. In 2024, the foundation made significant strides through initiatives aimed at improving water management, sustainability, and education, with a strong focus on Madagascar.

Key 2024 highlights include:

"Garden of Eden" Initiative: This project targets water infrastructure at the University of Antananarivo in Madagascar. The foundation is working on sustainable solutions, such as constructed wetlands and rainwater management systems, to alleviate water shortages. These efforts aim to improve academic conditions and serve as scalable models for other regions facing similar challenges.

Fellowship Programs: The foundation launched fellowship opportunities for graduate students in developing countries. These fellowships provide stipends to support innovative projects in fields like water management, sustainable engineering, and permaculture.

Community Support: In early 2024, the foundation distributed food baskets to families in Antananarivo, Madagascar. However, they shifted focus to addressing root causes of systemic issues, such as water scarcity and sustainable infrastructure.

Sustainable Vision Journal: The foundation introduced a journal to document and share insights from its projects, including research on sustainability and water resource management. This aligns with their mission to foster self-sustaining solutions globally.

These efforts reflect the foundation's commitment to creating long-term impact through collaboration, research, and innovative problem-solving.

"Our 'Garden of Eden' proposal is a multifaceted solution to the university's water infrastructure challenges. Developed in collaboration with students from Polytechnique and the University of Antananarivo, this approach focuses on three key components: Subsurface Flowing Constructed Wetlands for wastewater management, Surface-Level Free-Flowing Constructed Wetlands for freshwater capture and purification, and Biological Filtration for Drinking Water."

Off Grid Infrastructure globally:
The budding Partnership with Ayni Bahay in the Philippines

Our budding relationship with the Ayni Bahay community in the Philippines marks a pivotal step forward in our foundation's mission. This collaboration reflects our commitment to identifying and addressing the unique challenges faced by off-grid communities around the world. Situated in a remote area with a population of approximately 400 individuals, Ayni Bahay presents an invaluable case study for tackling systemic infrastructure deficits in environments with distinct cultural, geographic, and logistical obstacles.

For the community at Ayni Bahay, the absence of reliable infrastructure has led to significant hurdles in achieving basic needs such as access to clean water, sustainable energy, and sanitation systems. While these challenges mirror those faced in our previous projects, the specific dynamics—such as the dispersed layout of homes, reliance on subsistence agriculture, and vulnerability to extreme weather—require tailored approaches.

Towards Scalable and Modular Solutions

Our work with Ayni Bahay feeds directly into our overarching goal of developing scalable and modular solutions. By 2025, we aim to deliver a suite of standardized solutions—adaptable and continually improving based on insights from both past and ongoing projects. These solutions are designed to evolve with the lessons learned from each community, ensuring they are not only effective but also resilient in varying contexts.

The modularity of our approach allows for customization that respects local conditions and community priorities. For example, in Ayni Bahay, we are exploring hybrid renewable energy systems capable of withstanding typhoons, alongside water purification setups tailored to the region's specific contamination risks. These solutions build on the knowledge gained from earlier endeavors, incorporating feedback loops to refine both the technology and the implementation strategies.

A Case Study in Expanding Horizons

Our engagement with Ayni Bahay highlights the broader issues facing off-grid communities worldwide, such as equitable resource distribution, the integration of sustainable practices, and community-led governance of infrastructure projects. It challenges us to think beyond isolated deployments and consider the interconnected web of social, economic, and environmental factors that impact success.

This partnership also underscores the importance of local collaboration. By working closely with community leaders and residents, we ensure the solutions we design are not only technically sound but also deeply aligned with the community's aspirations and values.

The lessons from Ayni Bahay are shaping our perspective on what it means to scale effectively. Each community we engage with adds depth to our understanding and sharpens our ability to design interventions that are both replicable and respectful of local contexts. As we move forward, we see this collaboration as a cornerstone in our journey toward making off-grid living a viable and sustainable choice for all.

Call to Action: Join Us in Making a Difference

The Jacquelyn Jestine Sanders Foundation is on a journey to be an active participant in the global discussion on how to create meaningful solutions for those living in challenging circumstances. We are committed to being a source of innovative strategies and to fostering collaboration that addresses the pressing issues faced by communities around the world.

Our projects, like the "Garden of Eden" initiative, exemplify our dedication to providing sustainable solutions for water management, education, and food security. These efforts are rooted in our mission to assist those in need with empathy, determination, and innovation. But we can't do it alone — your support is critical to our success.
If you share our vision of a world where challenges are met with creativity, collaboration, and compassion, we invite you to join us.

Here's how you can contribute:

- **Contact Us**: Whether you're an individual or an organization, your involvement is invaluable. Reach out to us — we will warmly welcome your ideas, skills, and enthusiasm.

- **Financial Contributions**: Your donations enable us to expand our reach and deepen the impact of our programs. Every contribution helps us address immediate needs while working toward long-term solutions.

- **Corporate or NGO Partnerships**: If you represent an organization, we welcome your support in forming partnerships that amplify our efforts and broaden the scope of our work.

- **Pooling Resources**: Collaboration is at the heart of what we do. By joining forces, we can create a powerful collective voice for solving global challenges.

Together, we can be a beacon of hope and a source of innovative solutions for our global brothers and sisters. Let's work side by side to address the challenges of today and create a brighter tomorrow for those in need.

Contact us to get involved — your partnership and support mean the world to us.

JACQUELYN JESTINE SANDERS FOUNDATION
BUILDING VISION, REALIZING CHANGE

The Vision for Madagascar

Looking ahead to Madagascar, our aspirations deepen with plans to construct the "Garden of Eden" Solution, designed to transform rice fields into a thriving center for permaculture research in Africa. This ambitious vision hinges upon the effective capture and storage of rainwater in strategically designed ponds, which will also promote food production through various crops, including rice, water chestnuts, duckweed, and lotus roots. Each element of this plan integrates functional goals of natural water treatment and phytoremediation while also addressing food security for the region. To effectively mitigate evaporation and enhance the ecological balance, it is essential to introduce tree cover into this lush landscape. While we delve deeper into these concepts and their implications within the Journal, we emphasize that the essence of our mission remains straightforward: to deepen our love and commitment to our global family, especially those facing stark realities due to inadequate infrastructure.

A Commitment to Sustainable Solutions

Throughout this year, we have witnessed the incredible resilience of communities navigating these challenges and have cultivated a renewed perspective on the interconnectedness of global issues. By engaging with local partners, we have strengthened networks of support that extend beyond national borders, reinforcing our collective effort to foster sustainable development. Furthermore, our work has underscored the critical role that academic research and interdisciplinary collaboration play in paving the way for effective solutions. Empowering young scholars and professionals from diverse backgrounds has enriched our understanding of local contexts, demonstrating how varying perspectives can contribute to innovative problem-solving approaches.
In conclusion, through our collective efforts in academic research and engineering, we are dedicated to crafting tangible solutions that address these urgent needs. This mission embodies the heart of the Jacquelyn Sanders Foundation and the Sustainable Vision Journals—driving positive change through collaborative action. As we conclude 2024, we look forward to building on our successes, fostering further innovation, and empowering communities worldwide. Together, we remain steadfast in our commitment, aiming for a future where sustainable solutions are not only aspirational but achievable, so we can forge a more equitable and sustainable world for all.

JACQUELYN JESTINE SANDERS FOUNDATION
BUILDING VISION, REALIZING CHANGE

Kenneth Dale Coman
Sustainable Vision Journal Editor

Appendix I:

Water Testing Results from Prototype built and maintained in Niedersachsen, Germany 2024

JACQUELYN JESTINE SANDERS FOUNDATION
BUILDING VISION, REALIZING CHANGE

IVARIO

IHRE TESTERGEBNISSE

Brunnenwasser-PLUS

OF-252078-UQXDW - JJSF Foundation

Probenbezeichnung: Barksen Test 1 (Nov 2024)

Laboreingang der Probe:25.11.2024

Analysedatum: 27.11.2024

Jedes Analyseverfahren besitzt eine Bestimmungsgrenze. Alle Werte, die mit "kleiner als" (<) angegeben sind, befinden sich unterhalb der Bestimmungsgrenze des jeweiligen Verfahrens.

Ammonium

Wert OK ✓

Ihr Wert <0,50 mg/ltr

[redacted]

Grenzwert laut Trinkwasserverordnung 0,5 mg/ltr

Beryllium

Ihr Wert <0,0010 mg/ltr

[redacted]

Für Beryllium wird in der Trinkwasserverordnung kein Grenzwert festgelegt. Beryllium wirkt beweisenermaßen toxisch, wenn es inhaliert wird. Feste Grenzwerte für Beryllium in Trinkwasser sind in der deutschen Trinkwasserverordnung noch nicht festgelegt worden, da eine giftige Wirkung über die orale Aufnahme (sprich essen oder trinken) aktuell nicht eindeutig bewiesen ist. Hohe und gegebenenfalls gefährliche Konzentrationen des seltenen Berylliums im Trinkwasser sind zudem äußerst unwahrscheinlich.

Blei

Wert OK ✓

Ihr Wert <0,0010 mg/ltr

[redacted]

Grenzwert laut Trinkwasserverordnung 0,01 mg/ltr

Kalzium

Ihr Wert 17 mg/ltr

[redacted]

Für Calcium existiert kein Grenzwert in der Trinkwasserverordnung. Als Richtwert für die tägliche Aufnahme an Calcium gelten ca. 800-1200 mg.

Chlorid — Wert OK ✔

Ihr Wert 1,7 mg/ltr

[redacted]

Grenzwert laut Trinkwasserverordnung 250 mg/ltr

Coliforme Bakterien — Wert zu hoch ✖

Ihr Wert >00 kbE/100ml

[redacted]

Grenzwert laut Trinkwasserverordnung 0kbE/100ml

Achtung:

Coliforme Bakterien sind stäbchenförmige Bakterien, die als Hygiene-Anzeiger für Trinkwasser dienen. Nach einer Infektion produzieren diese Bakterien schädliche Säuren und Gase und können unser Immunsystem angreifen. In das Trinkwasser gelangen diese Bakterien über Fäkalien, die in unsere Grundwasser gespült werden. Da Ihre Probe einen zu hohen Wert dieser Bakterien aufweist, raten wir Ihnen zu weiteren Schritten. Unser geschultes IVARIO Team berät Sie hierzu gern telefonisch oder per E-Mail.

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E.coli — Wert zu hoch ✗

Ihr Wert 5 kbE/100ml

[redacted]

Grenzwert laut Trinkwasserverordnung 0kbE/100ml

Achtung:

E.coli (Escherichia coli) ist ein spezielles Bakterium aus der Gruppe der coliformen Keime. Es dient als Indikator für fäkale Verunreinigungen. (Kot von Mensch und/oder Tieren im Trinkwasser). E.Coli ist ein natürlicher Bewohner des menschlichen Darmtraktes. Kommt der menschliche Körper jedoch außerhalb des Darms mit dem Bakterium in Kontakt, können u.A. Harninfektionen, Blasenentzündungen und Wundinfektionen auftreten. Die gesetzliche Trinkwasserverordnung sieht daher vor, dass dieser Keim im Trinkwasser nicht vorkommen darf. Da Ihre Probe einen zu hohen Wert der E.coli Bakterien aufweist, raten wir Ihnen zu weiteren Schritten. Unser geschultes IVARIO Team berät Sie hierzu gern telefonisch oder per E-Mail.

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Eisen — Wert OK ✓

Ihr Wert 0,022 mg/ltr

[redacted]

Grenzwert laut Trinkwasserverordnung 0,2 mg/ltr

Elektrische Leitfähigkeit — Wert OK ✓

Ihr Wert 110 µS/cm

[redacted]

Grenzwert laut Trinkwasserverordnung 2790 µS/cm

Enterokokken

Wert zu hoch ✖

Ihr Wert 3 kbE/100ml

[redacted]

Grenzwert laut Trinkwasserverordnung 0kbE/100ml

Achtung:
Zusätzlich zu den bisherigen Grenzwerten für Escherichia coli und coliforme Keimen wird für Fäkalstreptokokken ein Grenzwert entsprechend der EG-Richtlinie, Anhang I, Parameter 59, festgesetzt. Fäkalstreptokokken sind ebenfalls Fäkalindikatoren, die aber resistenter gegenüber Umwelteinflüssen sind. Das Vorkommen von Enterokokken weist auf ältere Verunreinigungen hin, da diese in der Umwelt länger überleben können. Da in Ihrer Probe Enterokokken nachgewiesen wurden, raten wir Ihnen zu weiteren Schritten. Unser geschultes IVARIO Team berät Sie hierzu gern telefonisch oder per E-Mail.

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Wasserhärte

Ihr Wert 2,6 dH

[redacted]

Wasserhärte wird in "deutsche Härtegraden" (dH) angegeben und erschließt sich aus der Summe von Calcium und Magnesiumkonzentrationen. Hierfür wird ein spezieller Rechenweg angewandt. Das Ergebnis wird unterschieden in: Weich (<8,4 dH), Mittel (8,4 - 14,0 dH) und Hart (>14,0 dH). Die Wasserhärte spielt eine große Rolle bei verschiedenen industriellen Prozessen, ist aber auch die Ursache für z.B. verkalkte Haushaltsgeräte und Armaturen. Aufgrund der gesundheitlichen Bedeutung ist von einer Enthärtung auf unter 8,4 dH abzusehen.

Magnesium

Ihr Wert 0,9 mg/ltr

[redacted]

Für Magnesium existiert kein Grenzwert in der Trinkwasserverordnung. Magnesium ist ein essentieller Pflanzennährstoff und somit auch in vielen Düngemitteln enthalten. Neben Calcium ist Magnesium ein wesentlicher Bestandteil der Wasserhärte. Der tägliche Magnesiumbedarf eines Erwachsenen beträgt zwischen 300-400 mg.


Mangan
Wert OK
Ihr Wert <0,010 mg/ltr
Grenzwert laut Trinkwasserverordnung 0,05 mg/ltr
Nitrit
Wert OK
Ihr Wert <0,10 mg/ltr
Grenzwert laut Trinkwasserverordnung 0,5 mg/ltr
Nitrat
Wert OK
Ihr Wert 1 mg/ltr
Grenzwert laut Trinkwasserverordnung 50 mg/ltr
ph-Wert
Wert OK
Ihr Wert 7,9
Grenzwert laut Trinkwasserverordnung 6,5-9,5

Silber — Wert OK ✓

Ihr Wert <0,0010 mg/ltr

[redacted]

Grenzwert laut Trinkwasserverordnung 0,08 mg/ltr

Sulfat — Wert OK ✓

Ihr Wert 3,2 mg/ltr

[redacted]

Grenzwert laut Trinkwasserverordnung 250 mg/ltr

Zink — Wert OK ✓

Ihr Wert 0,022 mg/ltr

[redacted]

Grenzwert laut Trinkwasserverordnung 5 mg/ltr

Arsen — Wert OK ✓

Ihr Wert 0,001 mg/ltr

[redacted]

Grenzwert laut Trinkwasserverordnung 0,01 mg/ltr

Hinweis:
Bitte beachten Sie, dass dieser Test der Eigenkontrolle dient und behördlich und gerichtlich keinen Bestand hat, da die Probenahme durch Sie selbst als Privatperson erfolgt und nicht durch zertifiziertes Fachpersonal. Falls Sie Fragen zu Ihren Ergebnissen haben, kontaktieren Sie uns gerne. Sollten Sie gerichtlich und behördlich anerkannte Ergebnisse gemäß der Trinkwasserverordnung (TrinkwV2023) benötigen (z.B. für Vermieter oder Wohnungsgesellschaften), muss die Probenahme durch einen zertifizierten Probenehmer erfolgen.

Conclusions from the First Water Quality Test of the New World Garden Prototype Filter

The inaugural water quality test for the New World Garden's biological filtration system has yielded promising results, validating the system's potential to deliver clean, safe water. This first evaluation, conducted on rainwater stored in open-air ponds and filtered through a sand and biochar biofilter, demonstrated successful filtration in multiple key areas:

Key Successes - Chemical Parameters:
The water achieved desirable levels in several critical chemical indicators:

- Ammonium (NH_4^+)
- Beryllium (Be)
- Lead (Pb)
- Chlorides (Cl^-)
- Iron (Fe)
- Calcium (Ca^{2+})
- Magnesium (Mg^{2+})
- Total Water Hardness
- Electrical Conductivity

These positive results affirm the efficacy of the biofiltration system in reducing harmful substances and maintaining essential water quality metrics.

Areas for Improvement - Biological Parameters:
Due to early flow issues encountered during prototyping, the biofilter's biological component has not yet fully matured. Consequently, biological contaminants in the water exceeded optimal levels in this first test. This outcome was anticipated, given the open-air storage of the rainwater and the evolving nature of the biofilter's biological ecosystem.

Future Steps and Optimizations
Biological Maturation: Continued monitoring will support the biofilter's development into a robust biological system capable of consistently removing biological contaminants.
Potential UV Filtration: Should biological levels remain high, a UV filter — costing approximately €100 — will be integrated to achieve final purification, ensuring the water meets all desired safety standards.
Affordable Testing Solutions: Recognizing the high cost of regular water quality testing, the Jacquelyn Sanders Foundation is actively pursuing cost-effective, reliable testing methods for 2025. This will enable more frequent data collection and a comprehensive understanding of the system's long-term performance.

Outlook
The initial test results are encouraging and underscore the feasibility of producing high-quality filtered water. We remain confident that with continued refinement, the biofiltration system will meet all water quality objectives. Further updates and data will be shared on the project's website in spring.
The Jacquelyn Sanders Foundation is proud to support this vital water filtration initiative as part of the Garden of Eden project in Antananarivo, Madagascar.

Appendix II:

ARAFA Report from 2021 (Biology Department sponsored planning for Wastewater Management at the University of Antananarivo)

JACQUELYN JESTINE SANDERS FOUNDATION
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Preliminary design for wastewater treatment at the University of Antananarivo

Written by NilainaTsiafoy RANAIVOARIMANANA

Seconded and verified by : Armel Segretain

ARAFA Sarl
Date: Tuesday, September 8, 2020

Contents

Contents - Continued

Table of illustrations

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STAT 42201 11 2015 0 10041

I. Context

Ankatso University was founded in 1961 by French architect Jean Le Couteur. Since then, very little maintenance work has been carried out on the water network, causing it to deteriorate. In addition to the rehabilitation required by the state of the network, these infrastructures also need to be renovated to meet the water requirements of the University's activities

With this in mind, the project to draw up a preliminary design for the university's wastewater treatment system was initiated by the Plant Biology Department and entrusted to the ARAFA team, not least because the need for irrigation water has grown with the installation of experimental garden projects, which will be able to reuse wastewater after treatment.

The overall aim of the study is to put forward a program for the rehabilitation and renovation of the water network. During the course of the study, some emergency repair work was carried out to ensure normal drainage. The specific objectives are therefore: to rehabilitate the water network and propose a wastewater treatment system to enable its reuse as irrigation water.

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I.1.Methodology adopted

I.1.1. Canal cleaning

The official plan of the water network was inaccessible to the customer and ARAFA. Assessment of the condition of the water network was therefore based on discussions with university officials about the problems they had encountered, combined with field observations.

The canal cleaning work is accompanied by a range of emergency rehabilitation work to ensure that the canals are operational and put an end to overflows. In addition to cleaning out the canals, some sections were excavated to identify potential leaks and discover their exact location.

The customer's initial hypothesis that the cause of the flooding was due to leaks upstream of the manholes, which reduced the flow of water through the network, was verified.

I.1.2. Topographical survey of the site

A topographical survey of the site makes the job easier, both in terms of studying and drawing up a plan to better design the project, and in terms of setting out benchmarks on the ground to cost and guide the work.

Topographic surveys help to draw up plans or maps showing the main physical features of the terrain and the differences in level of the various reliefs. This part also helps to dimension the

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The survey lasted 2 days, with a full team of topographers and the company's Leica total station. The first day was devoted to collecting precise data on the altitude of the sump and the various possible conduits to the site garden. The second day was devoted to collecting data on the system's various installations, such as the location of the filters.

I.1.3. Effluent analysis

Samples of wastewater from the canals were sent to the Centre National de Recherches sur l'Environnement laboratory for characterization. This characterization not only classifies the water in relation to the standards in force in the country, but also determines the types of treatment suitable for reuse.

As well as analyzing the wastewater, it was also essential to determine the daily flow rate. The method is simple: by plugging the sump for 24 hours, the volume of water retained in the sump for 24 hours would be the flow rate in a day.

The existing 1m x 1m x 3m sump, connected to a manhole by a 200mm diameter pipe 20m away, was blocked at the manhole inlet. Taking into account the depth of the sump; 2.5m water level recovered in the sump gives a flow rate of 3m /d.3

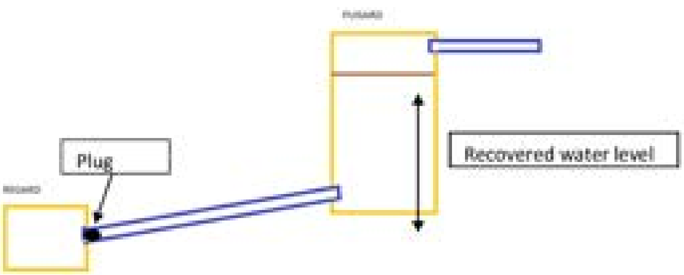

Figure 1: Sump illustration

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I.1.4. Literature consultation

Several documents relating to environmental discharge standards, classifications of surface waters in relation to their characteristics, and various works on wastewater treatment and reuse techniques were consulted as part of this study in order to propose the most appropriate solutions.

II. Water network condition

II.1. Initial state of the water network

Figure 2: The obstructed manhole

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Figure 3: Fibre pipe cut 5m upstream of the sump

II.2.Condition of water network after repair

Figure 4: Pipe replaced in PVC PN16

The original 200mm-diameter fibre pipe found was around 7m long, upstream of the sump.

The section destroyed 5m from the sump was replaced by a 5m-long PVC 200 PN 16 pipe.

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II.3. Hypothesis testing -client

The site survey and the various canal cleaning operations determined a water flow rate of 3.25m3 /day, made during the week of November 25, 2019, i.e. when the university was operating normally.

The flow rate was measured over a 24-hour period, but it was found that during the peak hour, from 10 a.m. to 3 p.m., the flow rate was between 5 and 7 liters per minute, i.e. 312.5 to 437.5 liters per hour.

The cleaning work also led to the conclusion that the majority of canals are clogged or non-operational due to their age and lack of maintenance.

- **The overflow was due to the condition of the pipe upstream of the sump and the rainwater manhole, which was clogged. Identifying the causes of the overflow then led to two essential points: repair work on part of the wastewater network andinstallation of a wastewater treatment system to meet the department's water requirements for the garden.**

III. Wastewater characterization

III.1. Definition of parameters studied

III.1.1. COD or Chemical Oxygen Demand

Chemical Oxygen Demand is expressed in milligrams per liter (mg/l) of oxygen, and effectively corresponds to the quantity of oxygen required to oxidize, under defined operating conditions, the organic matter, and therefore the pollution, present in a given sample.

Here, oxidation is carried out by a reagent with powerful oxidizing properties (potassium permanganate when heated in an acid medium).

The amount of reagent consumed in oxidizing the organic matter present, expressed in mg/l of oxygen, corresponds to COD.

III.1.2. BOD5 or Biochemical Oxygen Demand:

Self-purification in surface waters results from the degradation of organic pollutants by micro- organisms. Their activity tends to consume oxygen, and it is this reduction in oxygen in the environment that is measured by BOD 5.

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At 20°C, the degradation of organic matter begins immediately, and it is conventional to express BOD 5 in mg/l of oxygen consumed over 5 days at 20°C.

BOD 5 represents the proportion of biodegradable organic matter.

III.1.3. TSS or Suspended Solids

TSS refers to all the insoluble solids visible to the naked eye that are suspended in a liquid.

III.1.4. VSS or Volatile Suspended Solids

Mass of organic particulate matter obtained by the difference between TSS and its dry residue after passing through the furnace at 550°C. In other words, it is the solids suspended in water or other liquids that are burned when these dry solids are ignited at 550°C. Results are expressed in mg/L or as a percentage.

III.1.5. MO or Organic Matter

Organic matter in water is the undecomposed part of organic pollution (dead living matter or the excrement of living organisms). It is naturally present in water, but in low concentrations.

III.2. Ankatso effluents

This effluent, made up of grey and black water, comes from the university's laboratories and toilets. The results of analyses carried out on a sample of wastewater are as follows:

Parameters	Values	Units	Standards for effluent discharge
MY	37	Mg/L	60
COD	86.35	Mg/L in 02	150
BOD5	57.23	Mg/L in 02	50
MO	9.50	Mg/L in 02	
MVS	35	Mg/L	

Standards source: D2003-464_les_normes_des_eaux_usees

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Standards for effluent discharges into the environment are also given in the above table, to facilitate comparison and interpretation of analysis results.

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=>BOD5 is slightly higher than the standard, effluent treatment is required to lower it and allow the option of land application or discharge into the natural environment.

The COD / BOD5 ratio provides an indication of the source and origin of organic pollution. According to the literature, measurements with a COD/BOD5 ratio close to 1 indicate very good biodegradability:

- From 1 to 2: wastewater from agri-food industries contains elements that are easily degradable by biological treatment, resulting in a high COD5.
- From 2 to 3: urban wastewater.
- From 3 to 4: Industrial wastewater less easily biodegradable.
- >4: Effluent difficult to biodegrade

=>In this case, the DCO/DBO5 ratio of the effluent is 1.50, which means that it contains elements that bacteria love and are highly biodegradable.

IV. Topographic survey

IV.1. Assumption 1

Assumption 1 consists of a water transfer system from the sump to the treatment system via a reservoir, based on the following calculation assumption:

DRIVING	FLOW
Concrete Nozzle 100mm	Q=3.3m /J3
PVC 100 mm	Q=0.04 L/s

IV.1.1. Description

We have three variants for transferring water from the sump to the reservoir: pipe no. 1, pipe no. 2 and pipe no. 3, which can be either 100mm pressure PVC or 100mm concrete nozzle.

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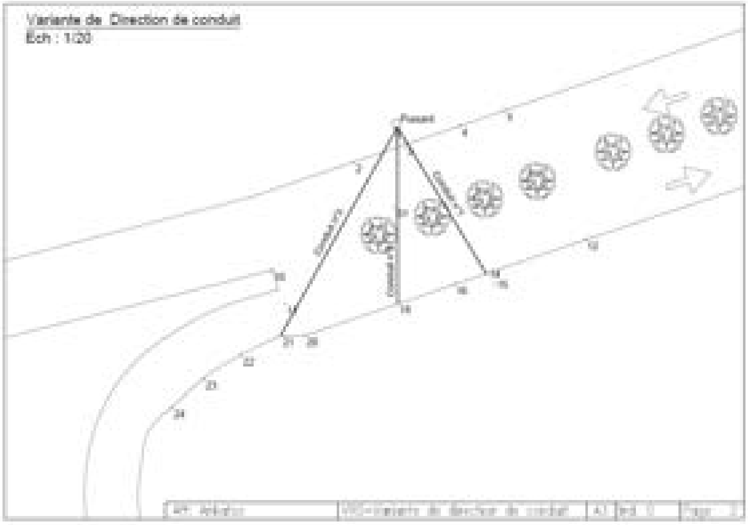

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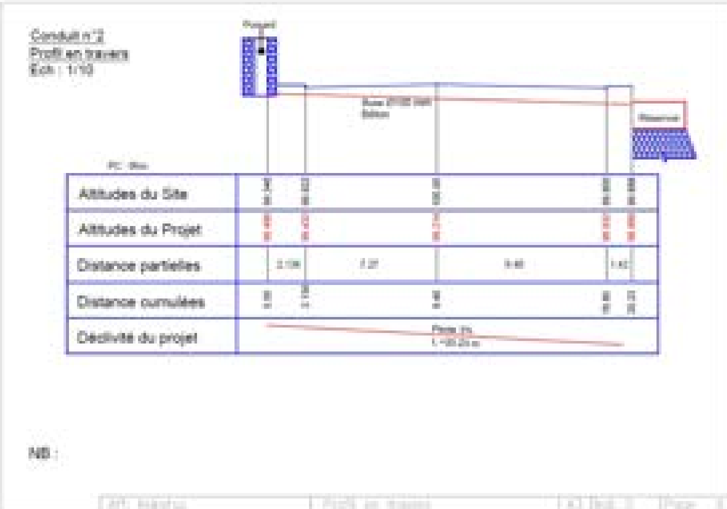

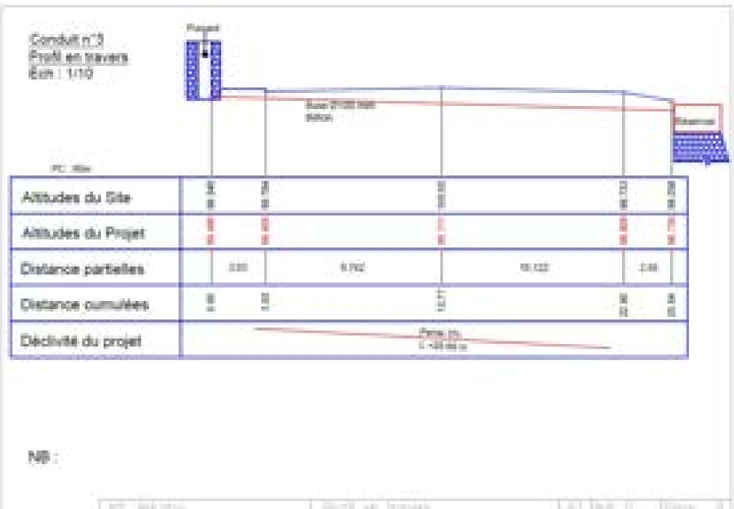

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IV.1.2. Conclusion of hypothesis 1

The wastewater crossing from the sump to the reservoir is feasible using either pipe no. 1, no. 2 or no. 3. However, pipe n°1 is the most economical for the project because of its minimal length compared with the other pipes for the same characteristics (slope, size).

Given the short distance between the pipe and the road, and from a strength point of view, the material used is preferably a concrete nozzle.

IV.2. Assumption 2

Option 2 involves using existing manholes to bring water directly from the sump to the treatment system.

IV.2.1. Description

The topographic surveys carried out showed the following results:
The distance between Manhole 2 and the recovery basin is approximately 50m, with a gradient of 8.5m. This gives a slope of 17%, allowing the effluent to flow by gravity.

IV.2.2. Conclusion of hypothesis 2

Piping wastewater from the sump to the system through the two existing manholes on the site is feasible.

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V. Wastewater treatment solutions for Ankatso

V.1.Water pipe installation

The optimum solution for the layout of the water pipes is hypothesis 2. As the manholes are operational and already in place, this minimizes the work required and the complexity of the piping.

Figure 5: Overview of the treatment system

- **The water pipe:** the water pipe works only concern the following parts: from manhole 2 to the bar screen, which is a 150-diameter PVC pressure pipe buried for safety; from the bar screen to the sand filter and then to the filters, which are built in parallel; and finally, at the outlet from the planted filters to the effluent recovery basin, which will be open pipes.
- **The bar screen: this is** a basin with a grid to filter out the solids contained in the water to be treated. This basin includes a water bypass pipe in the event of a bar screen clogging. The bar screen requires periodic maintenance to avoid clogging the system.
- **The weir:** this is a system built into the sand filter to prevent saturation of the system in the event of a storm or excessive flow.

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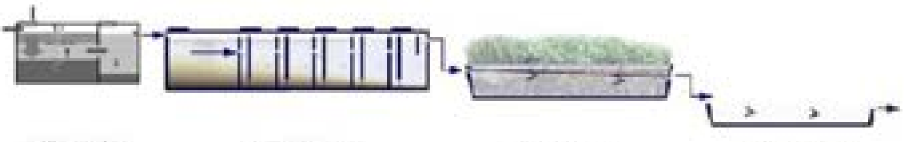
V.2.Wastewater treatment system description : DEWATS

DEWATS is a range of reliable, low-cost wastewater treatment systems developed by BORDA for developing countries, as they require little maintenance and upkeep, and can generally be operated without electricity. They can treat organic wastewater from domestic and industrial sources, with flows ranging from 1 to 1,000 m3 per day. The DEWATS system is an effective and efficient wastewater treatment solution that minimizes water and soil pollution in residential / housing complexes. DEWATS technology is based on the principle of low cost and low maintenance, as most of the important parts are available locally and operate without any technical energy input. Standard applications are based on four basic treatments using sedimentation and flocculation, and anaerobic and aerobic treatment using different filters and basins:

- settling and primary treatment in settling basins, septic tanks or Imhoff tanks
- anaerobic secondary treatment using fixed-support filters or compartmentalized septic tanks
- secondary and tertiary aerobic/anaerobic treatment using macrophyte beds (horizontal flow filters below the surface)
- secondary and tertiary aerobic/anaerobic treatment by lagooning.

The diagram below illustrates the DEWATS process.



The four systems listed above will be combined according to the composition of the incoming wastewater and the required effluent quality.

DEWATS has been successfully applied in housing complexes/settlements, schools, home-based biological industries as well as hotels, hospitals, livestock farms, abattoirs and municipal sludge treatment plants. In this project, due to the low level of water pollution, the sludge is fairly stabilized, as it is already treated by a septic tank upstream of the sump. The digester is therefore not essential, but will be replaced by a buffer tank to smooth out the flow over the day, and also enable the sedimentation of solids.

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The current technology installed at the university is the septic tank. This is already a primary treatment system, ensuring decantation, sludge stabilization and a BOD reduction of between 25% and 50%. However, the high level of BOD5, which just exceeds the standard in force in Madagascar, calls for the addition of secondary and/or tertiary treatment.

The most suitable system for Ankatso University is a sand filter followed by a planted filter.

V.2.1. Sand filter

A sand filter consists of a washed silica sand bed that replaces the natural soil. Rigid spreading pipes (pipes with downward-facing perforations) are placed in a layer of gravel covering the sand, thus distributing the effluent over the bed. The wastewater is then treated by the micro-organisms attached to the sand grains.

Sizing the sand filter depends on the volume of input. The flow rate measured during the period when ARAFA carried out the rehabilitation work and diagnosis was 3m3 /day, but the flow rate considered in the sizing is 6m3 /day, on the assumption that it could be higher during a certain period of greater use of the University.

V.2.2. Planted filters or macrophyte beds

Macrophyte beds are used for wastewater with a low concentration of suspended solids and a COD of less than 500 mg/l. This system ensures a 70-95% reduction in BOD.

Effluent from macrophyte beds is also suitable for watering gardens. However, the more the water is treated, the less fertilizing elements it contains. Although most pathogens have been eliminated, no effluent of domestic or agricultural origin can be stamped "pathogen-free". Irrigation of crops should end 2 weeks before harvest. It is preferable not to irrigate fruit crops and vegetables eaten raw after flowering.

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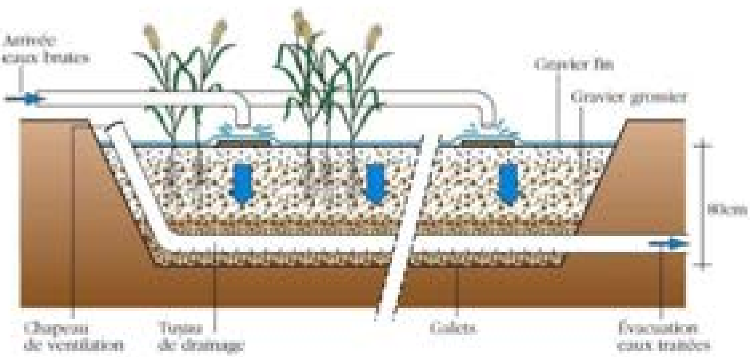
V.2.2.1. Vertical planted filter

In a vertical flow filter, the wastewater is distributed by a dosing device over 2 or 3 filter beds, which operate alternately. The intervals between loading must be scrupulously respected, which makes vertical flow filters unsuitable for the DEWATS principle. The aim of this alternation is to minimize filter clogging by mineralizing the organic matter during the rest phases. The rest time required on the first stage is, this means 3 parallel beds. On the second floor, resting times are equivalent, so 2 beds are sufficient. Rotation usually takes place every 3-4 days. The first-stage filters are made exclusively of different types of gravel, in which diffusion aeration phenomena are significantly higher than in sand.



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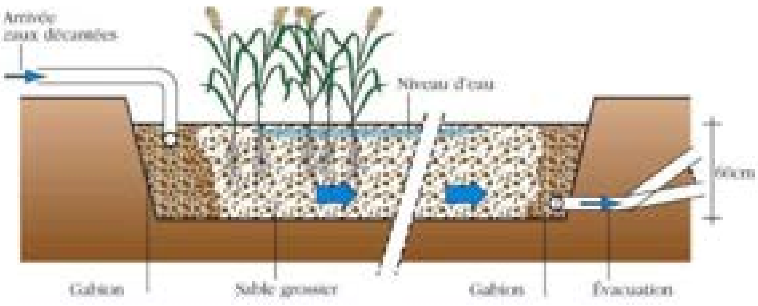
V.2.2.2. Horinzontal planted filter

Horizontal filters, on the other hand, are completely saturated with water, thanks to a siphon system at the outlet, which regulates the height of water in the basin. Distribution gabions at the filter inlet and outlet ensure more or less even water distribution and recovery. Horizontal filters are more susceptible to clogging than vertical-flow filters, and must therefore be fed with water that has been cleaned of suspended solids. In the present case, this is achieved by means of an upstream sand filter.



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V.3.DEWATS system sizing for Ankatso

V.3.1.1. Choosing and sizing the planted filter

The university's sanitation system already uses a septic tank as the main effluent treatment system, so the planted filter will act as a secondary treatment system. That's why the project was chosen for a horizontal flow planted filter.

The sizing basis for a macrophyte planted filter is 2 to 2.5 m2 /EH (population equivalent). The p.e. is a unit of measurement used to assess the capacity of a wastewater treatment plant. It is based on the amount of pollution emitted per person per day.
In the case of this project, the population equivalent is not known and the effluent pollution, i.e. the effluent concentration in TSS, COD and BOD, is below that of domestic wastewater. Given the low pollution input, all pollution will be treated in the filters, so the sizing factor used is volume. This is also done to avoid saturating the filtration system.

CORRESPONDENCE	
1 EH	120L/D of wastewater

Basic data for the Ankatso case after laboratory analysis of the sample:

	Quantity	Unit
Daily flow	6,000L	day

This gives the following result:

	Quantity	Unit
EH	50	EH
Area FP	100	m2

The horizontal flow planted filter will therefore have a total surface area of 100 m2, divided into two parallel filters.

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The plant we're going to use for both filters is Vetiver, a plant adapted to the tropical climate and which tolerates temperature variations well. According to the standard, 4 plants/m2 are required, so we need to provide 400 units of vetiver.

V.3.1.2. Sizing the sand filter

The role of the sand filter is to reduce organic pollutant loads in the effluent. Its sizing takes into account the input flow rate, which in the case of Ankatso University is 6000L/day. Given this maximum daily input flow and the flow velocity in the sand filter, which must not exceed 0.3m/s, the sand filter is 8m2. The sand filter contains an overflow in the event of a storm or excessive flow.

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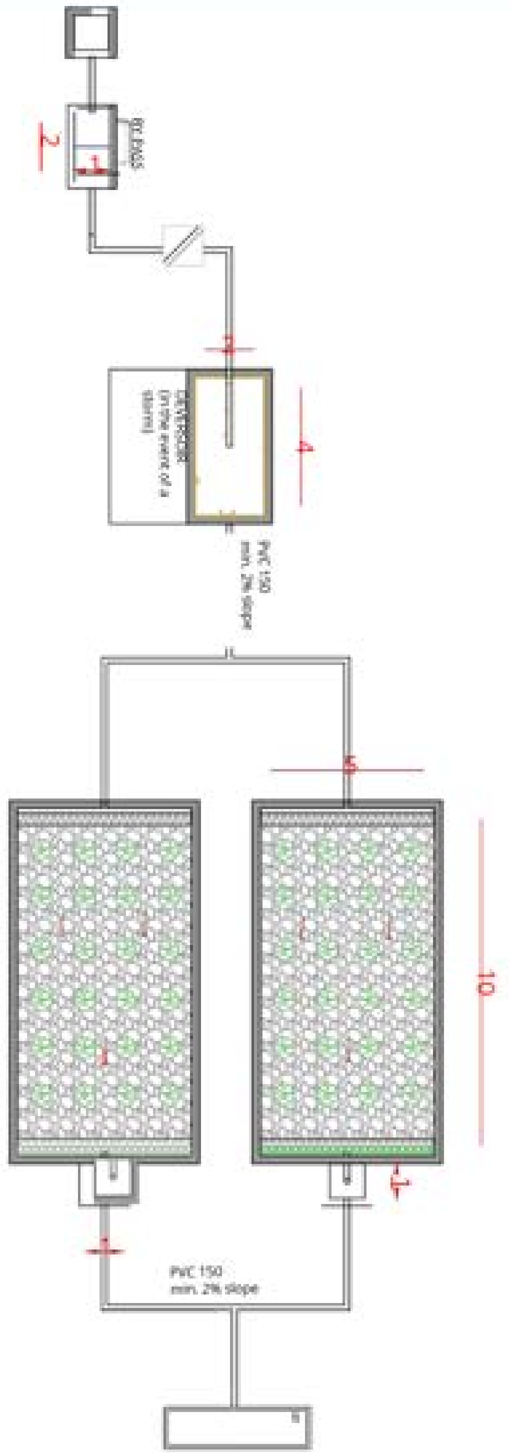
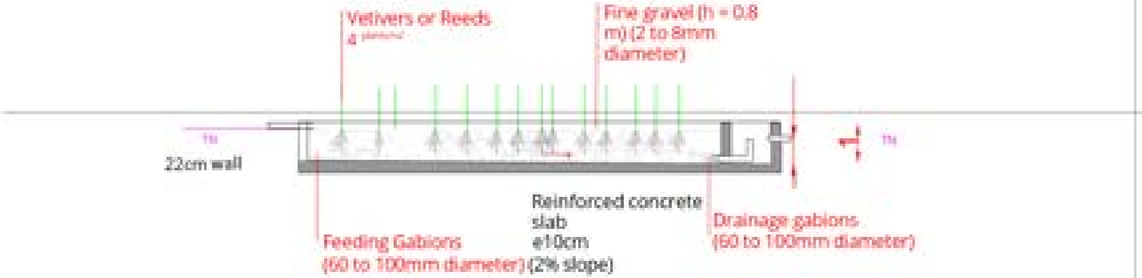
VI. Estimated cost of water network rehabilitation and wastewater treatment

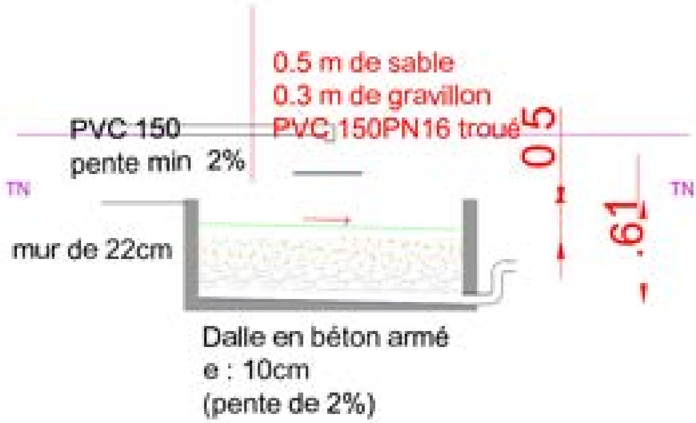
N°	DESIGNATION OF WORK	UNIT	QTE	PU	TOTAL EXCL.
00	Site installation	fft	1.00	450,000.00	450,000.00
01	Excavation and earthworks Bar screen basin in BA and	fft	1.00	1,150,000.00	1,150,000.00
02	brick masonry filled with cement mortar and waterproofed with sikalite, including all installation and maintenance work. work	fft	1.00	500,500.00	500,500.00
03	Sand filter manhole cover made of BA and brick masonry with cement mortar and sikalite waterproof coating including all installation requirements	fft	1.00	1,878,500.00	1,878,500.00
04	Filling the sand filter (2.5m3 of gravel and 4m3 of sand)	fft	1.00	920,400.00	920,400.00
05	Planted filter manhole in BA and cement-mortared hourdé brick masonry with waterproof sikalite coating, including all installation requirements	U	2.00	5,200,000.00	10,400,000.00
06	Filling the planted filter (3m3 of gabion 60 to 100mm in diameter and 27m3 of gravel 2 to 10mm in diameter and 200 feet of vetiver trees or reeds)	fft	2.00	3,770,000.00	7,540,000.00
07	Reinforced concrete 350kg/m3 CEMII for slab	m3	3.00	520,000.00	1,560,000.00
08	Overhead pipe in brick masonry filled with cement mortar and waterproofed with sikalite, including all installation work	ml	30.00	32,500.00	975,000.00
			TOTAL EXCL.		**25,374,400.00**
			20% VAT		**5,074,880.00**
			TOTAL TC		**30,449,280.00**

The amount required for this project is **thirty million four hundred and forty-nine thousand two hundred and eighty** Ariary all taxes included.

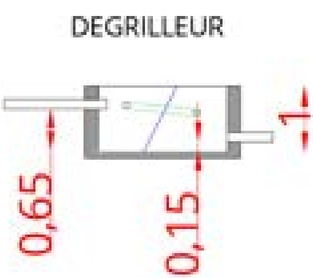
APPENDI
II.
E5
II.1 General system layout




Vetivers or Reeds
Fine gravel (h = 0.8 m) (2 to 8mm diameter)
TN
22cm wall
1
TN
Reinforced concrete slab e10cm (2% slope)
Drainage gabions (60 to 100mm diameter)
Feeding Gabions (60 to 100mm diameter)


0.5 m de sable
0.3 m de gravillon
PVC 150PN16 troué
PVC 150
pente min 2%
0.5
TN
.61
TN
mur de 22cm
Dalle en béton armé
e : 10cm
(pente de 2%)

DEGRILLEUR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Appendix III:

Letter of Intent from the University of Antananarivo
The Garden of Eden Proposal

JACQUELYN JESTINE SANDERS FOUNDATION
BUILDING VISION, REALIZING CHANGE

REPOBLIKAN'I MADAGASIKARA
Fitiavana - Tanindrazana - Fandrosoana

MINISTERE DE L'ENSEIGNEMENT SUPÉRIEUR ET DE LA RECHERCHE SCIENTIFIQUE

UNIVERSITÉ D'ANTANANARIVO

PRESIDENCE

Antananarivo, 10 SEP 2024

to Mr. Kenneth Coman
President of
Jacquelyn Jestine Sanders Foundation

N° 10[illegible]/24/UA/PUA/CAB

LETTER OF INTENT

The University's Board met on September 3, 2024, and the activities of the Jacquelyn Jestine Sanders Foundation, as a partner of the University, were presented to the Board members. The project fully shares the University's vision and strategic planning and embraces its core values of promoting both research excellence and human and ecological harmony.

Indeed, a "comprehensive planning of drinking water infrastructure at the University through the capture, storage, and filtration of rainwater and the implementation of wastewater treatment" as well as agro-forestry and rice permaculture, and concretizing this project as recommended in our previous correspondence, is crucial.

The University expresses its overriding interest in realizing the project named "Garden of Eden" as presented in the Eden article.

Thus, this letter of intent gives

> **the overall agreement of the University's Board, and of myself, President Mamy Ravelomanana, as the legal representative of the University of Antananarivo,**
>
> **to the Jacquelyn Jestine Sanders Foundation, to take all relevant steps to find partners, donors, and sponsors on behalf of the University for the realization of this "Garden of Eden" project.**

In addition, the University will retain for the Foundation the option of having the exclusivity of the supervision and the realization of this "Garden of Eden" project and related matters.

If necessary, the establishment of new infrastructures will be afforded to the project: a formal authorization requires an ulterior agreement of the Board. I hope our mutual project to be concretized as it is well aligned to the Sustainable Development goals of the United Nations.

Faithfully yours,

Le Président de l'Université d'Antananarivo

Mamy Raoul RAVELOMANANA
Professeur Titulaire

"The Foundation cannot fully express the joy of discovering with the Fellows - a promising solution to the University's water challenges. We are equally delighted by the University's commitment to working alongside us to bring this solution to life."

SUSTAINABLE VISION ACADEMIC JOURNAL

JACQUELYN JESTINE SANDERS FOUNDATION
BUILDING VISION, REALIZING CHANGE

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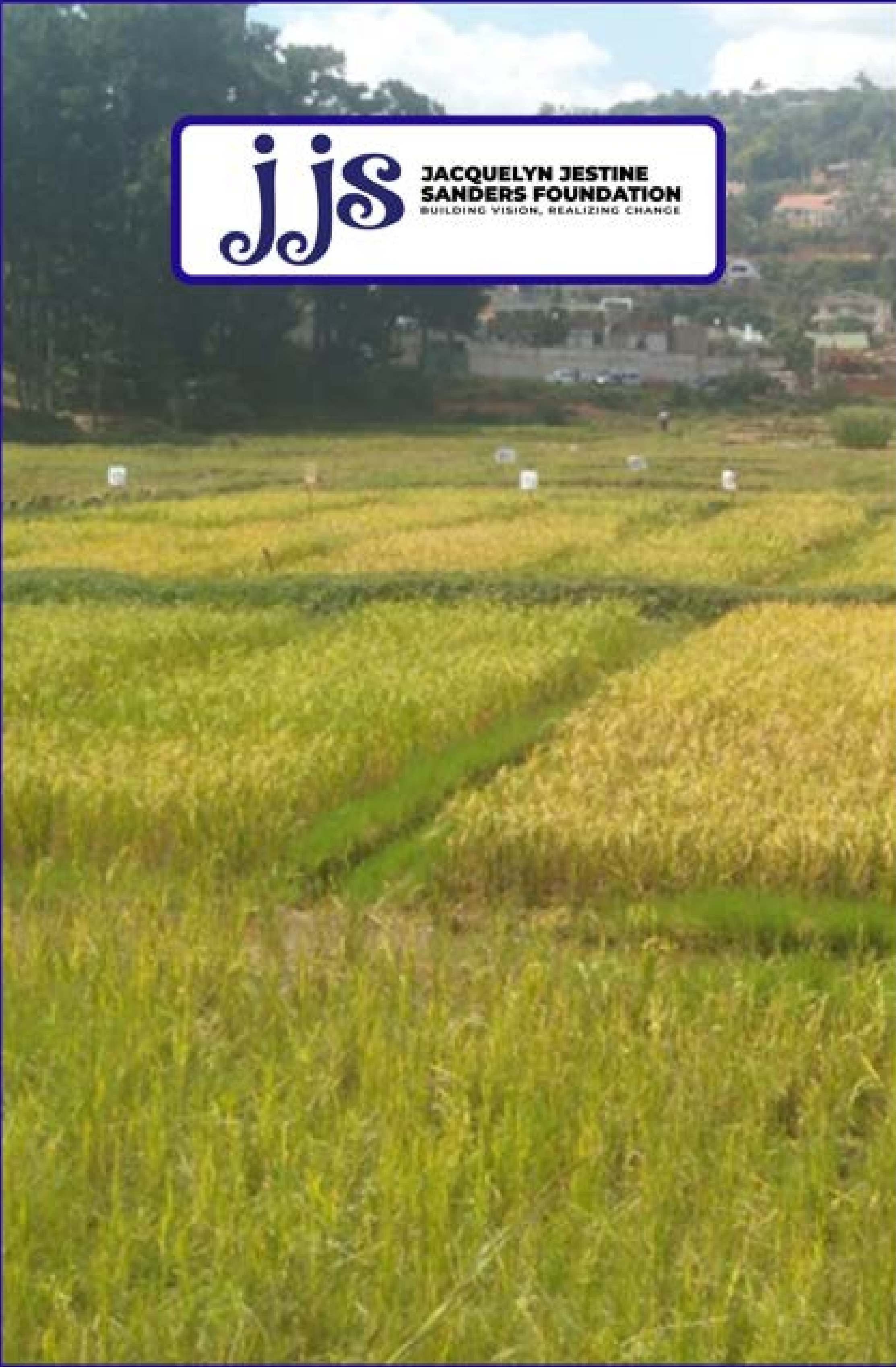
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2024

JJSF SUSTAINABLE VISION ACADEMIC JOURNAL

1.5 inch

2024 JJSF SUSTAINABLE VISION ACADEMIC JOURNAL

1 inch