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Socio-economic impact of water conservation in Antananarivo, Madagascar

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Abstract

Water conservation is crucial for tackling global resource sustainability and economic development challenges. This study analyzes the socio-economic impacts of water conservation growth in Antananarivo, Madagascar, evaluating different strategies' potential benefits and drawbacks. An investigation and survey targeting Mandroseza Lake, involving the Ministry of Agriculture, Ministry of Environment, National Institute of Statistics, and JIRAMA National Water Company. Parameters like water production, distribution, infrastructure maintenance, economic growth, and water loss reduction were analyzed. Descriptive statistics and Pearson correlation were used to assess relationships between variables. Significant positive correlations were found between water conservation efforts and economic growth in domestic sectors ($r=0.9856$, $p<0.0001$), industry ($r=0.9109$, $p<0.0001$), and agriculture ($r=0.8998$, $p<0.0001$). Similar positive correlations were observed between water production and agriculture ($r=0.9704$, $p<0.0001$), industry ($r=0.9541$, $p<0.0001$), and household consumption ($r=0.9256$, $p<0.0001$). Additionally, a positive correlation was found between population and tap water availability ($r=0.4219$, $p=0.0048$). The study highlights the strong positive association between water conservation and economic growth, societal well-being, and tap water access in Antananarivo. This emphasizes prioritizing and funding sustainable water practices for stakeholders, water management officials, and policymakers.

Key Words: water production, GDP, environmental sustainability, management, agriculture, industry

1-INTRODUCTION

Water conservation is a critical issue in the current global setting, impacting both environmental sustainability and economic growth. While Earth's surface is 75% water, only 3% is freshwater (Saurí, 2013; Balasubramanian, 2015). Madagascar, the fourth largest island, faces this challenge with its 29.6 million population experiencing significant economic expansion in agriculture, mining, and trade (Statista, 2018). Integrating conservation with development is crucial (Bidaud, 2015). Expanding industries and agriculture exacerbate water scarcity (Bouët, 2022). Madagascar's water resources vary regionally, with abundant summer rainfall (2,000-3,000mm annually) (CYCLE–Vol II, 2009). However, only 12,170 cubic meters per capita were available in 2020, with 60% lacking access to safe drinking water (Weiskopf et *al.*, 2021; Grönwall et *al.*, 2020). Antananarivo, the capital, faces water scarcity challenges due to a growing population, limited water sources, and unreliable rainfall (Rakotoarimanana et *al.*, 2022). Water shortages are common, especially during the dry season when demand exceeds supply (Suryanegara et *al.*, 2023). Insufficient infrastructure leaves many Antananarivo residents without reliable piped water, forcing them to endure intermittent supply and low pressure (Andey et *al.*, 2009). This strain on households makes meeting basic water needs a constant challenge. Contamination from industrial activities, inadequate sanitation, and improper waste disposal further aggravate the situation, polluting water sources and posing health risks through waterborne diseases (Bastaraud et *al.*, 2020). Inefficient distribution systems, poor maintenance, and limited investment in infrastructure exacerbate these issues. Additionally, weak regulations on pollution control and water conservation worsen the situation (Bastaraud et *al.*, 2020).

Efforts are underway to address these challenges such as governments, NGOs, and international partners collaborating on projects to improve water supply, upgrade infrastructure, promote conservation, and enhance management practices. The $220 million National Water Project aims to increase water access and improve utility performance in Greater Antananarivo and selected towns (World Bank, 2022). City-led programs focus on reducing water losses, improving continuity of supply, and increasing production capacity (Vivek et *al.*, 2020). Continued efforts towards better

infrastructure, efficient management, and awareness campaigns are crucial for promoting responsible water usage and environmental conservation. Achieving long-term improvement requires sustained commitment and investment. Antananarivo's rapid urbanization has strained its water infrastructure, making access to clean water a major concern. Population growth has outpaced water demand management, leading to difficulties for local authorities in providing consistent access (Hinz et *al.*, 2020). Despite infrastructure improvements, a significant portion of the city lacks clean drinking water due to outdated systems, poor maintenance, and insufficient capacity to meet rising demand (Rajaomahefasoa et *al.*, 2019). This issue disproportionately affects certain populations, exacerbating existing inequalities. The city's water treatment capacity has not kept pace with population growth since 1985, with daily production only increasing by 100,000 m3 while the population grew by 5% annually (Castelli, 2018; Miakatra, 2014). This aging infrastructure, with an efficiency of 60%, struggles to meet the current 2% annual water demand increase (D'EAU, 2020). Although a new component increased capacity in 2017, it's too early to assess its impact on water quality. With the projected population reaching 3.4 million by 2020, the demand-supply imbalance is expected to worsen (Ricci et *al.*, 2009). The link between population growth and water access highlights a critical issue requiring immediate attention. Comprehensive and sustainable solutions are crucial to ensure equitable access for all citizens. Addressing the complex challenges of urbanization and its impact on essential services necessitates proactive measures and international collaboration as the city continues to expand. The present work aims and objectives of this study are to analyze the socio-economic impacts growth of water conservation in Antananarivo, Madagascar, and assess the potential benefits and drawbacks of different conservation strategies, by examining several elements to understand the complex relationship between water conservation and economic outcomes.

2-METHODOLOGY

2.1 Site of Study

An investigation and survey were conducted at the offices of the Ministry of Agriculture, Ministry of Environment, National Institute of Statistics (https://www.instat.mg/), and JIRAMA (https://www.jirama.mg/), focusing on Mandroseza Lake in Antananarivo. Mandroseza Lake, one of Antananarivo's largest, is situated southwest of the city. This 40-hectare settling basin, with an estimated volume of 800,000 cubic meters, primarily relies on the Ikopa River for water supply, drawn through an intake dam equipped with five pumps. The lake's geographical coordinates in the Laborde system are X: 517053.86m - 518201.05m and Y: 795398.24m - 796984.48m, corresponding to latitudes 18°55'30.72''S - 18°56'22.56''S and longitudes 47°32'55.68''E - 47°33'34''E, at an altitude of approximately 1266 meters above sea level.

2.2 Data collection technique

This study employed a quantitative research approach to investigate the relationship between water conservation and economic performance in Antananarivo, Madagascar. One hundred questionnaires were randomly distributed and collected from respondents. Quantitative methods were chosen for their focus on numerical data and statistical analysis, enabling the testing of hypothesized relationships between variables. While utilizing secondary data analysis has limitations in terms of control and depth, it offers valuable insights into broad trends and allows for generalizability across Antananarivo. Data spanning from 2013 to 2022 were gathered based on availability. To evaluate the effectiveness of water conservation efforts, parameters such as survey questions, overall water production, water-related job creation rate evolution, percentage of water distribution infrastructure maintenance, percentage of production profit, growth rate of real GDP, wastewater rate diminution, number of tourists, number of improved freshwater ecosystems, water loss reduction rate, and infrastructure maintenance rate were considered.

2.3 Data Analysis

The collected data were organized in Microsoft Excel and analyzed using Prism 9 software. Descriptive statistics were employed for the survey questions. The relationship between variables related to water conservation and its impact was assessed using Pearson correlation analysis. A significance level of alpha ≤ 0.05 was adopted for determining statistical significance.

3-RESULTS AND DISCUSSIONS

Table 1 Perception of Respondents Toward Water Conservation

	Respondent's perception		
Inquiry into water conservation policies	Yes (%)	No (%)	Not sure (%)
Have you observed any measurable changes in economic indicators (e.g., job creation, GDP, investment) attributable to JIRAMA's water conservation policies?	74	14	12
Have collaborative efforts with stakeholders positively influenced the success of water conservation policies at JIRAMA?	75	11	14
Are you aware of the water conservation policies implemented by JIRAMA Mandroseza?	64	24	12
Do you believe that water conservation policies have contributed to job creation or economic opportunities in Mandroseza?	79	8	13
Do you feel that residents have been adequately involved in the decision-making process regarding water conservation policies in Mandroseza?	65	33	12
Is there a mechanism in place for residents to provide feedback or suggestions on water conservation policies?	67	20	13

The table (1) reflects the perceptions of respondents regarding water conservation policies and their impact. The majority of respondents answered positively to most questions, suggesting that they have observed measurable changes in economic indicators over the past years. This results in believing the positive influence of collaborative efforts of the administrative policies has contributed to job creation and economic opportunities.

A significant 74% of respondents detailed observing quantifiable changes in economic indicators connected to JIRAMA's water conservation policies. This recommends a predominant conviction among inhabitants that these activities have emphatically affected variables like work creation, GDP, and investment. The majority (75%) of members accepted that collaborative efforts with partners have emphatically impacted the victory of water preservation arrangements at JIRAMA. This demonstrates an agreement among inhabitants that including different partners is pivotal for the effectiveness of water preservation activities. Sixty-four percent (64%) of respondents claimed awareness of the water conservation policies implemented by JIRAMA, whereas 25% were not mindful. This disparity proposes a potential need for progressed communication or open outreach concerning the existing arrangements. An overpowering 79% of respondents accepted that water preservation arrangements have contributed to work creation or economic opportunities in Mandroseza. This positive recognition underscores a high level of confidence among inhabitants in the socio-economic benefits related to water preservation activities. Almost two-thirds (65%) of respondents felt that inhabitants have been satisfactorily included in the decision-making preparation concerning water preservation approaches. In any case, a critical 33% communicated disappointment with the level of citizen inclusion, highlighting potential holes in comprehensive decision-making forms. The study revealed that 67% of respondents were mindful of mechanisms input for inhabitants to supply feedback or recommendations on water preservation approaches. Whereas this demonstrates a direct level of mindfulness, the 20% who were not mindful recommend room for change in communicating accessible criticism channels. The survey conducted to gauge public perception of JIRAMA's water conservation initiatives in Mandroseza, Antananarivo, yielded valuable insights. Respondents predominantly held positive views regarding the impact of these initiatives on their communities, aligning with existing literature that highlights the potential economic benefits linked to water conservation programs (Ramaharo et *al.*, 2024; Ozcelik et *al.*, 2021).

The substantial consensus among respondents regarding the positive economic outcomes of specific approaches indicates that these initiatives not only contribute to community well-being but also have the potential to bolster regional economic stability. Nevertheless, the revelation that a quarter of respondents lacked a sufficient understanding of the policies raised concerns. Previous studies stress the importance of transparent communication in environmental policy

implementation (Kesti, 2019). Consequently, the survey results emphasize the necessity for JIRAMA and policymakers to craft targeted communication strategies to bridge this awareness gap, thereby cultivating a more informed and engaged community. These findings underscore the critical role played by community and stakeholder involvement in the success of water conservation initiatives. Through active engagement with residents and relevant stakeholders, JIRAMA and policymakers can harness collective knowledge and resources to implement sustainable water management practices effectively.

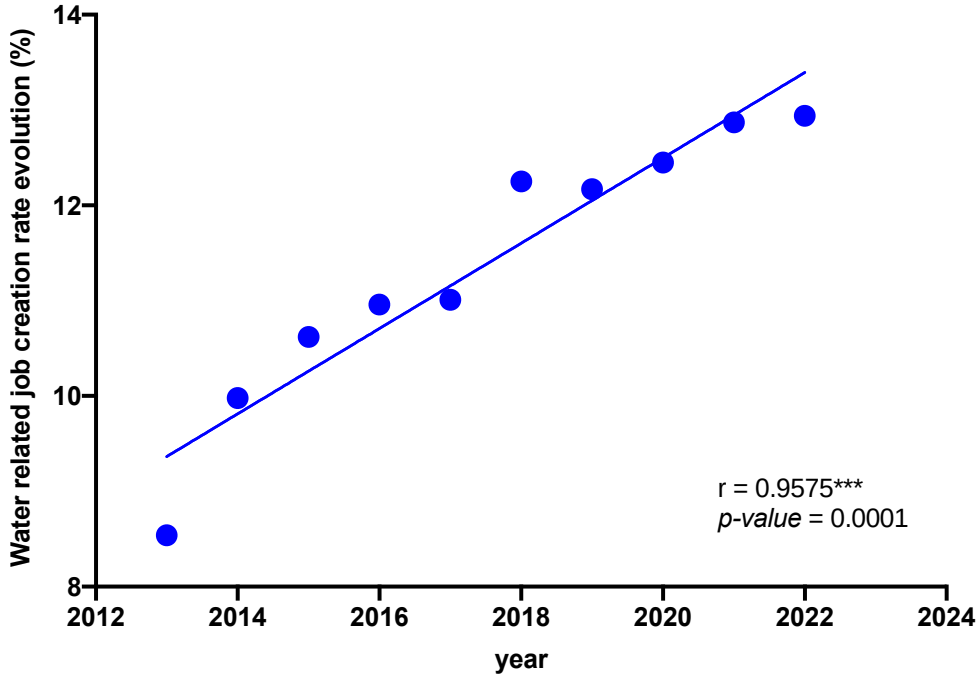

Figure 1: Water-related job creation rate evolution (%)

From Figure (1), a correlation coefficient (r) of 0.9575 signifies a very strong positive correlation between time and the water-related job creation rate. This indicates that as the years progress, the percentage of new jobs created within the water sector consistently rises. Moreover, the p-value of 0.0001 is exceptionally low, implying that the correlation is statistically significant. Thus, there is strong evidence suggesting a genuine connection between time and the growth of water-related jobs. As the global population expands and climate change intensifies, water resources become increasingly scarce. This scarcity often leads to heightened investments in water management, infrastructure development, and technological solutions, which create new job opportunities in these sectors. Technologies like desalination, wastewater treatment, and water recycling are witnessing considerable growth due to advanced technologies and growing demands for clean water. This expansion generates more job openings for engineers, scientists, technicians, and other professionals. This study reinforces the socio-economic impact of water conservation efforts in Madagascar, particularly in the JIRAMA Antananarivo region. It demonstrates a robust positive relationship between time and job creation in the water sector. This suggests a continuous increase in new employment opportunities over the years, indicating that intensified water preservation efforts have resulted in growth in job opportunities. These findings corroborate previous research highlighting environmental conservation initiatives' potential to stimulate economic development and employment (Dasgupta et *al.*, 2021). The measurably significant relationship, as evidenced by the extremely low p-value of 0.0001, further strengthens the validity of the observed relationship. A p-value lower than the conventional threshold of 0.05 indicates strong evidence against the null hypothesis, recommending that the relationship observed is highly improbable due to random chance alone (World Bank, 2021). In conclusion, the research highlights a strong link between time and the growth of water-related jobs in Madagascar. This emphasizes the importance of continued investment in water conservation initiatives for policymakers and stakeholders. Prioritizing effective water resource management can address environmental challenges and promote socio-economic development by creating job opportunities. Furthermore, the discoveries underscore the requirement for prolonged observation and evaluation of water conservation programs to accurately measure their socioeconomic impacts over time (Jagger and Shively, 2014). Longitudinal studies, such as the one conducted in this inquiry, offer valuable insights into the evolving relationship between water preservation efforts and business patterns over time (Ashraf et *al.*, 2023).

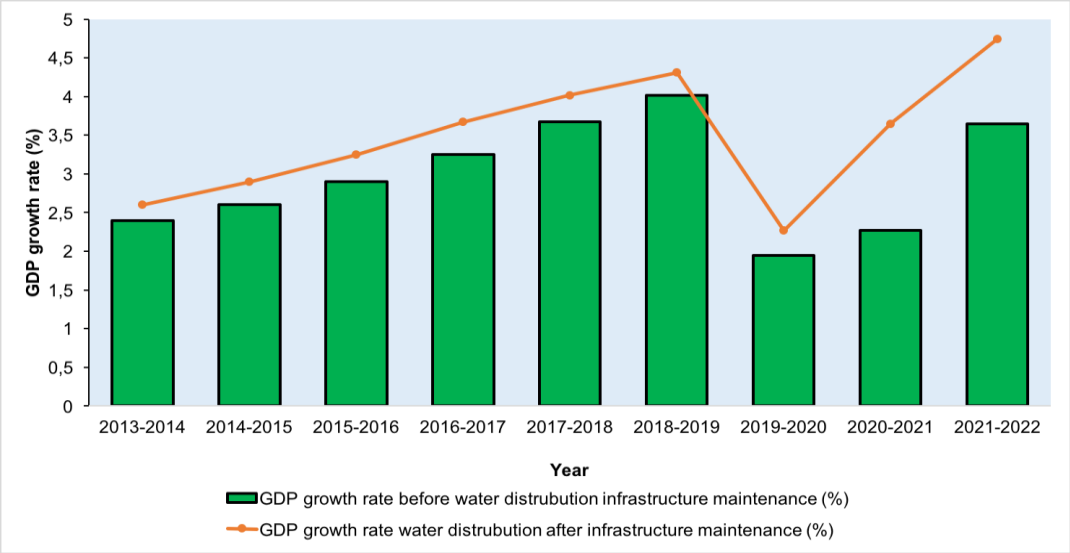

Figure 2: GDP growth rate over a period

Figure (2) presents the GDP growth rates before and after water distribution infrastructure maintenance over several years. The data exhibits a discernible pattern in GDP growth rates post-implementation of water distribution infrastructure maintenance, hinting at a link between enhanced water management and economic prosperity. Before infrastructure maintenance, Antananarivo's GDP growth rates gradually ascended from 1.12% in 2013-2014 to 5.02% in 2017-2018, although with variations in some years. Nonetheless, growth rates witnessed a minor decrease in succeeding years, reaching 2.65% in 2021-2022 (World Bank 2017). Following the maintenance of water distribution infrastructure, there emerged a striking alteration in GDP development rates. The development rates surpassed those of the pre-maintenance era, indicating a favorable impact of the infrastructure updates on economic growth. For example, the GDP growth rate escalated from 2.23% in 2013-2014 to 5.31% in 2018-2019 and advanced to 3.74% in 2021-2022 (Rakotoarimanana et *al.*, 2022).

Some factors appear to explain the observed enhancement in GDP development rates following water distribution infrastructure maintenance. Improved access to clean water promotes public health, reduces waterborne diseases, and augments productivity, contributing to higher economic output. Effective water management can foster investment and economic activity by supplying a reliable water source for industries and agriculture (Nematchoua, 2021). Water infrastructure maintenance supports economic development via environmental sustainability and climate resilience, conserving resources and mitigating water scarcity risks. Nevertheless, correlation does not necessarily imply causation; government policies and global economic conditions also affect GDP growth. Future research could employ econometric techniques to examine the causal impact of water conservation policies on Madagascar's economy.

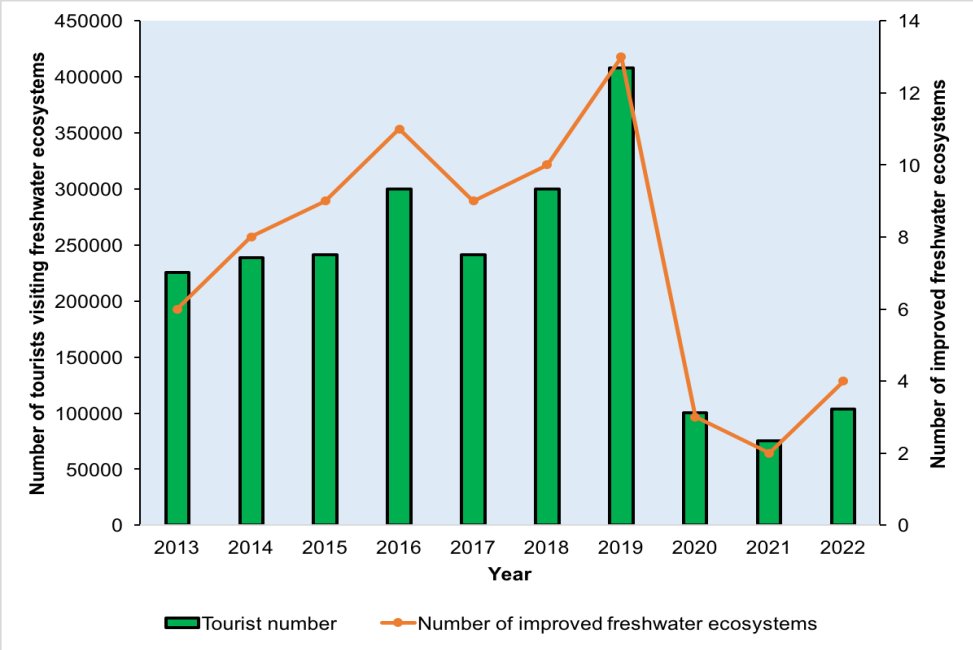

Figure 3: Number of tourists and the number of improved freshwater ecosystems as a function of year

Figure 3 provides information on the number of tourists and the number of improved freshwater ecosystems for different years. The graph displays fluctuations in both tourist numbers and the count of improved freshwater ecosystems over the years. The progressive rise in tourist entries in Antananarivo from 2013 to 2019 showcases a growing interest in Madagascar's tourism sector, potentially influenced by factors such as marketing efforts, political stability, and environmental attractions. The peak in 2016 with 300,150 tourists underscores the sector's potential economic significance. However, the significant drop in 2020 and 2021, attributed to the COVID-19 pandemic, highlights the sector's vulnerability to external shocks. Concurrently, the varying count of improved freshwater ecosystems suggests the government's endeavors to prioritize environmental conservation. The increase from 2013 to 2019 reflects proactive measures to protect natural resources and biodiversity, which are often essential for tourism development. However, the decline in 2020 and 2021 raises concerns about the progression and effectiveness of conservation policies amid challenges such as resource allocation and competing priorities.

Variations seen in both visitor numbers and the count of improved freshwater ecosystems underscore the complex relationship between conservation policies and economic growth. Costa Rica's successful implementation of Payment for Ecosystem Services (PES) programs gives valuable experiences. PES incentivizes landowners to preserve ecosystems, fostering biodiversity and eco-tourism, and subsequently supporting economic growth (Castro et *al.*, 2000). The decline in visitor numbers amid the COVID-19 outbreak emphasizes the significance of diversifying the economy beyond tourism. Rwanda's Agaciro Development Fund, Water Collection, Storage, and Slope Protection (LWH) program offers a pertinent example. LWH's focus on rural productivity and water management demonstrates how diversified economic initiatives can moderate the impacts of external shocks while promoting sustainable growth (Austin, 2013).

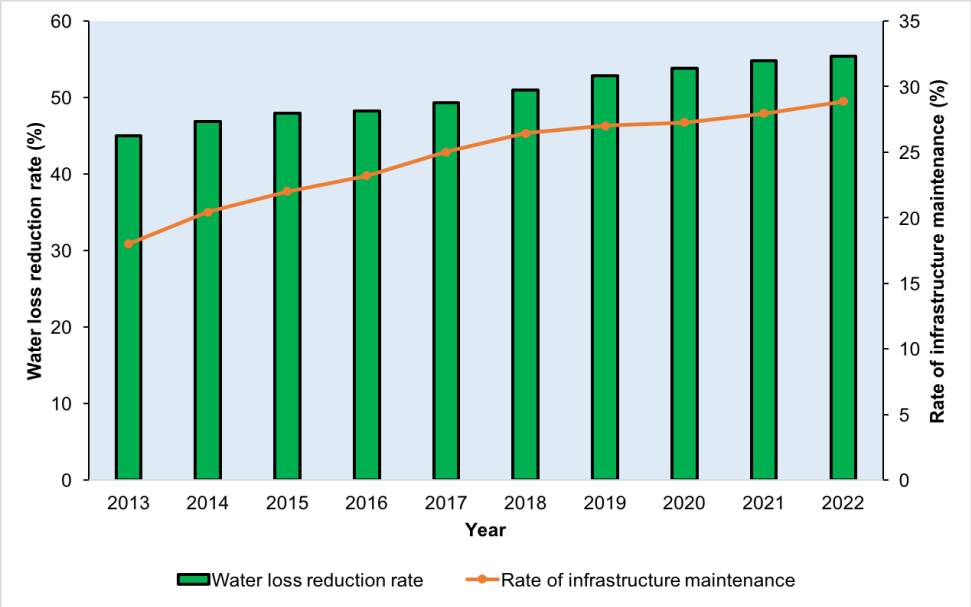

Figure 4: Water loss reduction rate and the rate of infrastructure maintenance as a function of year

The graph in Figure (4) provides information on the water loss reduction rate and the rate of infrastructure maintenance for different years. The graph indicates an upward trend in both the water loss reduction rate and the rate of infrastructure maintenance over the years. This suggests efforts to improve water conservation and maintain infrastructure integrity. The increasing values indicate progress and potentially more effective strategies implemented to reduce water loss and ensure infrastructure upkeep.

The information from Antananarivo, Madagascar, demonstrates a consistent upward trend in both the water loss reduction rate and the rate of infrastructure maintenance from 2013 to 2022. The water loss reduction rate consistently increased from 45% in 2013 to 55.37% in 2022, signifying critical changes in water usage efficiency and management practices over a long time. Essentially, the rate of infrastructure maintenance rose from 18% in 2013 to 28.87% in 2022, reflecting efforts to upgrade the reliability and longevity of water supply systems.

These trends suggest a proactive approach by the local authorities, possibly facilitated by water conservation policies, to address water management challenges and maintain basic foundations viably. The reliable increase in both the water loss reduction rate and the rate of foundation maintenance highlights the interconnects of effective water management and infrastructure upkeep in fostering sustainable development and supporting economic growth in Antananarivo.

The consistent upward trend within the water loss reduction rate reflects a commendable effort by the JIRAMA (Jiro sy Rano Malagasy) authorities in Antananarivo, Madagascar, to mitigate water losses through improved foundation and management practices. As water is a crucial resource for various sectors, including agriculture, industry, and domestic use, reducing losses can lead to more feasible water usage and contribute to economic growth (World Bank 2016). The progressive increase in the water loss reduction rate implies the effective implementation of water conservation policies and techniques aimed at minimizing leakages, unauthorized consumption, and inefficient distribution systems (Kabir et *al.*, 2021). At the same time, the rising rate of infrastructure maintenance is crucial for ensuring the reliability and longevity of water supply frameworks. The consistent investment in infrastructure maintenance indicates a proactive approach by the authorities to address the challenges posed by aging infrastructure and guarantee continuous access to safe and clean water (Herrera, 2019). Satisfactory maintenance not only decreases the risk of system failures and disruptions but also improves the overall productivity of water conveyance, hence supporting economic activities and development initiatives in the region (Chang et *al.*, 2021). The positive relationship between the water loss reduction rate and the rate of infrastructure maintenance underscores the interconnectedness of efficient water management and infrastructure upkeep. Effective arrangements and interventions aimed at reducing water losses must be complemented by investments in infrastructure support to achieve sustainable outcomes (He et *al.*, 2021). By prioritizing both perspectives, the local experts in Antananarivo are likely cultivating an environment conducive to economic development, as solid access to water is fundamental for various sectors, including agriculture, manufacturing, and tourism (ESCAP, 2013).

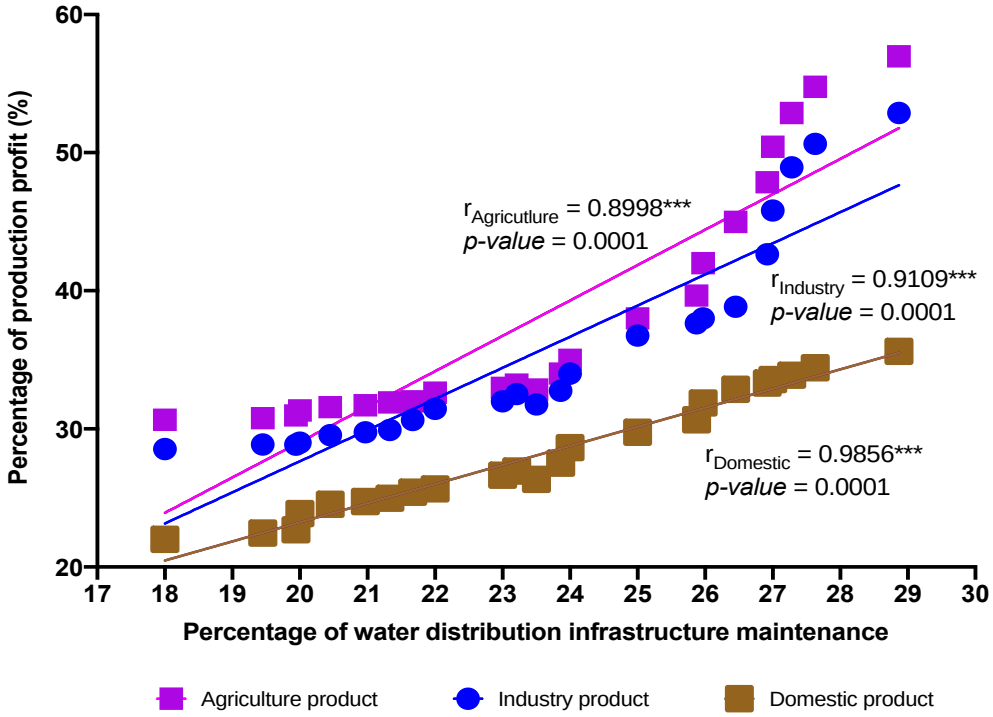

Figure 5: Percentage of water distribution infrastructure maintenance VS Percentage of production profit

Strong positive correlations have been established between water distribution infrastructure maintenance and production profit in agriculture, industry, and domestic sectors (Figure 5). Coefficients range from 0.8998 to 0.9856, indicating a substantial tendency for production profit to increase as the percentage of water distribution infrastructure maintenance rises. Low p-values (0.0001) confirm the statistical significance of these relationships, making them highly unlikely to occur by chance. Better upkeep of water distribution infrastructure is strongly associated with higher profits because it ensures efficient and uninterrupted water flow to farms, industries, and households. Reliable access to water is vital for crop growth, industrial processes, and daily activities, ultimately resulting in higher production and profits-damaged or leaky infrastructure results in water waste, affecting resource availability and increasing pumping costs. Proper maintenance helps minimize these losses, ensuring efficient water utilization and cost savings, thus contributing to improved profitability.

Well-maintained infrastructure also reduces contamination risks and guarantees the delivery of clean water. Enhanced product quality in agriculture and industry, along with health and hygiene promotion in domestic settings, all contribute to higher profits. The strong positive correlations demonstrate that maintaining water distribution infrastructure is a critical factor in achieving higher production profits across agriculture, industry, and domestic sectors. Investing in infrastructure maintenance can therefore be considered a strategic move towards promoting economic growth and development.

In summary, the strong positive correlations between water distribution infrastructure maintenance and production profit across different economic sectors highlight the importance of well-maintained infrastructure for achieving higher profits and promoting economic growth and development.

Importance of Water Conservation Infrastructure

The maintenance of the water distribution system, primarily overseen by JIRAMA (Jiro sy Rano Malagasy), plays a crucial role in the bustling metropolis of Antananarivo, Madagascar. Effective water distribution systems are vital for Antananarivo's agriculture sector, which significantly contributes to the city's GDP (Aubry, et *al.*, 2012). Water availability is indispensable for food production, livestock care, and irrigation practices (Raffo et *al.*, 2020). Proper infrastructure for water distribution is essential for enhancing agricultural output and ensuring food security in Madagascar, where agriculture plays a substantial role in the GDP (Andriamahefazafy, 2023). Water management in agriculture holds critical importance, as highlighted by the Food and Agriculture Organization (FAO) due to its impact on sustainable development (Kirda, 1999). The industrial sector in Antananarivo significantly contributes to water consumption and can exacerbate water scarcity without adequate oversight. Solutions for water conservation in this sector involve adopting water-efficient

technologies, recycling treated water, and enforcing wastewater treatment standards. Stricter regulations and incentives promoting sustainable water practices within industries are essential to mitigate environmental impact and reduce water usage (World Bank 1999). In Antananarivo, the expanding urban population strains water resources, particularly in the residential sector. Sustainable water management solutions include public awareness campaigns, promoting water-saving appliances, efficient water supply systems, implementing water harvesting systems, and enforcing water use restrictions during shortages (Ortigara, 2018; Rasolonjatovo, 2021). The infrastructure for water delivery in Antananarivo is vital for sustaining household, commercial, and agricultural activities. The references consulted emphasize the critical role of water across various industries and underscore the necessity of comprehensive water management plans to address the region's diverse water-related challenges.

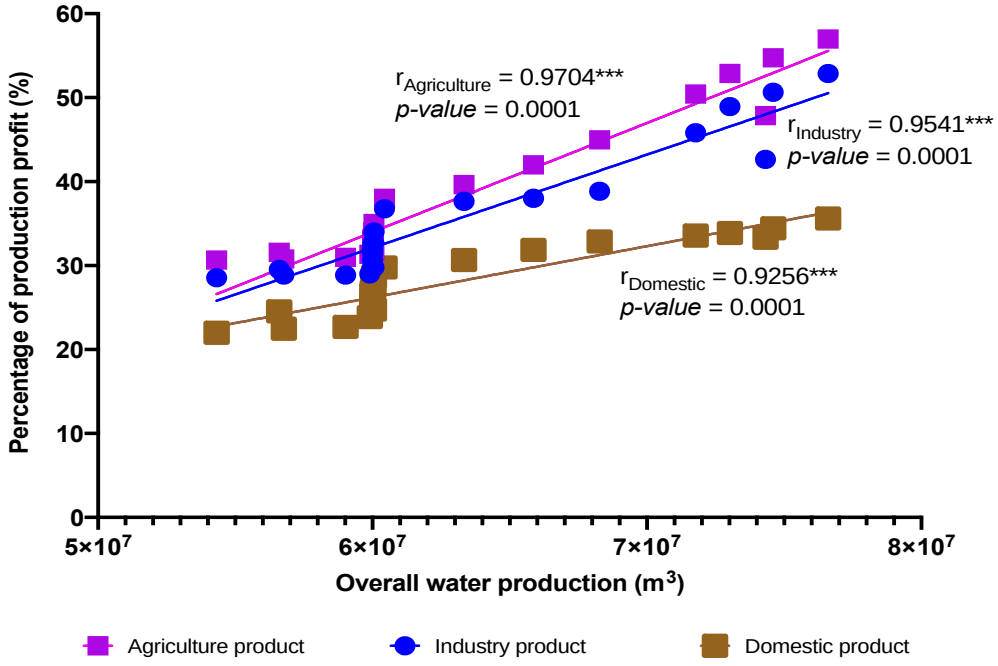

Figure 6: Overall water production VS Percentage of production profit

Across agriculture, industry, and domestic sectors, strong positive correlations exist between overall water production and production profit (coefficients ranging from 0.9256 to 0.9704 (Figure 6)). This suggests that increased water availability can significantly boost profits across various economic segments. Statistically significant p-values (0.0001) support the observed connections, indicating a genuine link between water production and profitability.

Increased water enables agricultural expansion and higher yields, facilitates efficient industrial processes, and promotes health and hygiene in domestic settings, all contributing to economic gains. Additionally, it may encourage water-saving technologies, potentially leading to higher profits even with increased production.

While increased water availability can spur economic opportunities, it's crucial to acknowledge limitations and other factors in water management strategies. While strong correlations suggest boosting water production can drive profits, we must prioritize sustainable practices to ensure long-term environmental and economic benefits.

In Antananarivo, households are major water users, driven by population growth and urbanization. Daily needs like drinking and sanitation put pressure on water resources. Conservation efforts focus on raising awareness, repairing leaks, and promoting water-saving devices. However, infrastructure limitations and affordability pose challenges. Continuous monitoring is crucial to assess effectiveness (Molden, 2001; Weerasooriya et *al.*, 2021).

Antananarivo's growing industries have increased water demand, straining local sources. Conservation strategies emphasize optimizing processes, recycling water, and using efficient technologies. Regulatory frameworks and incentives are essential for compliance. Collaboration between industries and environmental agencies can improve water management (Barrington et *al.*, 2013).

Farming is crucial to Madagascar's economy and impacts water use in Antananarivo. Traditional irrigation and expanding farmland consume significant water. Conservation efforts involve promoting efficient irrigation, selecting crops based on water availability, and managing watersheds. Collaboration among farmers, agricultural extension services, and government agencies is key to sustainable water use (Batalhão et *al.*, 2023).

Effective water conservation in Antananarivo requires integrated policies involving government, communities, and industries, addressing each sector's unique challenges. Continuous research, data collection, and international partnerships are crucial for monitoring progress and adapting strategies (Hukka et *al.*, 2010; Liu, 2018).

Water, essential for life and development, faces growing demand in Madagascar's capital, Antananarivo. This surge is driven by rapid population growth and urbanization, straining the city's ability to supply clean water to its residents (Howard et *al.*, 2020). Access to basic amenities like tap water becomes increasingly urgent as the city's population landscape rapidly changes.

4-CONCLUSION AND RECOMMENDATION

The investigation of water distribution systems in Antananarivo, Madagascar underscores their vital role in agricultural, industrial, and residential sectors. Strong relationship coefficients (r values) of 0.8998, 0.9109, and 0.9856 for agriculture, industry, and household use, along with highly significant p-values of 0.0001, highlight the critical dependence of these sectors on efficient water delivery systems. Noteworthy relationship coefficients of 0.9704, 0.9541, and 0.9256 for overall water production within agriculture, industry, and household domains further emphasize the interconnectedness between water infrastructure and sustained economic activities.

These findings advocate for targeted investments and strategic interventions in water distribution systems to ensure resilience and adequacy in meeting Antananarivo's diverse needs. The relationship between population size and tap water access rate ($r = 0.4219$, p-value = 0.0048) underscores the importance of aligning infrastructure development with demographic changes. Proactive measures are essential as the population grows to preserve and enhance tap water access rates for a reliable supply of clean water to the expanding community.

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