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ANALYZING THE IMPACT OF SUSTAINABLE WASTEWATER MANAGEMENT STRATEGIES ON PUBLIC HEALTH RESILIENCE IN BARANGAY SAN MANUEL, PUERTO PRINCESA, PALAWAN

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ABSTRACT

Aims: This study investigates the impact of sustainable wastewater management strategies on public health resilience in Barangay San Manuel, Puerto Princesa, Palawan. The aim is to evaluate the relationship between the level of implementation of wastewater management systems and the community's ability to prevent, respond to, and recover from sanitation-related health challenges. **Study design:** A quantitative, descriptive-correlational research design was employed. **Methodology:** Data were collected through a structured survey involving 100 respondents from the community. The study examined key wastewater management strategies, including wastewater treatment systems, greywater recycling, pollution control measures, water resource protection, and monitoring and regulation. **Results:** The implementation of sustainable wastewater management strategies in Barangay San Manuel is high, particularly in wastewater treatment systems and greywater recycling. Public health resilience, as measured by indicators such as waterborne disease incidence, hygiene practices, and community awareness, is also high. Regression analysis revealed that wastewater treatment systems, monitoring and regulation, and greywater recycling are significant predictors of public health resilience, with wastewater treatment systems being the strongest predictor. **Conclusion:** The study concludes that sustainable wastewater management plays a crucial role in enhancing public health resilience by improving disease prevention, hygiene behavior, and environmental health. The findings underscore the importance of infrastructure development, policy enforcement, and community education in fostering a healthy and resilient community. Recommendations include strengthening wastewater treatment infrastructure, enhancing monitoring, promoting greywater recycling, and supporting water resource protection initiatives.

Keywords: Environmental Health, Public Health Resilience, Sustainable Wastewater Management, Wastewater Treatment Systems, Waterborne Diseases.

INTRODUCTION

Sustainable wastewater management became a cornerstone of environmental protection and public health, particularly in communities experiencing rapid population growth and increasing domestic and industrial water use. At its core, sustainable wastewater management referred to the collection, treatment, and safe disposal or reuse of wastewater in ways that minimized environmental harm and maximized resource recovery. This included strategies such as the use of wastewater treatment systems like septic tanks and constructed wetlands, greywater recycling and reuse for non-potable activities like irrigation, and the implementation of pollution control measures that prevented untreated discharge into rivers, lakes, or coastal areas. Furthermore, it involved water resource protection through watershed management and conservation, as well as monitoring and regulation of wastewater discharge to ensure compliance with environmental and health standards (Tan and Santos, 2022; Mendoza and Dela Cruz, 2023).

These strategies were not only technical interventions but were also guided by the principle of sustainability—ensuring that current wastewater practices did not compromise the health and resources of future generations. Recent studies highlighted that the integration of wastewater treatment and reuse strategies was essential for maintaining ecological balance while promoting socio-economic development, especially in regions with limited access to sanitation (Hernandez and Santos, 2022; Salazar *et al.,* 2021). Furthermore, environmental health interventions, including wastewater management, were increasingly recognized for their role in enhancing resilience against health challenges in vulnerable communities (Panganiban *et al.,* 2023). However, in many local communities, such as Barangay San Manuel in Puerto Princesa, the level of implementation of these strategies was not well documented, and their direct impact on public health remained unclear (Delgado, 2022).

On the other hand, public health resilience referred to the community's capacity to anticipate, respond to, and recover from sanitation-related health challenges. It included the ability to prevent the spread of waterborne diseases, promote good hygiene practices, maintain access to clean water and sanitation facilities, and ensure healthcare systems remained functional during crises. Recent frameworks, like the Social-Ecological Resilience Theory (Folke, 2006), underscored the interdependence of health resilience and environmental conditions, emphasizing that the management of natural resources directly affected public health outcomes (Rodriguez and Villanueva, 2021).

While national and global development agendas emphasized sanitation and health as interconnected priorities, many local government units still lacked data-driven insights on how environmental strategies, such as wastewater management, influenced community health outcomes. This research addressed that gap by analyzing the impact of sustainable wastewater management strategies on public health resilience in Barangay San Manuel. The study assessed how the implementation of wastewater systems influenced disease prevention, hygiene behavior, and overall environmental health, with the goal of providing evidence to guide barangay-level planning and policy-making.

By understanding this relationship, the study aimed to contribute to a broader framework for sustainable development—one that

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recognized the critical role of environmental practices in protecting human health and enhancing community resilience.

Theoretical Framework

This study was anchored on the Integrated Water Resources Management (IWRM) theory by the Global Water Partnership (2000), which promoted the coordinated and sustainable use of water, land, and related resources, emphasizing pollution control, water recycling, and community-inclusive planning. The theory highlighted the importance of managing wastewater not as waste, but as a resource essential for health and sustainability.

Furthermore, this research was also grounded in the Social-Ecological Resilience Theory by Folke (2006), which viewed public health resilience as a dynamic capacity built through adaptive responses to environmental stressors such as waterborne diseases and sanitation crises. These two theories together provided a holistic lens for analyzing how sustainable wastewater strategies contributed to strengthening health systems, improving environmental outcomes, and building long-term community resilience.

The independent variable in this study was sustainable wastewater management strategies, which referred to a set of environmentally sound practices and systems designed to treat, reuse, and regulate wastewater in a way that protected human health and natural resources. These strategies aimed to prevent environmental degradation, reduce health risks, and promote water conservation at the community level. Among the key components examined in the study were wastewater treatment systems, which included septic tanks, constructed wetlands, and centralized treatment facilities that processed sewage before discharge or reuse. Another component was greywater recycling and reuse, which involved repurposing relatively clean wastewater from baths, sinks, and laundry for non-potable uses such as irrigation and toilet flushing, thereby conserving fresh water resources. The study also considered pollution control measures, which were actions that minimized or eliminated the release of untreated wastewater into natural water bodies through effective disposal and treatment mechanisms. Equally important was water resource protection, which involved watershed conservation, sustainable land use, and reforestation to ensure the long-term availability of clean water. Lastly, monitoring and regulation referred to systems that tracked water quality and enforced standards for wastewater discharge, ensuring compliance with environmental and public health guidelines. These five components collectively represented the level and quality of wastewater management being implemented in the community.

On the other hand, the dependent variable was public health resilience, which referred to the community's capacity to prevent, respond to, and recover from health threats that were influenced by environmental and sanitation conditions. Public health resilience was multidimensional, encompassing both preventive and reactive aspects of health management. One of the key indicators was the incidence of waterborne diseases, which reflected how often illnesses such as diarrhea, typhoid, and cholera occurred within the community due to contaminated water sources. Another critical factor was hygiene practices and behavioral change, which assessed whether residents were engaging in sanitary behaviors such as hand washing and proper waste disposal. The variable also included access to clean water and sanitation services, which was essential for disease prevention and the promotion of health. Moreover, responsiveness of the healthcare system was considered, measuring the capacity of local health facilities to address sanitation-related illnesses in a timely and effective manner. Additionally, community awareness of sanitation and health risks was a vital indicator, as informed communities were more likely to adopt proactive measures and demand proper services. Lastly, environmental health indicators, such as air, water, and soil quality, were assessed to understand the broader ecological context influencing human health. Together, these elements captured the level of resilience the community possessed in the face of public health challenges linked to wastewater management practices.

METHODOLOGY

This study employed a quantitative research design utilizing the descriptive-correlational method to assess and analyze the relationship between sustainable wastewater management strategies and public health resilience in Barangay San Manuel, Puerto Princesa, Palawan. The descriptive component was used to determine the level of implementation of various wastewater strategies and the degree of public health resilience in the community. Meanwhile, the correlational aspect, particularly through regression analysis, was employed to determine whether sustainable wastewater management strategies significantly influence the public health resilience of the residents.

The target population of the study consisted of community members residing in Barangay San Manuel. Using a purposive sampling technique, a total of 100 respondents were selected to participate in the survey. These respondents represented a mix of demographic backgrounds in terms of sex, civil status, occupation, educational attainment, and years of residency. The sample size was deemed sufficient to provide an initial yet meaningful understanding of the local context and to support the statistical analysis employed.

Data were gathered through a structured survey questionnaire developed based on the indicators of the independent and dependent variables. The questionnaire was divided into three main parts: demographic profile, assessment of sustainable wastewater management strategies, and evaluation of public health resilience indicators. Responses were rated using a Likert scale to quantify perceptions and practices.

For data analysis, descriptive statistics such as mean and standard deviation were used to interpret the levels of implementation and resilience across different indicators. In addition, regression analysis was conducted to determine the predictive relationship between the sustainable wastewater management strategies (independent variable) and public health resilience (dependent variable). This helped identify which components of wastewater management had the most substantial effect on the health resilience of the community.

The methods used in this study provided both a snapshot of current conditions in Barangay San Manuel and evidence of how environmental management practices influence public health outcomes. The findings aim to inform local policy, planning, and public health initiatives.

RESULTS AND DISCUSSIONS

1. What is the profile of the respondents

The demographic profile of the respondents from Barangay San Manuel, Puerto Princesa, Palawan, provides a comprehensive snapshot of the community's composition. Gender distribution is relatively balanced, with 48% male and 52% female participants, aligning with similar findings in other regional studies, which highlight gender parity in rural and semi-urban settings (Delos Santos, 2021).

Marital status data shows that 62% of respondents are married, 35% are single, and 3% are widowed. This distribution reflects a community with a significant family-oriented structure, consistent with trends observed in family-centered rural communities (Rivera & Torres, 2020).

In terms of occupation, the most common roles include private employees (13%), college students (10%), government employees (10%), and housewives (9%). This reflects a mixed socio-economic profile, where both public and private sector employment coexist, similar to the findings of Dela Cruz and Santos (2022) in their study of socio-economic roles in Palawan. A diverse occupational structure is often indicative of a community's adaptability to local economic opportunities and external labor markets (Gutierrez, 2020).

Educational attainment is another area where the respondents show notable diversity: 54% have completed high school, 44% have obtained a college degree, and 2% hold a master's degree. This relatively high educational level points to a growing emphasis on education in the area, which is in line with findings by Panganiban *et al.,* (2023), who identified education as a key factor in community development in rural areas of the Philippines.

The respondents' length of residency also provides insight into community stability. A majority (56%) have lived in Barangay San Manuel for more than six years, suggesting a well-established, rooted population, while 38% have resided there for two to five years, and only a small proportion are recent arrivals. These figures suggest a strong sense of community belonging and long-term stability, similar to patterns observed in other barangays with extended local residency (Salazar and Mendoza, 2021). This stability likely fosters social cohesion and a more consistent local development trajectory.

Overall, the demographic profile of the respondents highlights a community with a diverse socio-economic composition, a relatively high level of education, and long-term residents, providing a stable foundation for community-based initiatives and development programs.

2. What is the level of implementation of the following sustainable wastewater management strategies in the community?

As shown in Table 1, the overall mean score of 3.12 with a standard deviation of 0.72 reflects a high level of implementation of sustainable wastewater management strategies in Barangay San Manuel. This suggests that the community has made significant strides in adopting sustainable practices related to wastewater management. Among the five components assessed, Wastewater Treatment Systems (mean = 3.33) and Greywater Recycling and Reuse (mean = 3.34) received the highest ratings, categorized as "Very High." This indicates that residents strongly agree that these systems are actively utilized and contribute effectively to wastewater management in the barangay. These findings align with similar studies, which emphasize the importance of treating and recycling wastewater as key elements in sustainable environmental management (Martinez *et al.,* 2021).

Meanwhile, Pollution Control Measures (mean = 3.00), Water Resource Protection (mean = 2.75), and Monitoring and Regulation (mean = 3.20) were all rated as "High," suggesting that while these practices are consistently implemented, there is room for further improvement. Particularly, water resource protection and pollution control measures are critical for long-term sustainability. As noted by Hernandez and Santos (2022), enhancing pollution control and ensuring robust water protection mechanisms are essential for the effectiveness of wastewater management systems, as poor water quality can undermine the benefits of treatment and reuse initiatives.

The relatively lower score for Water Resource Protection (mean = 2.75) suggests that local authorities may need to strengthen community engagement in watershed conservation and increase enforcement of policies aimed at preventing water contamination. Additionally, Monitoring and Regulation (mean = 3.20), while rated as high, indicates that there may still be areas for improvement in ensuring consistent compliance with regulatory frameworks.

Table 1. The summary on the level of implementation of the following sustainable wastewater management strategies in the community

Items	Mean	SD	Description	Interpretation
Wastewater Treatment Systems	3.33	0.49	Strongly Agree	Very High
Greywater Recycling and Reuse	3.34	0.47	Strongly Agree	Very High
Pollution Control Measures	3.00	0.95	Agree	High
Water Resource Protection	2.75	0.87	Agree	High
Monitoring and Regulation	3.20	0.85	Agree	High
Overall Mean	**3.12**	**0.72**	**Agree**	**High**

Legend: 1.00 – 1.75 (Very Low, Strongly Disagree), 1.76 – 2.50 (Low, Disagree), 2.51 – 3.25 (High, Agree), 3.26 – 4.00 (Very High, Strongly Agree)

In conclusion, while Barangay San Manuel has made commendable progress in implementing sustainable wastewater management strategies, there is a clear need to focus on enhancing water resource protection and pollution control measures for the future sustainability of these efforts. Strengthening local policies, increasing public awareness, and promoting stricter enforcement could further elevate the community's environmental practices.

3. What is the level of public health resilience?

As presented in Table 2, the overall mean score of 2.99 with a standard deviation of 0.61 indicates a high level of public health resilience in Barangay San Manuel. The community demonstrates notable strengths in areas such as Waterborne Disease Incidence (mean = 3.25), Hygiene Practices and Behavioral Change (mean = 3.21), and Community Perception of Sanitation and Health Risks (mean = 3.20), all of which received high ratings. These results suggest that the residents possess good awareness of sanitation issues and are actively engaged in maintaining hygienic practices, which is consistent with findings from similar studies in rural Filipino communities (Bautista *et al.,* 2021). Public education campaigns and community health initiatives likely play a significant role in enhancing awareness and reducing sanitation-related health risks (Delgado, 2022).

However, Access to Safe Water and Sanitation Services scored the lowest among the indicators (mean = 2.51), yet it still falls within the "high" range. This suggests that while basic services are generally available, they may not be universally accessible or consistently reliable for all residents. Similar studies in rural areas have highlighted challenges related to the accessibility and reliability of water and sanitation services, particularly in less-developed regions (Mendoza and Tan, 2023). Improving infrastructure and expanding equitable access to these services could help address these issues.

The relatively lower score for Healthcare System Responsiveness (mean = 2.75) also points to areas where improvement is needed. While the healthcare system in the barangay appears to be functioning at a satisfactory level, enhancing responsiveness could further bolster the community's resilience to public health threats, particularly in emergencies (Rodriguez & Villanueva, 2021).

Table 2 The summary on the level of public health resilience

Items	Mean	SD	Description	Interpretation
Waterborne Disease Incidence	3.25	0.50	Agree	High
Hygiene Practices and Behavioral Change	3.21	0.47	Agree	High
Access to Safe Water and Sanitation Services	2.51	0.91	Agree	High
Healthcare System Responsiveness	2.75	0.50	Agree	High
Community Perception of Sanitation and Health Risks	3.20	0.71	Agree	High
Environmental Health Indicators				
Overall Mean	**2.99**	**0.61**	**Agree**	**High**

Legend: 1.00 – 1.75 (Very Low, Strongly Disagree), 1.76 – 2.50 (Low, Disagree), 2.51 – 3.25 (High, Agree), 3.26 – 4.00 (Very High, Strongly Agree)

Overall, the findings suggest that Barangay San Manuel has developed a strong foundation for public health resilience, largely due to successful community health education programs and relatively good access to healthcare services. However, further investments in infrastructure and inclusive access to safe water and sanitation services are needed to ensure that the benefits of public health resilience reach all members of the community. Addressing these gaps will be crucial for maintaining and improving the barangay's overall health outcomes in the long term.

4. Which among the sustainable wastewater management strategies best predicts public health resilience?

The results of the regression analysis, as shown in Table 3, indicate that among the five sustainable wastewater management strategies, wastewater treatment systems are the strongest predictor of public health resilience in Barangay San Manuel. With a high beta coefficient of 0.755 and a highly significant p-value of < .001, the effective implementation of treatment systems, such as septic tanks and community-based treatment plants, is found to have a substantial positive impact on the health resilience of the community. This suggests that well-established wastewater treatment infrastructure plays a crucial role in safeguarding public health by reducing the risk of waterborne diseases.

Monitoring and regulation also emerged as a significant predictor with a beta of 0.576 and a p-value of < .001, indicating that regular water quality checks and the enforcement of sanitation policies contribute significantly to preventing health risks. These findings align with research highlighting the importance of consistent monitoring and regulatory frameworks in maintaining public health standards (Salazar *et al.,* 2022). The role of greywater recycling and reuse in enhancing health resilience was also notable, with a beta coefficient of 0.386 (p < .001). This suggests that reusing lightly contaminated water for non-potable purposes, such as irrigation or cleaning, can reduce the burden on fresh water sources and mitigate environmental contamination, promoting overall community health.

On the other hand, while water resource protection (β = 0.269) and pollution control measures (β = 0.129) had smaller coefficients, they were still statistically significant predictors of health resilience, indicating that environmental conservation efforts and pollution prevention play a supportive role in enhancing community health outcomes. These findings align with studies emphasizing the critical importance of sustainable environmental management in the context of public health (Mendoza and Dela Cruz, 2023).

The overall model was statistically significant, with an adjusted R^2 of 0.80, meaning that 80% of the variation in public health resilience could be explained by these five sustainable wastewater management strategies. This highlights the strong explanatory power of the model and affirms the interconnectedness of wastewater management, health resilience, and environmental stewardship.

These results have practical implications for local government units (LGUs) and barangay officials in their efforts to improve public health outcomes. The strong influence of wastewater treatment systems emphasizes the need for investments in infrastructure, including the construction, maintenance, and upgrading of treatment facilities. Furthermore, the significant role of monitoring and regulation underlines the importance of having clear policies and ensuring consistent enforcement. Regular inspections, community reporting systems, and training for environmental officers will be key to maintaining high public health standards. Additionally, the positive impact of greywater recycling suggests that resource-efficient, low-cost innovations can play a pivotal role in addressing water stress while reducing environmental contamination.

While pollution control measures and water resource protection had more modest effects, their statistical significance underscores their importance in an integrated public health strategy. Taken together, these findings advocate for a holistic approach to public health resilience, one that combines infrastructure development, policy enforcement, community engagement, and environmental management.

Table 3 Linear Regression Analysis of Teachers' Ancillary Functions and Teachers' Competence

Predictor	Estimate	SE	t	p
Intercept	0.104	0.1128	3.919	0.030
X_1: Wastewater Treatment Systems	0.755	0.0581	12.995	<.001
X_2: Greywater Recycling and Reuse	0.386	0.0603	6.389	<.001
X_3: Pollution Control Measures	0.129	0.0622	2.082	0.040
X_4: Water Resource Protection	0.269	0.0902	2.980	0.004
X_5: Monitoring and Regulation	0.576	0.1135	5.077	<.001

Note: *Adjusted R^2=0.80 p=0.000*

CONCLUSION

This study aimed to analyze the impact of sustainable wastewater management strategies on public health resilience in Barangay San Manuel, Puerto Princesa, Palawan. The findings revealed that the level of implementation of sustainable wastewater management in the community is generally high, with wastewater treatment systems and greywater recycling receiving very high ratings. Public health

resilience was also found to be high, particularly in areas such as hygiene practices, waterborne disease prevention, and community awareness of sanitation-related health risks.

Through regression analysis, it was determined that all five wastewater management strategies significantly predicted public health resilience, with wastewater treatment systems, monitoring and regulation, and greywater recycling being the most influential factors. The results affirm the critical role that sustainable environmental practices play in strengthening the community's capacity to prevent and respond to sanitation-related health challenges.

In summary, the study concludes that sustainable wastewater management strategies are not only essential for environmental protection but are also strong determinants of public health resilience. Communities with better infrastructure, sound regulations, and environmental awareness are more likely to be protected from disease and environmental health risks.

Recommendations

Based on the findings, the following recommendations are proposed:

1. **Strengthen Infrastructure for Wastewater Treatment:** Local government units and barangay officials should prioritize the construction, upgrade, and maintenance of wastewater treatment facilities to ensure that all households and establishments have access to safe and effective waste disposal systems.
2. **Enhance Monitoring and Regulation:** There should be continuous enforcement of environmental policies, regular water quality assessments, and the establishment of community-based monitoring systems to ensure compliance with sanitation standards.
3. **Promote Greywater Recycling Practices:** Community awareness campaigns and technical support should be provided to encourage the safe reuse of greywater, especially for gardening, cleaning, and other non-potable uses.
4. **Support Pollution Control and Water Resource Protection:** Local ordinances should be enforced to limit the discharge of waste into natural water bodies, and conservation activities such as tree planting, reforestation, and watershed protection should be sustained.
5. **Integrate Public Health and Environmental Education:** Educational programs should be implemented to raise community awareness about the connection between sanitation, water safety, and health. Schools and barangay health workers can play a vital role in this.
6. **Conduct Further Research:** Future studies may include a larger sample size or comparative analysis with other barangays to validate and enrich the findings. Qualitative data may also be gathered to gain deeper insights into community behaviors and attitudes toward wastewater management.

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