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# Adaptive governance in the water-energy-food-ecosystem nexus for sustainable community sanitation

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ABSTRACT

As the intensity of global environmental challenges increases, so does the need to understand and strengthen the resilience of interconnected systems. This research underscores the crucial role of adaptive governance in navigating the complexities of the Water-Energy-Food-Ecosystem nexus, particularly under the pressures of changing climatic conditions. The study conducts an in-depth analysis of adaptive capacities by identifying critical components such as assets, flexibility, organization, learning, and agency as fundamental elements of adaptive governance in sanitation practices. Data were collected through structured questionnaires and analyzed using binary probit and logit models to examine how these attributes influence community engagement in sanitation. Descriptive analysis was also used to summarize respondent characteristics and attribute distributions.

## 1. Introduction

The escalating impacts of climate change present complex challenges to managing essential resources within the Water-Energy-Food-Ecosystem (WEFE) nexus, particularly in rapidly developing regions like Labuan Bajo, Indonesia. Labuan Bajo, known for its critical role as a gateway to the Komodo National Park, has experienced significant socio-economic transformations driven by tourism and fishing industries [1]. These transformations exert considerable pressure on local infrastructure, especially sanitation systems [2], which are crucial for sustainable development and environmental conservation. Sanitation, a critical component of urban infrastructure [3–6], directly influences the broader spectrum of the WEFE nexus by impacting water quality, energy consumption, food production safety, and ecosystem health. Effective sanitation systems reduce environmental pollution, prevent disease proliferation, and contribute to the overall health and well-being of the community [7,8]. However, traditional approaches to sanitation often fail to address the interconnected nature of these resources comprehensively.

Adaptive governance emerges as a promising approach to address these interlinkages by incorporating flexibility, learning, and stakeholder engagement into resource management practices [9,10]. This approach facilitates the development of resilient infrastructure systems that can adjust to ecological and societal changes without compromising functional integrity or sustainability. The concept of adaptive governance within the WEFE nexus emphasizes the need for integrated management strategies that consider the dynamic interactions between water, energy, food, and ecosystems. Despite the growing recognition of

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the interconnected challenges posed by climate change across the Water-Energy-Food nexus, particularly in coastal urban settings [3,6,11], significant gaps persist in our understanding and implementation of effective adaptive governance frameworks. While numerous studies have explored individual aspects of the WEFE nexus, such as water resource management or energy efficiency [12–16], fewer have addressed the comprehensive integration of all these elements within the context of community sanitation systems. This lack of holistic approach limits the effectiveness of interventions aimed at enhancing resilience and sustainability in response to environmental and societal pressures.

There is an evident gap in the practical application of adaptive governance strategies that explicitly connect sanitation with water, energy, food security, and ecosystem health. Most existing research and policy frameworks tend to silo these components, failing to capture the synergistic potential of an integrated approach. This oversight can lead to suboptimal resource use, increased environmental degradation, and missed opportunities for enhancing community resilience against climate variability [17,18]. While adaptive governance is touted for its potential to enhance system flexibility and stakeholder engagement [19–21], detailed empirical evidence on its implementation and outcomes in the sanitation sector is sparse. There is a particular lack of data on how adaptive governance principles are applied in real-world settings to improve sanitation infrastructure, especially in regions facing rapid urbanization and ecological sensitivity like Labuan Bajo. This gap in knowledge and practice underscores the need for targeted research that can bridge theoretical frameworks with actionable governance strategies. Furthermore, the role of community agency and participatory mechanisms in shaping sanitation practices within the WEFE nexus is not well-documented. Understanding how community inputs and interactions influence policy formation and resource management is crucial for ensuring that adaptive governance systems are not only inclusive but also effective in meeting the diverse needs of all stakeholders involved. There is a critical need for innovative methodologies that can quantify the impacts of integrated adaptive governance approaches on sanitation and overall nexus sustainability. Current evaluation models often lack the complexity to assess cross-sectoral dynamics and interdependencies effectively, making it challenging to measure the real-world effectiveness of nexus-oriented governance strategies.

This study is focused on investigating the implementation of adaptive governance in Labuan Bajo, with the goal of enhancing the sustainability and resilience of its sanitation systems. To achieve this, the research specifically examines the adaptive capacities essential for robust governance, which include assets, flexibility, organization, learning, and agency. These capacities are explored in depth to determine how they can be effectively leveraged to improve sanitation services amid the challenges posed by environmental variability and the pressures of an increasing urban population.This research aims to understand how these adaptive capacities can be optimized by examining their current status, identifying gaps, and proposing enhancements. It also considers the sociodemographic variables that influence public participation and support for sanitation initiatives, such as age, gender, income, and occupation, which are crucial for tailoring approaches to the specific context of Labuan Bajo. Through this detailed examination, the study seeks to offer comprehensive insights into how adaptive governance can be tailored to improve sanitation resilience and sustainability, thereby contributing to the broader goal of enhancing the quality of life and environmental health in urban settings.

## 2. Theoritical framework

Fig. 1 illustrates a theoretical framework that encapsulates the integration and interdependencies within the Water-Energy-Food-Ecosystem (WEFE) nexus, particularly focusing on sanitation. This framework visually organizes the relationships and synergies between the components of the WEFE nexus demonstrating the multifaceted interactions through various governance strategies that enhance resilience and sustainability. At the heart of the diagram is the WEFE nexus, with

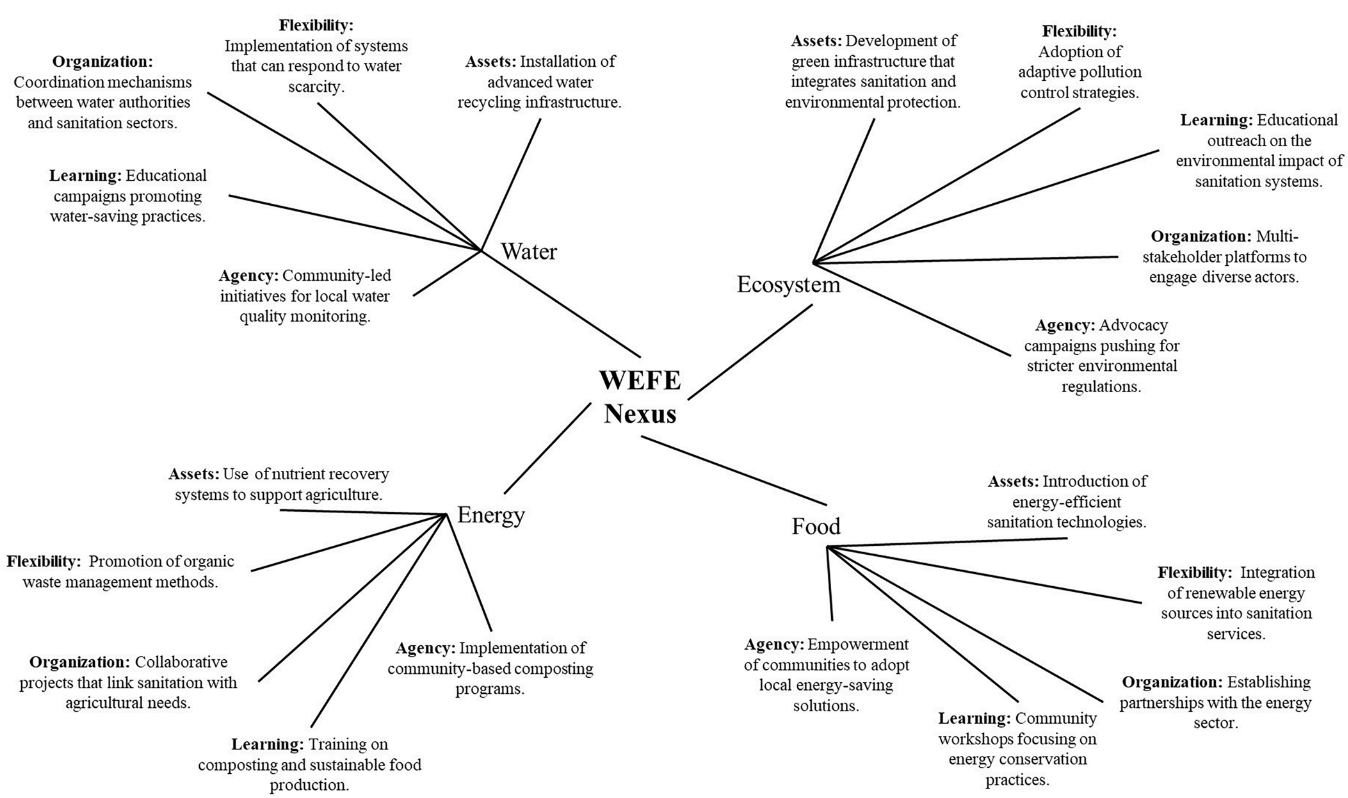


**Fig. 1.** Theoretical framework for the WEFE nexus in sanitation.

branching elements representing the specific interactions across different resources. Each segment, corresponding to a different resource within the nexus, is connected through adaptive capacity attributes such as assets, flexibility, organization, learning, and agency [22,23], which are essential for adaptive management and sustainable environmental governance [24,25].

In the water section of the framework, the focus is on advanced water recycling and treatment facilities, which are crucial assets for sustainable water management [26,27]. The framework also shows the importance of flexibility in systems that adapt to water scarcity and organizational coordination with water management authorities [28,29]. Additionally, it emphasizes community initiatives for water quality monitoring [30,31], showcasing a proactive approach to water resource management. For energy, the framework illustrates the integration of renewable energy sources and the importance of energy-efficient sanitation technologies [32,33]. It highlights organizational collaborations with energy sectors and community empowerment for adopting energy-efficient solutions, indicating the proactive roles communities play in energy sustainability. In terms of food, the framework addresses nutrient recovery systems that transform waste into agricultural resources, demonstrating an effective use of organic waste. It also includes community-led composting programs and joint projects between sanitation and agricultural sectors [34,35], suggesting a strong link between waste management and food production. The ecosystem component emphasizes green infrastructure that integrates sanitation with environmental conservation [36,37], underscoring the role of ecosystems in supporting overall nexus sustainability. It also points to the need for learning opportunities like workshops on energy conservation and education on sanitation's impact on the environment [38], which equip communities with the necessary knowledge to support ecosystem health.

Table 1 outlines the interconnected roles of WEFE components in enhancing sanitation practices and highlights how sanitation, in turn, supports broader sustainability goals within the WEFE nexus. The water segment emphasizes the dual role of sanitation in improving water quality for various uses while promoting conservation efforts through the recycling and reuse of wastewater [39–41]. This cyclical benefit enhances both the effectiveness of sanitation practices and the sustainability of water resources. In the energy sector, the focus is on how sanitation can reduce operational costs and environmental impacts by integrating renewable energy solutions [42,43]. Sanitation systems themselves contribute to energy production, particularly through the conversion of waste into biogas [44,45], which is a renewable energy source that also helps in reducing greenhouse gas emissions. For food, the table highlights how sanitation practices that ensure clean irrigation water can lead to healthier agricultural outputs. Furthermore, the recovery of nutrients from sanitation processes provides additional benefits by enriching soil quality [46,47], which in turn boosts agricultural productivity and sustainability. Lastly, the ecosystem component discusses how improved sanitation helps in reducing disease vectors and creating cleaner environments [45,48]. Effective sanitation is crucial for maintaining the health of ecosystems, as it prevents pollution and supports biodiversity by preserving natural habitats and balancing ecological interactions.

**Table 1**
Components of the WEFE Nexus Applied to Sanitation.

| WEFE component | Benefits to sanitation | Contributions of sanitation |
|---|---|---|
| Water | Improved water quality and availability for sanitation processes through sustainable water management practices. | Enhanced water conservation through efficient wastewater treatment and reuse in irrigation and industrial processes. |
| Energy | Access to renewable energy sources can power sanitation facilities, reducing operational costs and environmental impact. | Production of renewable energy (e.g., biogas) from the digestion of sewage sludge, contributing to the energy supply and reducing greenhouse gas emissions. |
| Food | Efficient sanitation ensures safer water for irrigation, promoting healthier agricultural practices. | Nutrient recovery from wastewater provides valuable fertilizers for agriculture, improving soil fertility and crop yields. |
| Ecosystem | Healthier ecosystems reduce disease vectors associated with poor sanitation, creating a cleaner environment. | Proper waste management minimizes pollution, protects biodiversity, and maintains the ecological balance of water bodies and land. |

Table 2 provides a comprehensive overview of the adaptive capacity within the WEFE nexus. These attributes are essential for the adaptive management and sustainable governance of environmental resources, ensuring that each component can effectively respond to the dynamic challenges presented by changing climatic and socio-economic conditions. In the water component, the focus is on advanced water recycling and treatment facilities that ensure the availability and quality of water [39,41], coupled with systems designed to adapt to water scarcity. This is complemented by the organizational coordination with water management authorities to align policies and practices and community-driven initiatives focused on water quality monitoring and advocacy, which are crucial for maintaining water-centric policies. The energy section highlights energy-efficient sanitation technologies that reduce power usage and the integration of renewable energy sources like solar-powered water treatment systems [49,50]. This includes collaborative efforts between energy sectors to manage the demands of sanitation systems and workshops aimed at conserving energy, which are vital for reducing the environmental impact of sanitation facilities.

Under food, nutrient recovery systems that convert waste into fertilizer for agricultural use are noted [47,51,52], alongside flexible waste management practices that provide organic fertilizers during peak farming seasons. This is supported by joint projects between sanitation and agricultural sectors to utilize waste as a resource, and training on the benefits and methods of using manure and compost in agriculture [53], which enhance the sustainability of food production. The ecosystem component illustrates the integration of green infrastructure that enhances sanitation with ecosystem conservation and the implementation of adaptive measures to prevent pollution [36,37]. This involves multi-stakeholder engagement in designing eco-friendly sanitation solutions and education programs focused on the impact of sanitation on biodiversity and ecosystem health [54]. Finally, the framework highlights the critical role of agency in empowering local communities to adopt and promote energy-efficient solutions and community-led composting programs [55–57]. This proactive community involvement supports local agriculture and contributes to environmental sustainability and resilience within the WEFE nexus.

## 3. Method

### 3.1. Study area and population

Labuan Bajo, situated on the western tip of Flores in the Nusa Tenggara region of Indonesia, was selected as the focal area for this study (Fig. 2). This location is renowned for its rapidly growing tourism industry, largely due to its proximity to the Komodo National Park. As of the year 2022, Labuan Bajo has a population of 6973, with a population density of 506 individuals per square kilometer. This setting presents a distinctive socio-economic and environmental context, shaped primarily by the tourism and fishing sectors. On one hand, tourism generates increased economic activity, public attention, and investment in infrastructure [1,24,58], offering an opportunity to improve basic services such as sanitation through public-private partnerships and government support [59,60]. On the other hand, the rapid and often uncoordinated expansion of tourism has led to increased waste generation, seasonal

**Table 2**
Adaptive capacity within the WEFE Nexus.

| Nexus Component | Adaptive capacity | | | | |
|---|---|---|---|---|---|
| | Assets | Flexibility | Organization | Learning | Agency |
| Water | Advanced water recycling and treatment facilities to ensure quality and availability. | Systems that adapt to water scarcity by optimizing water use in sanitation. | Coordination with water management authorities to align policies and practices. | Educational programs on water-saving techniques and the importance of water conservation in sanitation. | Community initiatives for water quality monitoring and advocacy for water-centric policies. |
| Energy | Energy-efficient sanitation technologies that reduce power usage. | Integration of renewable energy sources like solar-powered water treatment systems. | Collaboration with energy sectors to manage energy demands of sanitation systems. | Workshops on energy conservation in sanitation processes. | Empowerment of local communities to adopt and promote energy-efficient sanitation solutions. |
| Food | Nutrient recovery systems that convert waste into fertilizer for agricultural use. | Flexible waste management practices that provide organic fertilizers during peak farming seasons. | Joint projects between sanitation and agricultural sectors to utilize waste as a resource. | Training on the benefits and methods of using humanure and compost in agriculture. | Community-led composting programs that support local agriculture. |
| Ecosystem | Green infrastructure that integrates sanitation with ecosystem conservation. | Adaptive measures to prevent pollution and enhance the natural purification processes. | Multi-stakeholder engagement in designing eco-friendly sanitation solutions. | Education on the impact of sanitation on local biodiversity and ecosystem health. | Advocacy for stringent environmental regulations and clean-up campaigns. |
| | Physical and institutional assets that support effective sanitation | The ability of sanitation systems to adapt to varying conditions. | The structures and systems that govern sanitation operations. | Ongoing processes to enhance understanding and improve practices. | The capacity of individuals and groups to make informed decisions and take action. |

population surges, and spatial inequalities in access to clean water and sanitation especially among marginalized local communities. While central to local livelihoods, the fishing industry further contributes to coastal pollution and places stress on already vulnerable marine ecosystems. Together, these dynamics make Labuan Bajo a compelling case for investigating how adaptive governance can address sanitation challenges in the face of overlapping pressures from economic growth, environmental degradation, and demographic change [2].

Participants in this research included a diverse cross-section of the population, encompassing local residents, business owners, and individuals engaged in the tourism and fishing industries. These groups were intentionally selected due to their direct involvement in and impact on sanitation practices. A stratified sampling method was employed to ensure representativeness, categorizing respondents by occupation and residential area to capture varied socio-economic perspectives and geographic nuances. However, given Labuan Bajo's unique socio-economic (tourism, fishing) and environmental characteristics, the findings may not be fully generalizable to regions with different contextual conditions. The context of Labuan Bajo, influenced heavily by tourism and fishing industries, may limit the generalizability of findings to regions with different socio-economic dynamics. Nonetheless, similar small coastal towns or island communities in the Global South such as Zanzibar in Tanzania [61] and El *Nido* in the Philippines [62] may find this case study particularly relevant. Future studies should replicate this model in such contexts to validate its applicability and refine adaptive governance strategies tailored to their local realities.

### *3.2. Data collection*

In the study conducted in Labuan Bajo, a structured questionnaire was developed as the primary tool for data collection, specifically designed to delve into various components of the WEFE nexus in relation to sanitation. This questionnaire was crafted to assess several key aspects: physical and institutional assets that underpin effective sanitation, the adaptability of sanitation systems to changing conditions, the governance structures overseeing these operations, processes aimed at enhancing understanding and improving sanitation practices, and the capacity of individuals and groups to make informed decisions and initiate action. The questionnaire was structured to capture both quantitative and qualitative data. It included a series of binary questions where a response indicating the importance or presence of a feature was coded as '1′, and the absence or irrelevance as '0′. These questions addressed the presence of physical and institutional assets, the adaptability of sanitation systems, governance structures, ongoing improvement processes, and individual and group agency. Demographic variables such as gender, income, education, age, marital status, occupational roles such as fishermen and tourist operators, and the willingness to participate in sanitation initiatives were also coded in a binary format to streamline the analysis process.

To ensure the contextual relevance and clarity of the questionnaire, a pilot test was conducted in November 2023 involving 50 randomly selected residents from Labuan Bajo. This phase allowed the research team to identify potential linguistic, cultural, or conceptual misunderstandings, which were subsequently addressed through revisions to the wording, sequence, and phrasing of several questions. Feedback from the pilot also guided the development of interviewer scripts and behavior protocols, promoting culturally sensitive engagement with respondents. Data collection was conducted over a three-month period from January to March 2024 through face-to-face interviews administered by trained enumerators. This method was deliberately selected to maximize response accuracy, particularly in a setting with varying levels of literacy and familiarity with formal survey tools. In-person interviews enabled enumerators to clarify questions, ensure full comprehension, and reduce non-response rates. Additionally, this approach allowed researchers to observe non-verbal cues such as hesitation, confusion, or discomfort which were valuable in interpreting the sincerity and confidence behind responses. Nonetheless, the use of structured questionnaires inherently carries the risk of response bias, particularly in studies exploring behavioral engagement and community attitudes. Respondents may feel compelled to provide socially desirable answers, especially when discussing topics such as environmental responsibility or willingness to participate in public programs. This tendency can compromise the reliability of self-reported data, particularly when community members perceive the interviewer as being affiliated with government or academic institutions. To mitigate these limitations, multiple safeguards were integrated into the research design. First, the pilot test helped refine question phrasing to minimize leading or suggestive wording that might cue a 'desirable' answer. Second, all enumerators received intensive training in neutral interviewing techniques, with a focus on maintaining nonjudgmental posture and tone throughout the interview process. Third, the face-to-face interviews were conducted in the local dialects, ensuring comfort and clarity. Fourth, participants were assured of anonymity, data confidentiality, and the voluntary nature of their participation. These reassurances were critical in encouraging openness and candidness, particularly when participants expressed dissatisfaction or hesitation about local sanitation conditions.

Each interview session lasted between 5 and 15 min, during which

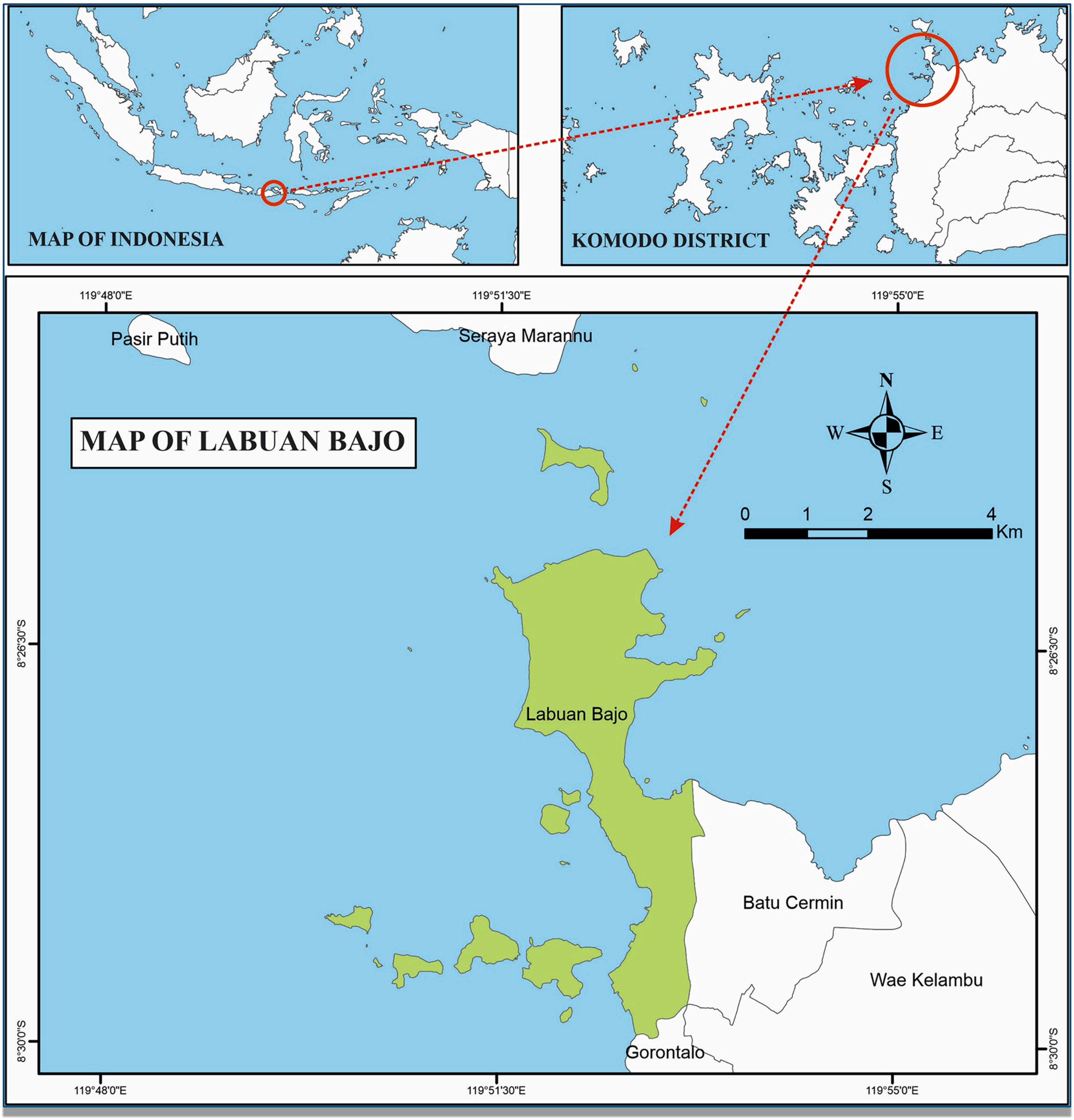


**Fig. 2.** Map of Labuan Bajo, western tip of Flores, Indonesia: Study area.

the interviewers collected comprehensive data while observing high ethical standards. All participants were fully informed about the study's objectives, the voluntary nature of their participation, and the confidentiality of the information they provided. Informed consent was obtained from all participants prior to the interviews. Additionally, the entire study protocol, including the data collection methods and ethical considerations, was reviewed and approved by a local ethics committee to ensure it met international standards for research involving human subjects. Collectively, these methodological and ethical safeguards were designed to enhance the credibility, validity, and reliability of the findings, while acknowledging and transparently addressing the inherent limitations of structured, self-reported survey methods.

### 3.3. *Data analysis*

Upon the completion of data collection, the responses gathered from the structured questionnaires in Labuan Bajo were meticulously digitized to facilitate a systematic analysis. The digitization process was critical, ensuring that all collected data were accurately entered into a computerized database for subsequent analysis. This phase was essential in transforming the raw data from the field into a format suitable for detailed statistical evaluation. The analytical phase of the study utilized a blend of descriptive and inferential statistical techniques to dissect and understand the data comprehensively. Descriptive statistics played a pivotal role in this process by providing initial insights into the distribution and central tendencies of the responses. This involved calculating means, medians, modes, and standard deviations, which helped in summarizing the general patterns in the data and setting the stage for more complex analyses.

For the inferential analysis, the study employed binary probit and logit regression models. These models are particularly suited for dealing with binary dependent variables, such as the willingness to participate in sanitation activities, which was the primary outcome of interest in this research. The choice of probit and logit models was driven by their robustness in estimating relationships between a binary dependent variable and multiple independent variables, providing insights into the factors that significantly influence the likelihood of participation [24,25,63,64]. The inferential analysis was structured around three specific models, each designed to explore different facets of the factors influencing participation willingness:

1. Overall Model: This model combined variables from both adaptive and socio-demographic categories, offering a comprehensive view of how various factors converge to affect participation willingness. It integrated aspects related to physical, institutional, and adaptability features of sanitation systems alongside personal attributes like income, education, and occupation.
2. Adaptive Preference Model: Focused specifically on the adaptability aspects of sanitation systems, this model aimed to isolate and examine how the perceived importance of adaptive capacity in sanitation systems influences participation decisions. This model was particularly important for understanding the responsiveness of the community to changes in sanitation infrastructure and policy.
3. Socio-Demographic Model: Concentrating exclusively on demographic factors, this model assessed how variables such as gender, age, income, and educational levels impact the willingness to engage in sanitation practices. This analysis was crucial for identifying demographic predictors of participation and tailoring community-specific interventions.

While these statistical models offered robust insights into the relationships between adaptive governance factors and participation willingness, we also recognized the importance of qualitative depth to contextualize and validate our findings. To complement and confirm our quantitative results, we conducted a series of key stakeholder interviews with local tourism operators, village heads, and academic researchers familiar with sanitation governance in Labuan Bajo. These semi-structured interviews provided firsthand narratives about sanitation challenges, governance bottlenecks, and community motivations, offering a richer understanding of the socio-political and environmental dynamics at play. The qualitative feedback helped triangulate the statistical results supporting, for instance, the importance of physical infrastructure and institutional presence in fostering engagement and also revealed nuanced barriers such as uneven coordination across government levels, seasonal tourism pressures, and varying degrees of trust in local institutions. This integration of stakeholder perspectives not only enhances the validity of the study but also addresses concerns regarding the limitations of relying solely on structured survey data. This detailed methodological framework grounded in both quantitative modeling and qualitative confirmation was designed to ensure rigor, depth, and contextual relevance. By thoroughly examining the interdependencies within the WEFE nexus and the diverse influences on individual and collective behavior, the research provides valuable knowledge to the field of environmental management and public health.

## 4. Result

Table 3 provides a detailed descriptive analysis of various factors associated with the Water-Energy-Food-Ecosystem (WEFE) nexus in sanitation adaptation, emphasizing the role these elements play in local governance and individual commitment to sanitation improvements in Labuan Bajo. This analysis delves into the components critical for adaptive governance, specifically examining the perception of importance among community members regarding physical and institutional assets, adaptability, organizational structures, learning processes, and agency in sanitation decisions. The table enumerates the frequency and percentage of respondents acknowledging the importance of these components. For instance, physical and institutional assets supporting effective sanitation are considered important by 50.31 % of respondents, with a mean score of 0.503, indicating a balanced view on its significance across the sampled population. Similarly, the ability of sanitation systems to adapt to varying conditions is recognized by 42.98 %, with a mean of 0.430, reflecting a substantial acknowledgment of the need for adaptive sanitation infrastructure.

**Table 3**
Descriptive analysis of variables in the WEFE nexus for sanitation adaptation.

| Variables | Frequency | Percent | Mean | Std. Deviation |
|---|---|---|---|---|
| Physical and institutional assets that support effective sanitation (yes importance=1; otherwise=0) | 240 | 50.31 % | 0.503 | 0.501 |
| The ability of sanitation systems to adapt to varying conditions. (yes importance=1; otherwise=0) | 205 | 42.98 % | 0.430 | 0.496 |
| The structures and systems that govern sanitation operations. (yes importance=1; otherwise=0) | 220 | 46.12 % | 0.461 | 0.499 |
| Ongoing processes to enhance understanding and improve practices. (yes importance=1; otherwise=0) | 228 | 47.80 % | 0.478 | 0.500 |
| The capacity of individuals and groups to make informed decisions and take action. (yes importance=1; otherwise=0) | 264 | 55.35 % | 0.553 | 0.498 |
| Gender (1=Female; 0=Male) | 255 | 53.46 % | 0.535 | 0.499 |
| Income (1=More than minimum wage; otherwise=0) | 289 | 60.59 % | 0.606 | 0.489 |
| Education (1=More than diploma or bachelor degree; otherwise=0) | 263 | 55.14 % | 0.551 | 0.498 |
| Age (1=>30 years old; otherwise=0) | 313 | 65.62 % | 0.656 | 0.475 |
| Marital status (1=Married; otherwise=0) | 161 | 33.75 % | 0.338 | 0.473 |
| Fisherman (1=yes; otherwise=0) | 21 | 4.40 % | 0.044 | 0.205 |
| Tourist operator (1=yes; otherwise=0) | 30 | 6.29 % | 0.063 | 0.243 |
| Willingness to participate (1=yes; otherwise=0) | 153 | 32.08 % | 0.321 | 0.467 |

Governance structures are deemed important by 46.12 % of respondents, highlighted by a mean of 0.461, while processes to enhance understanding and improve sanitation practices are valued by 47.80 %, with a mean of 0.478. The capacity for individual and group agency in making informed decisions is notably recognized by 55.35 % of participants, the highest among the governance-related attributes, underscored by a mean of 0.553. Demographic factors are also included to gauge their influence on perceptions related to sanitation governance. A significant 65.62 % of respondents over 30 years old see these issues as important, reflected by a mean of 0.656, suggesting that older community members might be more invested or experienced in sanitation issues. Income levels show that 60.59 % of those earning above the minimum wage rate the discussed factors as important, with a mean value of 0.606, possibly indicating that higher income levels correlate with greater awareness or ability to engage with advanced sanitation management.

Table 4 employs binary probit and logit regression models to

**Table 4**
Probit and Logit models for willingness to participate in sanitation adaptation.

| Variables | Overall model | | Adaptive preference model | | Socio demographic model | |
|---|---|---|---|---|---|---|
| | Probit | Logit | Probit | Logit | Probit | Logit |
| Constant | −2.136*** (0.266) | −3.652*** (0.478) | −1.086*** (0.164) | −1.795*** (0.278) | −1.422*** (0.198) | −2.451*** (0.355) |
| Physical and institutional assets that support effective sanitation (yes importance=1; otherwise=0) | 0.423*** (0.136) | 0.718*** (0.229) | 0.400*** (0.129) | 0.667*** (0.214) | – | – |
| The ability of sanitation systems to adapt to varying conditions. (yes importance=1; otherwise=0) | 0.372*** (0.132) | 0.604*** (0.222) | 0.328*** (0.126) | 0.553*** (0.207) | – | – |
| The structures and systems that govern sanitation operations. (yes importance=1; otherwise=0) | 0.251* (0.135) | 0.431* (0.228) | 0.142 (0.126) | 0.246 (0.209) | – | – |
| Ongoing processes to enhance understanding and improve practices. (yes importance=1; otherwise=0) | 0.299** (0.136) | 0.509** (0.228) | 0.303** (0.129) | 0.507** (0.214) | – | – |
| The capacity of individuals and groups to make informed decisions and take action. (yes importance=1; otherwise=0) | 0.184 (0.140) | 0.297 (0.234) | 0.075 (0.132) | 0.101 (0.217) | – | – |
| Gender (1=Female; 0=Male) | 0.692*** (0.135) | 1.193*** (0.234) | – | – | 0.653*** (0.129) | 1.128*** (0.222) |
| Income (1=More than minimum wage; otherwise=0) | 0.192 (0.170) | 0.354 (0.285) | – | – | 0.257 (0.163) | 0.469* (0.274) |
| Education (1=More than diploma or bachelor's degree; otherwise=0) | 0.503*** (0.166) | 0.853*** (0.278) | – | – | 0.437*** (0.160) | 0.748*** (0.267) |
| Age (1=>30 years old; otherwise=0) | −0.056 (0.175) | −0.070 (0.300) | – | – | 0.041 (0.169) | 0.091 (0.284) |
| Marital status (1=Married; otherwise=0) | 0.157 (0.167) | 0.273 (0.283) | – | – | 0.224 (0.160) | 0.385 (0.269) |
| Fisherman (1=yes; otherwise=0) | 1.230*** (0.320) | 2.095*** (0.541) | – | – | 0.974*** (0.306) | 1.650*** (0.504) |
| Tourist operator (1=yes; otherwise=0) | 0.452* (0.254) | 0.746* (0.431) | – | – | 0.401 (0.247) | 0.675 (0.416) |
| Goodness of fit | | | | | | |
| χ2 value, p-value=1 % | 26.217; df=12 | | 15.086; df=5 | | 18.475; df=7 | |
| Log likelihood function | −257.417 | −256.902 | −282.466 | −282.146 | −274.969 | −274.256 |
| LLR | 83.742 | 84.772 | 33.642 | 34.282 | 48.636 | 50.063 |
| McFadden Pseudo R-squared | 0.140 | 0.142 | 0.056 | 0.057 | 0.081 | 0.084 |
| AIC/N | 1.134 | 1.132 | 1.210 | 1.208 | 1.186 | 1.183 |

Notes: ***, **, * are significant differences at $p < 0.01$, $p < 0.05$, and $p < 0.1$, respectively.

examine the factors influencing willingness to participate in sanitation adaptation. The study in Labuan Bajo applies three models each capturing different but interconnected dimensions of community engagement. Together, these models offer a more complete understanding of the key drivers behind participation. The **overall model**, which integrates both governance-related and socio-demographic variables, reveals that people are more likely to participate when they perceive strong physical and institutional support for sanitation. This underscores the importance of well-functioning infrastructure and trusted institutions in fostering public confidence and engagement. The model also highlights the significance of adaptability namely, the ability of sanitation systems to respond to changes such as seasonal tourism surges or extreme weather. Furthermore, the presence of ongoing learning processes and public awareness efforts is positively associated with participation, suggesting that continuous outreach and education play an essential role in motivating action. In contrast, individual capacity to act such as making informed decisions or initiating change independently does not significantly affect participation, indicating that people may rely more on collective systems and institutional leadership than personal agency. The **adaptive preference model**, which focuses exclusively on governance-related variables, reinforces these patterns. Physical infrastructure, system adaptability, and learning processes remain statistically significant, confirming that people's willingness to participate is closely tied to how well the sanitation system functions and its responsiveness to local challenges. However, governance structures and individual decision-making capacity do not emerge as significant, suggesting that tangible and visible features of sanitation systems carry more weight in shaping public engagement than internal management or abstract agency. The **socio-demographic model**, which isolates personal characteristics, provides further insight. Women are significantly more likely than men to participate, likely reflecting their central role in managing household sanitation and hygiene. Higher education is also positively associated with participation, indicating that awareness and understanding of sanitation's health and environmental benefits influence engagement. Income shows a modest but meaningful effect, with higher-income individuals having greater capacity or flexibility to participate. Occupational roles also matter fishermen and tourism operators are more likely to engage, possibly because their livelihoods depend directly on a clean and healthy environment. Across all three models, it is clear that both system quality and individual background play important roles in shaping sanitation participation. The Overall Model effectively blends governance-related factors within the WEFE nexus with demographic profiles, demonstrating that both institutional and personal factors must be considered to foster inclusive and resilient sanitation governance.

To support and triangulate these quantitative findings, the study also conducted semi-structured interviews with key stakeholders, including local tourism operators, village heads (kepala desa), and academic researchers experienced in sanitation governance. These interviews provided valuable real-world perspectives that reinforced the statistical results. Stakeholders consistently emphasized the importance of reliable infrastructure, institutional support, and system adaptability mirroring the key factors identified in the regression models. This qualitative validation strengthens the study's conclusions and provides a more grounded understanding of the conditions necessary to promote sustained community participation in sanitation adaptation.

The statistical significance of the overall model is robust, with goodness of fit indicators like the Chi-squared (χ2) values surpassing the log likelihood ratio (LLR), suggesting a strong model fit. Key findings highlight the crucial role of physical and institutional assets, showing a statistically significant positive impact on participation willingness in both the probit and logit models ($p < 0.01$). This suggests that robust support structures greatly enhance community members' likelihood to engage in sanitation efforts. Similarly, the capacity for sanitation systems to adapt to variable conditions emerges as another significant factor, consistently valued across both models ($p < 0.01$), underscoring the community's high regard for flexible and responsive sanitation solutions. The adaptive preference model focuses more narrowly on the adaptability of sanitation systems, exploring how the perceived importance of this adaptability influences willingness to participate. Findings from this model reaffirm the critical value placed on adaptive capacity, with similar coefficients in both statistical approaches ($p < 0.01$), highlighting a strong and consistent preference for adaptable systems.

Conversely, the socio-demographic model isolates the impact of personal demographic characteristics on participation decisions. This model illuminates how gender significantly influences these decisions, with women more likely to participate than men, as indicated in both the probit and logit analyses ($p < 0.01$). Education also significantly affects participation willingness, with better-educated individuals more likely to engage in sanitation practices, reflecting the importance of knowledge and awareness in fostering environmental stewardship ($p < 0.01$). Additionally, the model offers fascinating insights into how specific professional roles influence willingness to participate. Fishermen and tourist operators, for instance, display unique participation patterns likely shaped by their direct interactions with environmental conditions and their economic dependence on a healthy ecosystem.

## 5. Discussion

The study conducted in Labuan Bajo presents valuable insights into the factors that influence willingness to participate in sanitation adaptation, focusing on both adaptive system features and socio-demographic variables. Using binary probit and logit regression models, the analysis reveals several significant factors that help explain community dynamics and individual motivations in supporting environmental management. One key finding is the importance of effective and accessible sanitation facilities. The presence of reliable infrastructure not only improves environmental conditions but also encourages community members to actively engage in maintaining these systems [65,66]. The adaptability of sanitation systems also stands out as a significant factor. Systems that can adjust to changing environmental and socio-economic conditions such as seasonal tourism pressures or climate-related impacts are more likely to earn community support. This reflects a clear community preference for resilient systems that can respond to evolving needs. To support this, future policies should enhance the flexibility and responsiveness of sanitation systems to better address environmental changes and public health challenges [67,68]. Another significant factor is the role of continuous education and awareness-building efforts. The findings show that when communities are engaged through outreach campaigns and local education programs, participation increases. These initiatives help build not only knowledge but also a sense of ownership and responsibility among residents [69–71].

From a socio-demographic perspective, the analysis highlights the importance of gender, education, and income in shaping participation. Women are significantly more likely to engage, reflecting their central role in managing household sanitation and hygiene [72–74]. Moreover, gender also affects access to facilities, decision-making power, and exposure to sanitation-related risks [75,76]. These findings underline the need for gender-sensitive sanitation programs that empower women not only as participants but also as key decision-makers in adaptive governance. Education is another strong predictor of participation. Individuals with higher levels of education are more likely to understand the importance of sanitation, support adaptive efforts, and contribute to public health and environmental sustainability [77–79]. This underscores the need for public education campaigns tailored to different literacy levels to strengthen inclusive engagement [80,81]. Income, while showing a more nuanced role, remains relevant. Higher-income individuals are more likely to participate, likely due to greater flexibility and fewer financial constraints [82–84]. In contrast, low-income residents face multiple barriers, including affordability issues, time constraints, and limited access to infrastructure [80,85]. These disparities point to the need for equity-focused interventions [86,87] such as targeted subsidies, incentives, or community-led cost-sharing models, to ensure that participation is inclusive across income groups.

The Labuan Bajo case also reflects broader global issues tied to the Water-Energy-Food-Ecosystem (WEFE) Nexus. Community willingness to participate is closely linked to the presence of reliable institutions and adaptable systems principles that resonate with the global call for resilience across interconnected sectors. As climate change continues to affect water, energy, and food systems, the lessons from Labuan Bajo emphasize the importance of integrating flexible, community-centered sanitation into wider nexus planning [88,89]. Moreover, Labuan Bajo's positive response to infrastructure investment and institutional support supports the need for stronger physical foundations that can withstand environmental stress. Technologies like modular wastewater treatment systems [90] show how localized, flexible infrastructure can reduce climate-related risks and improve system resilience. At the same time, the nexus approach itself has limitations. Some models, such as the Water–Employment–Migration (WEM) nexus, have been criticized for being too abstract or lacking clear implementation strategies, especially in the Global South [91]. For example, while governments express interest in the WEM framework, there remains a gap between theoretical interest and practical policy action. The COVID-19 pandemic further exposed these weaknesses. Despite the interlinked nature of water, energy, and food systems, the crisis was often managed in silos, with missed opportunities for coordinated responses [92]. This highlights the urgent need for more integrated planning, risk-based governance, and cross-sector collaboration to prepare for future shocks. Lastly, recent work on the circular economy and resource nexus shows that although sustainability initiatives are expanding in countries like Saudi Arabia, many are not yet fully aligned with national policy frameworks [93]. To be truly effective, nexus-based approaches must be embedded in long-term strategies that include clear goals, policy coherence, and meaningful community participation.

### *5.1. Longitudinal perspectives and challenges in implementing adaptive governance*

The probit and logit regression models used in this study offer a valuable snapshot of the factors shaping community willingness to participate in sanitation adaptation. By integrating governance-related factors from the WEFE nexus with key socio-demographic characteristics, the results point to strong associations between participation and enabling conditions such as physical and institutional infrastructure, system adaptability, gender, education, and occupation. These findings underscore the importance of context-specific policy interventions that respond to both community needs and structural realities. However, while this cross-sectional analysis provides useful insights into present conditions, it captures only a single point in time. Adaptive governance and community participation are dynamic processes shaped by evolving environmental pressures, shifting political contexts, changes in institutional trust, and ongoing learning. For instance, the adaptive preference model reveals a current preference for flexible and responsive sanitation systems. Yet, without longitudinal data, it remains uncertain whether these preferences will remain stable, intensify, or diminish as circumstances change. Similarly, although institutional support appears strong now, it may weaken under future leadership transitions, funding cuts, or declining public trust.

To fully understand how adaptive governance functions over time, longitudinal research is needed. Following communities, institutions, and policy outcomes across multiple phases would help capture how engagement matures, how feedback loops develop, and how governance strategies are adjusted. This would provide richer insights into the long-term effectiveness and sustainability of adaptive governance, not just in Labuan Bajo but in comparable settings across the Global South. Translating adaptive governance principles into lasting practice also faces real-world constraints. While its theoretical benefits such as flexibility, learning, and stakeholder inclusion are well recognized, implementation often struggles against structural and political challenges. In

Indonesia and other Global South contexts, sanitation governance is frequently fragmented across multiple agencies and layers of government. This results in overlapping responsibilities, weak accountability, and limited coordination, making it difficult to execute integrated, cross-sectoral strategies especially those requiring collaboration across water, energy, food, and environmental sectors.

Funding constraints present another major hurdle. Adaptive governance is a continuous process that demands investment in innovation, monitoring, and sustained community involvement. Yet, many local governments rely on short-term, project-based funding, with limited capacity to plan for long-term resilience. These financial limitations are compounded by political cycles and shifting development priorities, which can interrupt or even reverse progress particularly when higher-profile sectors like tourism or physical infrastructure overshadow sanitation. Community engagement, too, is vulnerable to change over time. Although this study reveals strong local willingness to participate, maintaining that engagement requires consistent communication, meaningful inclusion in decision-making, and visible outcomes. Without these, trust can erode, and participation may decline especially if past programs failed to deliver. Moreover, institutional inertia, including rigid procedures and reluctance to share power with communities, can slow innovation and limit opportunities for co-management.

## 6. Conclusion

Our findings highlight that robust physical and institutional asset, coupled with the adaptability of sanitation systems to changing conditions, are strongly linked to increased community participation. These elements are underpinned by effective organizational structures, ongoing learning processes, and the agency of individuals and communities, which collectively foster a conducive environment for engaging local populations in sustainable practices. The importance of socio-demographic factors such as gender, education, and income in influencing participation decisions also emerged distinctly from the data. These factors are critical in tailoring community-specific approaches that can enhance the inclusivity and effectiveness of sanitation governance. The study underscores the need for integrated approaches that consider the intricate interconnections within the WEFE Nexus. It advocates for the implementation of policies that enhance physical and institutional sanitation infrastructures, promote system adaptability, and foster an organizational environment conducive to community learning and participation. Policymakers are encouraged to consider these insights in the design of community engagement strategies and sanitation projects. Specifically, there is a compelling case for initiatives that bolster education and awareness programs, enhance the responsiveness of sanitation systems to environmental and demographic changes, and actively involve diverse community segments in decision-making processes.

### *6.1. Policy implications*

From a socio-demographic perspective, gender, education, and income are key factors that influence people's willingness to participate in sanitation initiatives. Women are generally more involved in sanitation activities, often because they are more directly responsible for managing household health and hygiene. At the same time, individuals with higher levels of education are more likely to understand the importance of sanitation and be motivated to take part in related programs. Income level also plays an important role. People with higher incomes tend to have more resources and time to engage in sanitation activities, while those with lower incomes may face challenges such as affordability or time constraints. These differences highlight the need for policies that make it easier for low-income groups to participate—such as financial support, flexible programs, or community-based incentives. A more nuanced understanding of how these factors especially gender and income interact would help improve the design of inclusive sanitation policies. Tailored strategies that recognize these overlapping challenges can ensure that programs are accessible and relevant to all segments of the community, especially those who are often overlooked.

## CRediT authorship contribution statement

**Evi Siti Sofiyah:** Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Imelda Masni Juniaty Sianipar:** Writing – review & editing, Methodology, Formal analysis, Data curation, Conceptualization. **Ari Rahman:** Writing – review & editing, Writing – original draft, Data curation, Conceptualization. **Naila Putri Caesarina:** Project administration, Investigation, Funding acquisition, Data curation. **Sapta Suhardono:** Writing – review & editing, Validation, Supervision, Funding acquisition, Formal analysis, Data curation. **I Wayan Koko Suryawan:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Chun-Hung Lee:** Supervision, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### *AI Use Declaration*

During the preparation of this manuscript, generative AI (ChatGPT by OpenAI) was used solely to improve the readability and language clarity of the text. The AI was not used to generate scientific insights, conclusions, or original research content. All use was conducted under the direct supervision of the authors, who carefully reviewed and edited the output to ensure accuracy and appropriateness. The authors take full responsibility for the content of the manuscript.

## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.wds.2025.100220.

## References


[1] I.M.J. Sianipar, C.-H. Lee, H.-J. Wang, D-C Kim, Unraveling factors influencing local willingness to participate in sustainable Komodo conservation and protected area tourism, For. Soc. 8 (2024) 350–371, https://doi.org/10.24259/fs.v8i2.32880.

[2] N.M.U. Dwipayanti, A. Nastiti, H. Johnson, et al., Inclusive WASH and sustainable tourism in Labuan Bajo, Indonesia: needs and opportunities, J. Water Sanit. Hyg. Dev. 12 (2022) 417–431, https://doi.org/10.2166/washdev.2022.222.

[3] R.A. Bellezoni, F. Meng, P. He, K.C. Seto, Understanding and conceptualizing how urban green and blue infrastructure affects the food, water, and energy nexus: a synthesis of the literature, J. Clean. Prod. 289 (2021) 125825, https://doi.org/10.1016/j.jclepro.2021.125825.

[4] P.N. Carvalho, D.C. Finger, F. Masi, et al., Nature-based solutions addressing the water-energy-food nexus: review of theoretical concepts and urban case studies, J. Clean. Prod. 338 (2022) 130652, https://doi.org/10.1016/j.jclepro.2022.130652.

[5] K.V. Heal, A. Bartosova, M.R. Hipsey, et al., Water quality: the missing dimension of water in the water–energy–food nexus, Hydrol. Sci. J. 66 (2021) 745–758, https://doi.org/10.1080/02626667.2020.1859114.

[6] K. Javan, A. Altaee, S. BaniHashemi, et al., A review of interconnected challenges in the water–energy–food nexus: urban pollution perspective towards sustainable development, Sci. Total. Environ. 912 (2024) 169319, https://doi.org/10.1016/j.scitotenv.2023.169319.

[7] D.C. Ferreira, I. Graziele, R.C. Marques, J. Gonçalves, Investment in drinking water and sanitation infrastructure and its impact on waterborne diseases dissemination: the Brazilian case, Sci. Total. Environ. 779 (2021) 146279, https://doi.org/10.1016/j.scitotenv.2021.146279.

[8] G.M. Kumar, P. Chaturvedi, A.K. Rao, et al., Flowing futures: innovations in WASH for sustainable water, sanitation, and hygiene, E3S Web Conf. 453 (2023).

[9] E. Andriollo, A. Caimo, L. Secco, E. Pisani, Collaborations in environmental initiatives for an effective "Adaptive governance" of social–Ecological systems: what existing literature suggests, Sustainability (2021) 13.
[10] I. Farsari, Exploring the nexus between sustainable tourism governance, resilience and complexity research, Tour. Recreat. Res. 48 (2023) 352–367, https://doi.org/10.1080/02508281.2021.1922828.
[11] N.-B. Chang, U. Hossain, A. Valencia, et al., The role of food-energy-water nexus analyses in urban growth models for urban sustainability: a review of synergistic framework, Sustain. Cities Soc. 63 (2020) 102486, https://doi.org/10.1016/j.scs.2020.102486.
[12] A. Afshar, E. Soleimanian, H. Akbari Variani, et al., The conceptual framework to determine interrelations and interactions for holistic water, energy, and Food nexus, Environ. Dev. Sustain. 24 (2022) 10119–10140, https://doi.org/10.1007/s10668-021-01858-3.
[13] N.A. Al-Thani, T. Al-Ansari, Comparing the convergence and divergence within industrial ecology, circular economy, and the energy-water-food nexus based on resource management objectives, Sustain. Prod. Consum. 27 (2021) 1743–1761, https://doi.org/10.1016/j.spc.2021.04.008.
[14] J.B.S.O. de Andrade Guerra, I.I. Berchin, J. Garcia, et al., A literature-based study on the water–energy–food nexus for sustainable development, Stoch. Environ. Res. Risk. Assess. 35 (2021) 95–116, https://doi.org/10.1007/s00477-020-01772-6.
[15] D. Han, D. Yu, Q. Cao, Assessment on the features of coupling interaction of the food-energy-water nexus in China, J. Clean. Prod. 249 (2020) 119379, https://doi.org/10.1016/j.jclepro.2019.119379.
[16] X.-C. Wang, P. Jiang, L. Yang, et al., Extended water-energy nexus contribution to environmentally-related sustainable development goals, Renew. Sustain. Energy Rev. 150 (2021) 111485, https://doi.org/10.1016/j.rser.2021.111485.
[17] J. Barron, S. Skyllerstedt, M. Giordano, Z. Adimassu, Building climate resilience in rainfed landscapes needs more than good will, Front. Clim. 3 (2021).
[18] M. Petersen-Rockney, P. Baur, A. Guzman, et al., Narrow and brittle or broad and nimble? Comparing adaptive capacity in simplifying and diversifying farming systems, Front. Sustain. Food Syst. 5 (2021).
[19] J. Månsson, L. Eriksson, I. Hodgson, et al., Understanding and overcoming obstacles in adaptive management, Trends. Ecol. Evol. 38 (2023) 55–71.
[20] S. Moosavi, G.R. Browne, Advancing the adaptive, participatory and transdisciplinary decision-making framework: the case of a coastal brownfield transformation, Cities 111 (2021) 103106, https://doi.org/10.1016/j.cities.2021.103106.
[21] R.J. Stoffels, D.J. Booker, P.A. Franklin, R. Holmes, Monitoring for the adaptive management of rivers, J. Environ. Manage 351 (2024) 119787, https://doi.org/10.1016/j.jenvman.2023.119787.
[22] P.J. Cohen, S. Lawless, M. Dyer, et al., Understanding adaptive capacity and capacity to innovate in social–ecological systems: applying a gender lens, Ambio 45 (2016) 309–321, https://doi.org/10.1007/s13280-016-0831-4.
[23] F.A. Johnson, M.J. Eaton, J. Mikels-Carrasco, D. Case, Building adaptive capacity in a coastal region experiencing global change, Ecol. Soc. 25 (2020) 1–22, https://doi.org/10.5751/ES-11700-250309.
[24] I.W.K. Suryawan, I.M.J. Sianipar, C.H. Lee, Community importance-performance preferences and policy adaptiveness in marine debris management: a case study from the Komodo Subdistrict, Indonesia, Mar. Policy 174 (2025) 106592.
[25] I.W.K. Suryawan, S. Suhardono, V.V. Nguyen, C.H. Lee, Importance-Performance Evaluation of Coral Reef Conservation in Advancing the Bioeconomy of Marine Tourism in Bali, Indonesia, Aquat. Conserv.: Mar. Freshw. Ecosyst. 35 (3) (2025) e70085.
[26] S.H.A. Koop, C. Grison, S.J. Eisenreich, et al., Integrated water resources management in cities in the world: global solutions, Sustain. Cities Soc. 86 (2022) 104137, https://doi.org/10.1016/j.scs.2022.104137.
[27] S.K. Sharma, A. Seetharaman, K. Maddulety, Framework for sustainable Urban Water management in context of governance, infrastructure, technology and economics, Water Resour. Manag. 35 (2021) 3903–3913, https://doi.org/10.1007/s11269-021-02916-1.
[28] J. Ananda, D. McFarlane, M. Loh, The role of experimentation in water management under climate uncertainty: institutional barriers to social learning, Environ. Policy Gov. 30 (2020) 319–331, https://doi.org/10.1002/eet.1887.
[29] J. Lawrence, P. Blackett, N.A. Cradock-Henry, Cascading climate change impacts and implications, Clim. Risk. Manage. 29 (2020) 100234, https://doi.org/10.1016/j.crm.2020.100234.
[30] M. Duijn, J. Van Popering-Verkerk, Integrated public value creation through community initiatives—evidence from Dutch Water Management, Soc. Sci. (2018) 7.
[31] A. Kumar, A. Thakur, Chapter 7 - industrial water conservation by water footprint and Sustainable Development Goals, in: S.A. Bandh, Malla FABT-CD in WSR (Eds.), Water Footprints and Sustainable Development, Elsevier, 2024, pp. 87–117.
[32] A. Krause, V.S. Rotter, Linking energy-sanitation-agriculture: intersectional resource management in smallholder households in Tanzania, Sci. Total. Environ. 590–591 (2017) 514–530, https://doi.org/10.1016/j.scitotenv.2017.02.205.
[33] N. Lourenço, L.M. Nunes, Review of dry and wet decentralized sanitation technologies for rural areas: applicability, challenges and opportunities, Environ. Manage. 65 (2020) 642–664, https://doi.org/10.1007/s00267-020-01268-7.
[34] S. Mariwah, J.-O. Drangert, E.A. Adams, The potential of composting toilets in addressing the challenges of faecal sludge management in community-led total sanitation (CLTS), Glob. Public Health 17 (2022) 3802–3814, https://doi.org/10.1080/17441692.2022.2111453.
[35] M. Mijthab, R. Anisie, O. Crespo, Mosan: combining circularity and participatory design to address sanitation in low-income communities, Circ. Econ. Sustain. 1 (2021) 1165–1191, https://doi.org/10.1007/s43615-021-00118-w.
[36] B.-W. Liu, M.-H. Wang, T.-L. Chen, et al., Establishment and implementation of green infrastructure practice for healthy watershed management: challenges and perspectives, Water-Energy Nexus 3 (2020) 186–197, https://doi.org/10.1016/j.wen.2020.05.003.
[37] S. Pauleit, A. Vasquéz, S. Maruthaveeran, et al., Urban green infrastructure in the global south, in: C.M. Shackleton, S.S. Cilliers, E. Davoren, M.J. du Toit (Eds.), Urban Ecology in the Global South, Springer International Publishing, Cham, 2021, pp. 107–143.
[38] G. Martínez-Borreguero, J. Maestre-Jiménez, M. Mateos-Núñez, F.L. Naranjo-Correa, An integrated model approach of education for sustainable development: exploring the concepts of water, energy and waste in primary education, Sustainability (2020) 12.
[39] K. Obaideen, N. Shehata, E.T. Sayed, et al., The role of wastewater treatment in achieving sustainable development goals (SDGs) and sustainability guideline, Energy Nexus 7 (2022) 100112, https://doi.org/10.1016/j.nexus.2022.100112.
[40] J.A. Silva, Wastewater treatment and reuse for sustainable water resources management: a systematic literature review, Sustainability (2023) 15.
[41] C. Tortajada, Contributions of recycled wastewater to clean water and sanitation Sustainable Development Goals, NPJ Clean. Water. 3 (2020) 22.
[42] L. Khalil, S. Abbas, K. Hussain, et al., Sanitation, water, energy use, and traffic volume affect environmental quality: go-for-green developmental policies, PLoS ONE 17 (2022) e0271017.
[43] G. Kyriakarakos, G. Papadakis, Is small scale desalination coupled with renewable energy a cost-effective solution? Appl. Sci. (2021) 11.
[44] M.J.B. Kabeyi, O.A. Olanrewaju, Biogas production and applications in the sustainable energy transition, J. Energy 2022 (2022) 8750221, https://doi.org/10.1155/2022/8750221.
[45] A.A. Werkneh, S.B. Gebru, Development of ecological sanitation approaches for integrated recovery of biogas, nutrients and clean water from domestic wastewater, Resour. Environ. Sustain. 11 (2023) 100095, https://doi.org/10.1016/j.resenv.2022.100095.
[46] H.A.C. Lohman, J.T. Trimmer, D. Katende, et al., Advancing sustainable sanitation and agriculture through investments in Human-derived nutrient systems, Environ. Sci. Technol. 54 (2020) 9217–9227, https://doi.org/10.1021/acs.est.0c03764.
[47] A. Rosemarin, B. Macura, J. Carolus, et al., Circular nutrient solutions for agriculture and wastewater – a review of technologies and practices, Curr. Opin. Environ. Sustain. 45 (2020) 78–91, https://doi.org/10.1016/j.cosust.2020.09.007.
[48] S.Y. Agyemang-Badu, E. Awuah, S. Oduro-Kwarteng, et al., Environmental management and sanitation as a malaria vector control strategy: a qualitative cross-sectional study among stakeholders, Sunyani Municipality, Ghana, Environ. Health Insights 17 (2023), https://doi.org/10.1177/11786302221146890, 11786302221146890.
[49] A. Hafeez, Z. Shamair, N. Shezad, et al., Solar powered decentralized water systems: a cleaner solution of the industrial wastewater treatment and clean drinking water supply challenges, J. Clean. Prod. 289 (2021) 125717, https://doi.org/10.1016/j.jclepro.2020.125717.
[50] S.K. Sansaniwal, Advances and challenges in solar-powered wastewater treatment technologies for sustainable development: a comprehensive review, Int. J. Ambient Energy 43 (2022) 958–991, https://doi.org/10.1080/01430750.2019.1682038.
[51] D. Hidalgo, F. Corona, J.M. Martín-Marroquín, Nutrient recycling: from waste to crop, Biomass Convers. Biorefinery 11 (2021) 207–217, https://doi.org/10.1007/s13399-019-00590-3.
[52] K.D. Orner, F. Camacho-Céspedes, J.A. Cunningham, J.R. Mihelcic, Assessment of nutrient fluxes and recovery for a small-scale agricultural waste management system, J. Environ. Manage. 267 (2020) 110626, https://doi.org/10.1016/j.jenvman.2020.110626.
[53] M.J. Adegbeye, A.Z.M. Salem, P.R.K. Reddy, et al., Waste recycling for the eco-friendly input use efficiency in agriculture and livestock feeding, in: S. Kumar, R. S. Meena, M.K. Jhariya (Eds.), Resources Use Efficiency in Agriculture, Springer, Singapore, Singapore, 2020, pp. 1–45.
[54] Perez Cuso M., Zhao Y., Bakeer-Markar A., et al. (2024) Strategy to promote inclusive and sustainable businesses to achieve the Sustainable Development Goals in Sri Lanka: background note.
[55] R.C. Brears, Best practices, in: R.C. Brears (Ed.), The Green Economy and the Water-Energy-Food Nexus, Springer International Publishing, Cham, 2023, pp. 355–387.
[56] S. Rasul, A.Y. Cheng, Policy frameworks and governance structures supporting green City movements, Adv. Urban Resil. Sustain. City Des. 15 (2023) 37–51.
[57] V. Zavratnik, D. Podjed, J. Trilar, et al., Sustainable and community-centred development of smart cities and villages, Sustainability (2020) 12.
[58] A. Rahman, S. Suhardono, E.S. Sofiyah, I.M.J. Sianipar, C.H. Lee, I.W.K. Suryawan, Impact of COVID-19 on visitor attitude and management strategies at Komodo National Park: insights for enhancing park adaptive experience, Trees For. People 20 (2025) 100825.
[59] E.S. Sofiyah, B. Ridhosari, S. Suhardono, C.-H. Lee, I.W.K. Suryawan, Impact of COVID-19 on subjec-tive well-being and community importance-performance in sanitation programs in Jakarta, Indonesia, Forum Geogr. 39 (1) (2025) 64–78, https://doi.org/10.23917/forgeo.v39i1.5366.
[60] E.S. Sofiyah, I.M.J. Sianipar, A. Rahman, H.A. Rafida, S. Suhardono, C.H. Lee, I.W. K. Suryawan, Advancing the 2030 agenda with community importance-performance perspective and public relations strategies for community-based sanitation, Sustain. Futures 20 (2025) 100633.
[61] M.A. Moynihan, D.M. Baker, A.J. Mmochi, Isotopic and microbial indicators of sewage pollution from Stone Town, Zanzibar, Tanzania, Mar. Pollut. Bull. 64 (2012) 1348–1355, https://doi.org/10.1016/j.marpolbul.2012.05.001.

[62] Tin Tun Kirkpatrick Cho, Pioneering pathways to sustainability: a case study of EL Nido Resorts in Palawan, J. Hosp. Tour. Cases (2025), https://doi.org/10.1177/21649987251314896, 21649987251314896.

[63] N. Ulhasanah, M.M. Sari, A. Sarwono, K. Johari, S. Suhardono, D.V. Sanda, Exploratory factors in community-based adaptation strategies for managing marine microplastics, Reg. Stud. Mar. Sci. 82 (2025) 104015.

[64] A. Rahman, I.W.K. Suryawan, S. Suhardono, V.V. Nguyen, C.H. Lee, Determinants of electric vehicle adoption in urban and peri-urban areas, Energy Sustain. Dev. 85 (2025) 101664, https://doi.org/10.1016/j.esd.2025.101664.

[65] M.L. Schmitt, O.R. Wood, D. Clatworthy, et al., Innovative strategies for providing menstruation-supportive water, sanitation and hygiene (WASH) facilities: learning from refugee camps in Cox's bazar, Bangladesh, Confl. Health 15 (2021) 10, https://doi.org/10.1186/s13031-021-00346-9.

[66] J. Willetts, F. Mills, M. Al'Afghani, Sustaining Community-scale Sanitation Services: co-management by local government and low-income communities in Indonesia, Front. Environ. Sci. (2020) 8.

[67] T. Chan, M.C. MacDonald, A. Kearton, et al., Climate adaptation for rural water and sanitation systems in the Solomon Islands: a community scale systems model for decision support, Sci. Total. Environ. 714 (2020) 136681, https://doi.org/10.1016/j.scitotenv.2020.136681.

[68] T. Yasmin, S. Dhesi, I. Kuznetsova, et al., A system approach to water, sanitation, and hygiene resilience and sustainability in refugee communities, Int. J. Water Resour. Dev. 39 (2023) 691–723, https://doi.org/10.1080/07900627.2022.2131362.

[69] L. Morris, S. Wilson, W. Kelly, Methods of conducting effective outreach to private well owners – a literature review and model approach, J. Water. Health 14 (2015) 167–182, https://doi.org/10.2166/wh.2015.081.

[70] A.M. Muktar, C.K.S. Saba, D.D. Adzo, Knowledge, attitudes and practices (KAP) towards community-led total sanitation (CLTS) behaviours among communities in Northern Ghana, J. Heal. Environ. Res. 8 (2024) 65–77.

[71] N. Phaswana-Mafuya, F.M. Olsson, Safe Hygiene Practices in a Rural Municipality of the Eastern Cape, South Africa, HSRC Libr Shelf, 2008.

[72] T.Z. Abu, E. Bisung, S.J. Elliott, What if your husband doesn't feel the pressure? An exploration of women's involvement in WaSH decision making in Nyanchwa, Kenya, Int. J. Environ. Res. Public Health (2019) 16.

[73] E.R. MacRae, T. Clasen, M. Dasmohapatra, B.A. Caruso, "It's like a burden on the head": redefining adequate menstrual hygiene management throughout women's varied life stages in Odisha, India, PLoS ONE 14 (2019) e0220114.

[74] S. Winter, M.N. Dzombo, F. Barchi, Exploring the complex relationship between women's sanitation practices and household diarrhea in the slums of Nairobi: a cross-sectional study, BMC Infect. Dis. 19 (2019) 242, https://doi.org/10.1186/s12879-019-3875-9.

[75] B.A. Caruso, A. Conrad, M. Patrick, et al., Water, sanitation, and women's empowerment: a systematic review and qualitative metasynthesis, PLoS Water 1 (2022) e0000026.

[76] A. Mgwele, J.I. Bhanye, K.S. Mocwagae, Water and sanitation for urban health: a gender perspective on impacts and coping strategies in Mangaung metropolitan municipality, in: A.R. Matamanda, V. Nel (Eds.), Sustainable Development Goals and Urban Health: Strides, Challenges and Way Forward for Poor Neighborhoods, Springer Nature Switzerland, Cham, 2024, pp. 49–67.

[77] I. Suárez-Perales, J. Valero-Gil, D.I. Leyva-de la Hiz, et al., Educating for the future: how higher education in environmental management affects pro-environmental behaviour, J. Clean. Prod. 321 (2021) 128972, https://doi.org/10.1016/j.jclepro.2021.128972.

[78] J. Tianyu, L. Meng, Does education increase pro-environmental willingness to pay? Evidence from Chinese household survey, J. Clean. Prod. 275 (2020) 122713, https://doi.org/10.1016/j.jclepro.2020.122713.

[79] Á. Zsóka, Z.M. Szerényi, A. Széchy, T. Kocsis, Greening due to environmental education? Environmental knowledge, attitudes, consumer behavior and everyday pro-environmental activities of Hungarian high school and university students, J. Clean. Prod. 48 (2013) 126–138, https://doi.org/10.1016/j.jclepro.2012.11.030.

[80] R.A. Ayelazuno, S. Tetteh, Sanitation struggles and public health concerns in Ghana: insights from Sodom and Gomorrah slum, SN Soc. Sci. 5 (2025) 32, https://doi.org/10.1007/s43545-025-01063-3.

[81] S. Danladi, M.S.V. Prasad, U.M. Modibbo, et al., Attaining sustainable development goals through financial inclusion: exploring collaborative approaches to fintech adoption in developing economies, Sustainability (2023) 15.

[82] X. Chu, J. Zhan, C. Wang, et al., Households' Willingness to accept improved ecosystem services and influencing factors: application of contingent valuation method in Bashang Plateau, Hebei Province, China, J Environ Manage 255 (2020) 109925, https://doi.org/10.1016/j.jenvman.2019.109925.

[83] A. Deshpande, N. Kabeer, Norms that matter: exploring the distribution of women's work between income generation, expenditure-saving and unpaid domestic responsibilities in India, World Dev. 174 (2024) 106435, https://doi.org/10.1016/j.worlddev.2023.106435.

[84] K.J. Miner, I.T. Rampedi, A.P. Ifegbesan, F. Machete, Survey on household awareness and willingness to participate in E-waste management in Jos, Plateau State, Nigeria, Sustainability (2020) 12.

[85] B. Bolaane, N. Tema, B. Phuthologo, Barriers and coping strategies of households with no access to drinking water and waterborne sanitation in two low-income neighbourhoods in Botswana, Habitat. Int. 115 (2021) 102372, https://doi.org/10.1016/j.habitatint.2021.102372.

[86] Y. Baek, Z. Ademi, J. Fisher, et al., Equity in economic evaluations of early childhood development interventions in low-and middle-income countries: scoping review, Matern. Child Health J. 27 (2023) 1009–1029, https://doi.org/10.1007/s10995-023-03650-3.

[87] J. Corburn, Water and sanitation for all: citizen science, health equity, and urban climate justice, Environ. Plan. B 49 (2022) 2044–2053, https://doi.org/10.1177/23998083221094836.

[88] A. Molajou, A. Afshar, M. Khosravi, et al., A new paradigm of water, food, and energy nexus, Environ. Sci. Pollut. Res. 30 (2023) 107487–107497, https://doi.org/10.1007/s11356-021-13034-1.

[89] A. Molotoks, P. Smith, T.P. Dawson, Impacts of land use, population, and climate change on global food security, Food Energy Secur. 10 (2021) e261, https://doi.org/10.1002/fes3.261.

[90] S. Eggimann, B. Truffer, U. Feldmann, M. Maurer, Screening European market potentials for small modular wastewater treatment systems – an inroad to sustainability transitions in urban water management? Land Use Policy 78 (2018) 711–725, https://doi.org/10.1016/j.landusepol.2018.07.031.

[91] H. Hussein, F. Ezbakhe, The Water–Employment–Migration nexus: buzzword or useful framework? Dev. Policy. Rev. 41 (2023) e12676 https://doi.org/10.1111/dpr.12676.

[92] M. Al-Saidi, H. Hussein, The water-energy-food nexus and COVID-19: towards a systematization of impacts and responses, Sci. Total. Environ. 779 (2021) 146529, https://doi.org/10.1016/j.scitotenv.2021.146529.

[93] A.I. Almulhim, M. Al-Saidi, Circular economy and the resource nexus: realignment and progress towards sustainable development in Saudi Arabia, Environ. Dev. 46 (2023) 100851, https://doi.org/10.1016/j.envdev.2023.100851.