
Research article

Environmental sanitation monitoring using EHRA for sustainable health risk reduction in small island tourism areas

Muhammad Arsyad¹, Anwar Mallongi², Muhammad Sabiq³ and Eymal Bahsar Demmallino^{1,*}

¹ Environmental Science Study Program, The Graduate School, Hasanuddin University, Makassar, Indonesia

² Environmental Health Department, Faculty of Public Health, Hasanuddin University, Makassar, Indonesia

³ Department of Sociology FISIPOL, Hasanuddin University, Makassar, Indonesia

* **Correspondence:** Email: demmallino2019@gmail.com; Tel: +628124201351.

Abstract: Small island tourism areas are highly vulnerable to environmental health risks due to limited infrastructure for municipal solid waste and wastewater management. In this study, we applied an Environmental Health Risk Assessment (EHRA)-based environmental monitoring approach to evaluate sanitation conditions, community behavior, and health risk levels in two small island tourism destinations in Selayar Islands Regency, Indonesia, namely Pasi Gusung Island and Bahuluang Island. A quantitative ecological study design using an EHRA-based environmental monitoring approach was conducted across 295 households selected through multistage random sampling. Data collection primarily involved direct field observation, environmental sanitation inspection, infrastructure verification, and EHRA-based environmental scoring, supported by limited household validation forms and guided interviews. The results showed that access to clean water sources was relatively high, with 72.4% of households on Pasi Gusung Island and 88.5% on Bahuluang Island classified in the good category. Similarly, latrine ownership was also high, reaching 78.6% on Pasi Gusung Island and 98.1% on Bahuluang Island. However, household solid waste management remained predominantly poor, affecting 74.9% and 73.1% of households, respectively. In addition, inadequate wastewater disposal systems were observed in 66.7% of households on Pasi Gusung Island and 53.8% on Bahuluang Island. Although handwashing with soap was reported as good among most households (95.1% on Pasi Gusung Island and 100% on Bahuluang Island), substantial gaps in solid waste and wastewater management remained and were reflected in moderate EHRI values of 2.23 and 2.33, respectively. The findings indicate that sanitation improvements are uneven and that behavioral

interventions alone may be insufficient to reduce environmental health risks without corresponding infrastructure development. This study highlights that integrated municipal solid waste and wastewater management are important determinants of reducing faecal–oral exposure risks in small island tourism settings. The EHRA-based monitoring approach provides a practical tool for identifying priority sanitation interventions to support sustainable health risk reduction and environmental protection in vulnerable coastal tourism areas.

Keywords: EHRA; environmental monitoring; sanitation infrastructure; wastewater management; solid waste management; coastal health risk; small island tourism; sustainable environmental management

1. Introduction

Small island regions are globally recognized as highly vulnerable socio-ecological systems due to their limited land availability, restricted environmental carrying capacity, and weak infrastructure development, particularly in sanitation services. These characteristics make small islands highly sensitive to anthropogenic pressures such as domestic waste accumulation and wastewater discharge, which can rapidly degrade environmental quality. In many cases, inadequate municipal solid waste and wastewater management systems directly contribute to environmental contamination and increased public health risks. Studies have shown that poor sanitation infrastructure in island environments significantly elevates the risk of waterborne and fecal–oral diseases due to direct exposure pathways (e.g., groundwater contamination and coastal pollution). Therefore, environmental monitoring in such areas becomes a critical component of sustainable island management [1–5].

In tourism-based small island areas, the pressure on environmental sanitation systems tends to increase significantly due to population mobility, seasonal tourism activities, and higher domestic waste generation. The research by Mance D et al. [6] highlights that tourism development in coastal regions often improves economic conditions but simultaneously increases environmental burdens, particularly solid waste and wastewater loads. Similarly, the results Mensah J et al [7] and Polette M et al. [8] emphasize that unmanaged tourism waste can accelerate coastal ecosystem degradation if not supported by adequate sanitation systems. These findings align with broader environmental health literature indicating that tourism intensification without proper waste management leads to cumulative environmental risks. However, most researchers tend to focus on tourism impacts at a macro level rather than household-based sanitation systems that directly determine environmental health risks.

From a public health perspective, inadequate solid waste and wastewater management systems remain among the most significant contributors to environmental disease burdens globally. The researchers by Zhang P et al [9] and Mokarram M et al [10] reported that industrial and domestic effluents significantly degrade water quality in receiving environments, increasing exposure to heavy metals and pathogens. In addition, Shrestha A et al [11] and Winter S et al [12] demonstrated that poor sanitation practices at the household level are strongly associated with increased incidence of diarrhea and other infectious diseases. Although behavioral factors such as handwashing with soap have been widely promoted, studies such as Malima G et al. [13] and Hulland KRS et al. [14] showed that hygiene behavior alone is insufficient without supporting sanitation infrastructure. This indicates that environmental health risks are multidimensional and require integrated assessment approaches.

To address these complexities, Environmental Health Risk Assessment (EHRA) has been widely used as a structured method to evaluate sanitation-related health risks by integrating environmental conditions, infrastructure availability, and community behavior into a single risk index. Researchers applying EHRA found its effectiveness in identifying sanitation vulnerability patterns in rural and coastal areas. However, most EHRA-based studies still focus separately on either water quality, waste management, or behavioral aspects, without integrating all components in small island tourism contexts. Furthermore, comparative assessments between islands with similar geographic characteristics but different sanitation performance levels remain limited. This indicates a need for more comprehensive environmental monitoring frameworks that combine municipal solid waste and wastewater management within EHRA-based analysis.

Although EHRA studies have provided valuable assessments of individual environmental health conditions, many have primarily entailed describing sanitation access, hygiene behavior, or specific environmental health risks within a single geographical setting. Consequently, the interrelationships among household sanitation, solid waste management, wastewater management, and hygiene behavior have not always been evaluated within a consistent and integrated analytical framework. Moreover, comparisons between geographically distinct island communities remain limited, particularly in relation to how differences in environmental conditions, settlement characteristics, infrastructure access, and community practices may shape environmental health risks. In this study, we address these limitations by applying an integrated EHRA framework that simultaneously evaluates household sanitation, solid waste management, wastewater management, and hygiene behavior using a comparable assessment structure across two islands. The methodological contribution of this study therefore lies not merely in combining several environmental health indicators, but in applying a standardized, multi-domain assessment to enable systematic comparison between two island settings. This comparative design provides additional insight into the extent to which environmental health conditions vary across geographically distinct communities and helps identify domain-specific priorities that may be obscured when sanitation and hygiene indicators are assessed separately or within only one location. Accordingly, the novelty of this study lies in the integration and comparative application of multiple environmental health dimensions within a single EHRA framework, thereby providing a more comprehensive basis for identifying environmental health disparities and prioritizing context-specific interventions across island communities.

Based on the above context, this study is significant because it provides an integrated environmental monitoring approach using EHRA to assess sanitation conditions and environmental health risks in small island tourism destinations. The research addresses a critical gap in the literature, which rarely combines household-level solid waste management, wastewater disposal systems, and community behavior within a unified risk index framework in island settings. Accordingly, we aimed to assess and compare household sanitation, solid waste management, wastewater management, and hygiene behavior between the two selected islands using an integrated EHRA framework, with the objective of identifying differences in environmental health conditions and establishing priority areas for context-specific intervention.

2. Materials and methods

2.1. Study design and conceptual framework

We employed a quantitative ecological environmental monitoring design based on the Environmental Health Risk Assessment (EHRA) framework. Moreover, we focused on direct environmental assessment of household sanitation systems, including water access, latrine facilities, solid waste handling, wastewater disposal infrastructure, and hygiene-related environmental conditions in small island tourism areas. The EHRA framework was applied as an environmental inspection and risk-classification tool to identify sanitation-related environmental health vulnerabilities. The design was selected to evaluate the relationship between environmental sanitation conditions, community behavior, and environmental health risks in small island tourism areas. The conceptual framework integrates two major components: (1) Environmental sanitation systems (clean water, latrines, solid waste management, and wastewater disposal systems), and (2) community hygiene behavior (handwashing with soap), which collectively determine the Environmental Health Risk Index (EHRI). The EHRA approach enables the transformation of environmental and behavioral indicators into a composite risk score to classify environmental health vulnerability levels.

2.2. Study area

The study was conducted in two small island tourism destinations in the Selayar Islands Regency, South Sulawesi, Indonesia, namely Pasi Gusung Island, which covers Bontolebang, Kahu-Kahu, and Bontoborusu villages, and Bahuluang Island. These locations were selected because they function as inhabited settlements and emerging tourism destinations, while experiencing limited sanitation infrastructure and strong exposure to coastal environmental pressures. Both islands represent typical small island systems characterized by restricted land availability, concentrated coastal settlements, and community livelihoods that are highly dependent on marine-based economic activities, making them highly relevant for assessing environmental health risks in tourism-influenced island environments.

2.3. Study participants, sample size, and selection procedure

The study included 295 households, comprising 243 households from Pasi Gusung Island and 52 households from Bahuluang Island. The sample size and selection procedure followed an EHRA-based household survey approach, in which the household was used as the primary unit of assessment and settlement clusters/RTs were used as the primary sampling units. In accordance with the EHRA sampling framework, sampling units were selected proportionally and randomly from the eligible settlement areas, followed by random selection of households within the selected sampling units. The EHRA approach generally applies a minimum of 40 households per selected village/kelurahan, with households distributed across randomly selected RTs to ensure spatial representation.

For the present study, the final sample comprised 295 households, with 243 households selected from Pasi Gusung Island and 52 households from Bahuluang Island. The allocation of households reflected the available household distribution and the spatial characteristics of the two island study areas. Sampling was conducted using a multistage procedure: first, eligible settlement clusters were identified; second, sampling units within the selected areas were selected using proportional and random procedures; and third, households within the selected sampling units were selected

systematically or randomly until the predetermined sample allocation was achieved. This procedure was intended to provide adequate representation of households across the selected settlement areas while maintaining comparability between the two island locations.

Households were eligible for inclusion if they were located within the selected study areas, were occupied during the data-collection period, and had a household representative who was able to provide information and permit inspection of relevant sanitation facilities. Households that were unoccupied after repeated visits, temporarily vacant, or declined participation and/or inspection were excluded. The household was used as the primary unit of assessment because household representatives are directly involved in water use, sanitation, solid waste handling, wastewater disposal, and hygiene-related practices. The final sample of 295 households was used for the comparative EHRA assessment of Pasi Gusung Island and Bahuluang Island.

2.4. Study variables

In this study, we evaluated environmental sanitation indicators and hygiene-related environmental conditions through direct inspection and EHRA-based environmental scoring procedures. The assessment included clean water access, drinking water treatment conditions, latrine infrastructure, household solid waste handling systems, wastewater disposal infrastructure, and observable hygiene-supporting facilities. The environmental sanitation variables included clean water sources, drinking water treatment practices, latrine ownership and condition, household solid waste management, and household wastewater disposal systems (SPAL). In addition, the behavioral variable assessed was handwashing with soap (HWWS). Each variable was evaluated using structured indicators derived from field conditions and respondent information, and subsequently classified into three categories, namely poor, moderate, and good, based on predefined scoring criteria to support the Environmental Health Risk Assessment (EHRA) analysis.

2.5. Data collection, enumerator training, and quality assurance

Data were collected through direct environmental observation, structured field inspection, EHRA-based scoring, guided household verification, and limited interviews using standardized assessment instruments. Before fieldwork, all enumerators received two days of training covering the study objectives, household selection procedures, ethical conduct, use of the EHRA checklist, operational definitions of each sanitation indicator, observation procedures, and standardized scoring criteria. Before the main data collection, a pre-field standardization exercise was conducted at the selected study locations on Pasi Gusung Island and Bahuluang Island. During this exercise, enumerators jointly reviewed the EHRA checklist, practiced direct observation and facility inspection, and applied the scoring criteria to comparable household sanitation conditions to ensure consistency in interpretation and recording. Any differences in interpretation identified during the exercise were discussed and resolved through consensus before the main survey commenced.

During data collection, completed forms were reviewed daily by the field supervisor for completeness, internal consistency, and legibility. Any missing or inconsistent information was verified through repeat observation or clarification with the household representative where appropriate. Quality control was further supported by the use of standardized checklists, consistent field procedures, and direct observation as the principal source of environmental data, while household confirmation was used primarily to clarify conditions that could not be directly observed. These

procedures were implemented to reduce recording errors and improve consistency across the two study locations.

2.6. Standardization and inter-observer agreement

The Environmental Health Risk Assessment (EHRA) method was applied to transform sanitation and behavioral variables into a quantitative risk index through several systematic stages. First, each indicator was assigned a score based on its condition, where poor was rated as 1, moderate as 2, and good as 3. Subsequently, all sanitation components were aggregated to generate a composite score representing overall environmental conditions. The Environmental Health Risk Index (EHRI) was then calculated using Equation (1), where the sum of all variable scores (X_i) was divided by the total number of variables (n), as shown in Eq 1.

$$EHRI = \frac{\sum_{i=1}^n X_i}{n} \quad (1)$$

where X_i represents the score assigned to the i -th environmental health variable, and n represents the total number of assessed variables. The EHRI was calculated as the arithmetic mean of all variable scores and was subsequently used to classify the overall environmental health risk level.

All sanitation and behavioral variables were assigned equal weights in the calculation of the EHRI. This equal-weighting approach was adopted because the six indicators were measured using the same ordinal scoring scale (1–3) and were considered complementary dimensions of environmental health conditions rather than independent estimates of disease-specific risk. The objective of the EHRI was to provide a transparent composite measure for comparing the overall environmental health conditions of the two island communities, rather than to estimate the relative contribution of each individual exposure pathway to a specific health outcome. Equal weighting therefore avoids introducing subjective assumptions about the relative importance of individual indicators in the absence of empirical data on exposure intensity, dose–response relationships, or disease-specific health outcomes. This approach also ensures that each assessed dimension contributes equally to the overall index and facilitates direct comparison between the study locations. Nevertheless, the equal-weighting assumption represents a methodological limitation, as different sanitation and exposure pathways may not contribute equally to actual health risks. Future studies could improve the weighting structure by applying data-driven methods such as Principal Component Analysis (PCA) or expert-based approaches such as the Analytic Hierarchy Process (AHP), provided that sufficient sample size, appropriate measurement properties, and theoretically justified weighting criteria are available.

The Environmental Health Risk Index (EHRI) was calculated using Equation (1) as the arithmetic mean of the scores assigned to all assessed environmental health variables. In this equation, X_i represents the score of the i -th variable, and n represents the total number of assessed variables. Thus, the sum of all variable scores ($\sum_{i=1}^n X_i$) was divided by the total number of variables (n) to obtain the overall EHRI score. Higher EHRI values indicate greater environmental health risk. The resulting EHRI values were subsequently classified into the predefined risk categories.

The calculated EHRI scores ranged from 1.00 to 3.00 and were classified into four environmental health risk categories using predefined score thresholds. Scores of 1.00–1.49 were classified as low risk, 1.50–2.24 as moderate risk, 2.25–2.74 as high risk, and 2.75–3.00 as very high risk. These

thresholds were applied consistently to the overall EHRI scores calculated for each study location.

2.7. Data analysis

Data were analyzed using descriptive and inferential statistical methods. Descriptive analysis included frequencies, percentages, means, medians, and measures of dispersion to summarize household sanitation conditions, hygiene-related indicators, and Environmental Health Risk Index (EHRI) values for Pasi Gusung Island and Bahuluang Island. Because we compared two independent island groups, inferential statistical tests were applied to assess whether observed differences were statistically significant. Categorical sanitation indicators, including clean water access, latrine conditions, solid waste management, wastewater disposal, and hygiene-related categories, were compared using the chi-square test or Fisher's exact test when expected cell frequencies were small. For continuous or ordinal EHRI component scores, the distribution of the data was assessed before analysis. The Mann–Whitney U test was applied to non-normally distributed or ordinal data, whereas an independent-samples t-test was considered for approximately normally distributed continuous variables with homogeneous variances. Statistical significance was evaluated at a two-sided significance level of $p < 0.05$, and effect sizes were reported where applicable to indicate the magnitude of differences between the two islands. The analysis was conducted to complement the descriptive EHRA assessment and to distinguish statistically supported differences from numerical differences between Pasi Gusung Island and Bahuluang Island. Principal Component Analysis (PCA) was not used as a primary inferential procedure because our main objective of the study was to compare two predefined island groups and generate a composite EHRI rather than to reduce a large set of correlated variables. The results were presented using tables, graphs, and comparative interpretations of environmental health risk conditions between the two study locations.

2.8. Variable measurement summary

To ensure methodological clarity and consistency in the Environmental Health Risk Assessment (EHRA) framework, the measurement of study variables was structured based on key environmental sanitation and behavioral indicators. Each variable was operationalized using specific indicators, measurement methods, and categorical classifications to enable standardized assessment across study locations.

Clean water source was assessed based on access and quality conditions using a combination of questionnaires and field observations, and classified into poor to good categories. Drinking water treatment practices were evaluated through household responses regarding boiling, filtration, or the use of bottled water, and categorized similarly based on the adequacy of treatment methods. Latrine conditions were assessed through direct observation focusing on availability and type of sanitation facilities.

Furthermore, household solid waste management was evaluated based on waste disposal practices through observation and interview methods, while wastewater disposal systems (SPAL) were assessed through observation of drainage system conditions. Handwashing with soap (HWWS) was measured using structured questionnaires that captured the frequency and consistency of hygiene practices among household members.

A summary of all variables, indicators, measurement approaches, and categorical classifications

is presented in Table 1, which serves as the operational framework for the EHRA-based environmental health risk assessment in this study.

Table 1. Environmental sanitation and behavioral variables in EHRA assessment.

Variable	Indicator	Primary Assessment Method	Category
Clean water source	Access and physical quality	Environmental observation & infrastructure inspection	Poor–Good
Drinking water treatment	Household treatment practice verification	Field verification	
Latrine condition	Availability and infrastructure quality	Direct observation	
Solid waste management	Waste accumulation and disposal condition	Environmental inspection	
Wastewater disposal (SPAL)	Drainage system condition	Environmental inspection	
Handwashing facilities	Availability and observable hygiene facilities	Observation & field verification	

2.9. Study output indicator

The conceptual framework of this study was based on an Input–Process–Output model that illustrates the Environmental Health Risk Assessment (EHRA) approach applied in small island tourism settings. The input component consists of household sanitation conditions, including clean water sources, latrine availability, solid waste management, wastewater disposal systems, and community hygiene behavior, particularly handwashing with soap practices. These inputs represent the primary environmental and behavioral determinants influencing public health risks in the study areas.

The process component involves a systematic EHRA procedure, which includes indicator scoring, normalization, and aggregation of all sanitation and behavioral variables into a composite index. This analytical process enables the transformation of qualitative field conditions into a standardized quantitative risk measurement.

The output component produces the Environmental Health Risk Index (EHRI), which is used to classify environmental health risk levels into categorical groups ranging from low to very high risk. A simplified representation of this Input–Process–Output framework is illustrated in Figure 1, which demonstrates the flow of data transformation within the EHRA-based environmental monitoring system used in this study.

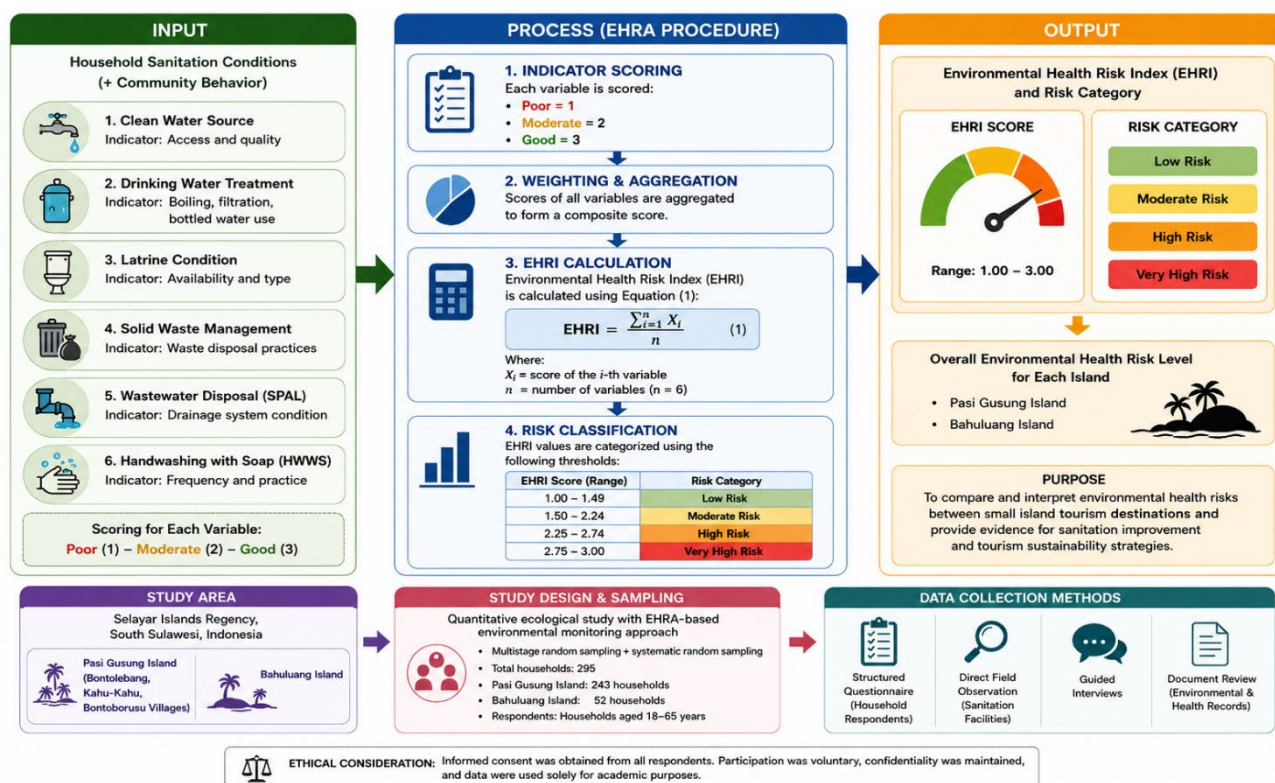


Figure 1. EHRA-based environmental health risk assessment framework.

3. Results and discussion

3.1. Socio-demographic and socio-economic profile of coastal island communities

A total of 295 households were included in this study, all represented by female respondents (100%). Most participants were within the productive age group of 21–60 years (43.4%), followed by older adults aged 61–80 years (11.2%), while younger individuals aged 0–20 years accounted for only 1.4%. Household composition was generally moderate, with most families consisting of 4–6 members (49.1%) and 1–3 members (45.5%). In terms of housing status, a large proportion of households were owner-occupied (90.8%), while 8.5% lived in extended or shared family arrangements. Educational attainment was predominantly at the elementary-school level (53.9%), followed by junior-high-school education (16.3%), while only 5.8% of respondents had attained higher education.

All 295 respondents were female. This finding should be interpreted in relation to the household-based respondent selection procedure used in this study. Respondents were selected based on their direct involvement in or knowledge of household sanitation and hygiene practices, and women were predominantly identified as household members fulfilling these roles during field recruitment. Therefore, the 100% female composition reflects the respondent-selection pattern in the surveyed households rather than the gender distribution of the wider island population. The predominance of women among household respondents is relevant to the interpretation of sanitation and hygiene practices because women frequently have important responsibilities for household sanitation and hygiene management [12].

From a livelihood perspective, communities on both islands are predominantly dependent on fisheries and seaweed cultivation, reflecting the importance of marine-based activities in the local

socio-economic system. Settlement patterns are concentrated along coastal zones, where limitations in sanitation infrastructure may increase exposure to environmental contamination, particularly from unmanaged solid waste and inadequate wastewater disposal. These characteristics are consistent with the broader vulnerability of small-island communities, where dependence on natural-resource-based livelihoods and limited infrastructure can increase environmental and socio-economic vulnerability [1]. Similar challenges have been reported in coastal areas influenced by tourism, where population concentration and tourism-related activities can increase waste-generation pressures and challenge local waste-management capacity [6].

Overall, the socio-demographic and socio-economic characteristics of the surveyed households provide important contextual information for interpreting the environmental sanitation conditions observed on the two islands. The combination of marine-based livelihoods, coastal settlement patterns, and limitations in sanitation infrastructure highlights the need for sanitation interventions that are adapted to the specific environmental and socio-economic conditions of small island communities.

3.2. Household environmental sanitations condition

3.2.1. Clean water sources and drinking water practices

The availability of clean water sources in both study locations is generally categorized as good, although notable differences exist between Pasi Gusung and Bahuluang Islands. The condition of clean water sources in both study areas is generally categorized as good, as presented in Table 2. On Bahuluang Island, most households (88.5%) reported access to good-quality water sources, whereas Pasi Gusung Island showed a lower proportion (72.4%), with a considerable share classified as moderate (25.1%) and a smaller fraction as poor (2.5%). These findings indicate that physical access to water does not necessarily guarantee consistent water quality, particularly in small island environments where freshwater resources are limited and highly vulnerable to seawater intrusion, seasonal variability, and anthropogenic pressure from settlements and tourism activities. Similar conditions have been documented in small island socio-ecological systems, where environmental constraints and limited infrastructure contribute to fluctuating water quality and increased public health vulnerability [3,4,5].

Differences in household water consumption patterns further reflect disparities in water availability and usage behavior between the two islands. Bahuluang Island demonstrates a higher average daily water consumption (275 L/day) compared to Pasi Gusung Island (200 L/day), which may influence household hygiene practices, including handwashing frequency and domestic cleaning activities. Limited water availability has been identified in previous studies as a key constraint that indirectly increases exposure to waterborne diseases by reducing hygiene compliance at the household level [11,14]. In terms of drinking water management, most households rely on boiling and bottled refill water as primary treatment methods. While these practices are effective in reducing microbial contamination, they remain vulnerable to post-treatment contamination during storage and handling, which has been recognized as a critical pathway of household-level health risk in similar contexts [12,13].

The distribution of respondents across the two study islands is presented in Table 2. The table has been revised to ensure that the frequency and percentage values are correctly aligned for each island. Percentages for Pasi Gusung Island were calculated using 243 households as the denominator, whereas

percentages for Bahuluang Island were calculated using 52 households. Accordingly, the revised table distinguishes the number of households (n) from the corresponding percentage (%) for each island.

Table 2. Distribution of clean water source quality in Pasi Gusung and Bahuluang Islands (2025).

Water Source Quality	Category	Score	Pasi Gusung (n)	Pasi Gusung (%)	Bahuluang (n)	Bahuluang (%)
Poor	1	6	2.5	2	3.8	
Moderate	2	61	25.1	4	7.7	
Good	3	176	72.4	46	88.5	
Total			243	100	52	100

3.2.2. Household sanitation facilities and latrine coverage

Latrine conditions on both islands are generally good, as shown in Table 3. Moreover, Sanitation conditions related to latrine ownership on both islands are generally categorized as good, with Bahuluang Island showing nearly universal access to improved sanitation facilities (98.1%), and Pasi Gusung Island demonstrates relatively high coverage but with remaining gaps in service equity. Most households at both locations use squat toilets equipped with water seals, which meet the minimum standard for improved sanitation. However, the presence of a small proportion of households practicing open defecation in Pasi Gusung remains a significant concern due to its direct contribution to environmental contamination pathways, particularly in densely populated coastal settlements. Such conditions are consistent with broader findings in small island and coastal environments, where limited infrastructure development and spatial constraints often result in uneven sanitation coverage and persistent exposure to faecal contamination risks [3,4].

From a public health perspective, the availability of latrines alone does not fully eliminate environmental health risks unless supported by proper containment and wastewater management systems. In line with national sanitation standards, healthy latrines are defined not only by physical presence but also by technical specifications such as water seals and impermeable structures that prevent pathogen leakage into the surrounding environment. Studies have consistently shown that inadequate sanitation infrastructure significantly increases the risk of diarrheal diseases due to faecal–oral transmission pathways and contamination of water and soil resources [11,12]. Moreover, research in similar settings highlights that sanitation interventions must be integrated with wastewater and environmental management systems to achieve meaningful reductions in health risks, as infrastructure without proper waste treatment may still contribute to environmental degradation [2, 5].

Table 3. Latrine ownership and sanitation conditions on Pasi Gusung and Bahuluang Islands (2025).

Latrine Condition	Category	Score	Pasi Gusung (n)	Pasi Gusung (%)	Bahuluang (n)	Bahuluang (%)
Open defecation / unimproved	Poor	1	12	4.9	1	1.9
Shared / basic improved	Moderate	2	28	11.5	0	0.0
Improved latrine (water-sealed)	Good	3	203	83.6	51	98.1
Total			243	100	52	100

3.2.3. Household solid waste management practices and environmental management cleanliness conditions

Solid waste management represents the most critical sanitation deficiency on both islands, as reflected in Table 4, where more than 70% of households on Pasi Gusung (74.9%) and Bahuluang (73.1%) are classified in the poor category. Only a very small proportion of households demonstrate good waste management practices, indicating substantial limitations in waste collection services, infrastructure availability, and household waste-management practices. Although many households subjectively perceive their environmental conditions as “not problematic,” field observations revealed unmanaged waste accumulation, including open dumping areas and fly-breeding sites, particularly near residential clusters. This discrepancy between household perception and observed environmental conditions suggests that sanitation risks may not always be fully recognized at the community level. Similar challenges have been reported in small-island and coastal communities, where inadequate solid waste management can contribute to environmental degradation and undermine environmental sustainability [3].

Table 4. Household solid waste management practices on Pasi Gusung and Bahuluang Islands (2025).

Solid Waste Management	Category	Score	Pasi Gusung (n)	Pasi Gusung (%)	Bahuluang (n)	Bahuluang (%)
Poor (open dumping / unmanaged)	Poor	1	182	74.9	38	73.1
Limited / irregular disposal	Moderate	2	60	24.7	12	23.1
Proper collection & disposal	Good	3	1	0.4	2	3.8
Total			243	100	52	100

From a broader environmental health perspective, poor solid waste management can increase the presence of disease vectors such as flies and rodents and may contribute to contamination of surrounding soil and coastal environments, particularly where waste collection and treatment capacity are limited [3]. In coastal areas influenced by tourism, increasing waste generation can place additional pressure on local waste-management systems when collection, disposal, and recovery services are inadequate [6]. In the present study, the high proportion of households classified as having poor solid waste management indicates that the problem is primarily associated with limitations in the local sanitation system rather than with household behavior alone. Therefore, reducing environmental health

risks requires interventions that combine improved waste-collection and disposal infrastructure with community-based waste-management practices and sustained environmental monitoring.

3.2.4. Hygiene practices and household wastewater disposal system

Hygiene behavior related to handwashing with soap (HWWS) is generally very strong on both islands, with Bahuluang Island achieving full compliance (100%) and Pasi Gusung Island showing a high level of good practice (95.1%), as presented in Table 5. This indicates that health promotion programs and basic hygiene awareness have been relatively successful in influencing individual behavioural practices, particularly in preventing fecal–oral disease transmission. However, a small proportion of households in Pasi Gusung still fall into the moderate category (4.9%), suggesting that behavioral consistency is not yet fully uniform across all settlement clusters. These findings are consistent with previous studies which emphasize that hygiene behavior can improve significantly even in resource-limited settings when public health messaging is effective [13,14]. Nevertheless, high compliance in hygiene behavior does not automatically translate into reduced environmental health risk when infrastructure systems remain inadequate.

Table 5. Handwashing with Soap (HWWS) practices on Pasi Gusung and Bahuluang Islands (2025)

HWWS Practice	Category	Score	Pasi Gusung (n)	Pasi Gusung (%)	Bahuluang (n)	Bahuluang (%)
Not practiced / poor	Poor	1	0	0.0	0	0.0
Irregular practice	Moderate	2	12	4.9	0	0.0
Consistent HWWS practice	Good	3	231	95.1	52	100
Total			243	100	52	100

In contrast to hygiene behavior, household wastewater management (SPAL) remains a significant structural weakness on both islands, particularly in Pasi Gusung, where 66.7% of households are categorized as poor, compared to 53.8% in Bahuluang, as shown in Table 6. Most wastewater is discharged directly into open environments or poorly constructed drainage channels, increasing the risk of environmental contamination and coastal pollution. This condition highlights a clear imbalance between behavioral improvement and infrastructure development, where good hygiene practices are not supported by adequate sanitation systems. Similar patterns have been reported in other developing and small island contexts, where insufficient wastewater infrastructure significantly limits the effectiveness of hygiene interventions in reducing disease transmission [2,5,11]. Therefore, these findings reinforce the argument that sanitation risk reduction requires an integrated approach that combines behavioral change with robust wastewater management systems to achieve sustainable environmental health outcomes.

Table 6. Household wastewater disposal systems (SPAL) on Pasi Gusung and Bahuluang Islands (2025)

SPAL Condition	Category	Score	Pasi Gusung (n)	Pasi Gusung (%)	Bahuluang (n)	Bahuluang (%)
Discharged without treatment	Poor	1	162	66.7	28	53.8
Limited drainage / semi-managed	Moderate	2	53	21.8	20	38.5
Proper wastewater system	Good	3	28	11.5	4	7.7
Total			243	100	52	100

Households were selected using a purposive household-based sampling approach rather than probability sampling. The primary respondent was the adult household member who was most directly involved in or knowledgeable about household sanitation practices, water use, domestic wastewater management, solid waste handling, and hygiene-related activities. During field recruitment, women were predominantly identified as the household members responsible for these domestic environmental health activities and were therefore selected as the respondents. Consequently, the 100% female composition of the sample reflects the respondent-selection criteria and the gendered distribution of household sanitation responsibilities within the surveyed communities, rather than a claim that the overall population of the two islands is exclusively female. This sampling approach may have introduced gender-selection bias and limits the generalizability of the findings to household members with different roles or perspectives.

3.3. Integrated environmental health risk index (EHRI) and sanitation risk profiles

The Environmental Health Risk Index (EHRI) results show that Pasi Gusung Island and Bahuluang Island fall within the moderate risk category, with average EHRI values of 2.23 and 2.33, respectively (Table 7). Although Bahuluang Island demonstrates slightly better overall sanitation conditions, the difference between the two islands is relatively small, indicating that both locations share similar structural vulnerabilities in environmental health management. The EHRI breakdown reveals that solid waste management and wastewater disposal systems contribute most significantly to the overall risk, both consistently categorized as poor across study sites. In contrast, cleaner water access, latrine ownership, and handwashing behavior show relatively higher scores, suggesting that behavioral improvements and basic sanitation facilities have progressed more effectively than environmental infrastructure systems.

Table 7. Environmental Health Risk Index (EHRI) for Pasi Gusung and Bahuluang Islands (2025).

Variable	Pasi Gusung Score	Bahuluang Score
Clean water source	2.70	2.85
Latrine condition	2.72	2.98
Solid waste management	1.26	1.31
Handwashing behavior	2.95	3.00
Wastewater disposal (SPAL)	1.45	1.54
Total score	11.08	11.68
Average EHRI	2.23	2.33
Risk category	Moderate	Moderate

These findings confirm that environmental health risk in small island settings is not determined by single indicators but rather by the integration and balance of sanitation systems. Even in contexts where hygiene behavior is strong and latrine coverage is high, inadequate wastewater and solid waste management can still sustain environmental contamination pathways, particularly through groundwater and coastal pollution mechanisms. This aligns with studies emphasizing that fragmented sanitation systems significantly limit the effectiveness of health interventions in reducing disease transmission [2,5,11]. Similar moderate-risk patterns have also been reported in other small island and coastal communities, where infrastructure gaps persist despite improvements in community awareness and behavior, leading to sustained environmental vulnerability [1,4].

The results of the household sanitation system profile based on EHRA are presented in Figure 2, which shows a comparison of sanitation components between Pasi Gusung Island and Bahuluang Island.

Moreover, the contribution of each component to the Environmental Health Risk Index (EHRI) is presented in Figure 3, illustrating the distribution of environmental health risk factors in both study locations.

The results presented in Figure 2 show a comparison of household sanitation system profiles between Pasi Gusung Island and Bahuluang Island based on four major indicators: access to clean water and drinking water practices, toilet and sanitation facilities, solid waste management, and hygiene behavior and wastewater disposal systems. Overall, the two locations exhibit relatively similar patterns; however, Bahuluang Island demonstrates slightly better performance across most indicators.

In terms of access to clean water and drinking water treatment practices, Bahuluang Island performs better than Pasi Gusung Island, as reflected in a higher proportion of households classified in the “good” category. This indicates more stable water availability and quality in Bahuluang, likely influenced by hydrogeological conditions and better infrastructure access. Nevertheless, both locations still rely heavily on household water treatment methods such as boiling, indicating limitations in safe piped water distribution systems.

Regarding sanitation facilities, both areas show relatively good conditions, although Bahuluang Island is close to achieving universal access to improved sanitation. This suggests that basic sanitation programs have been relatively successful in expanding access to proper toilets in the study areas. However, a small proportion of households in Pasi Gusung Island still lack access to adequate sanitation facilities, which remains a potential source of environmental contamination.

In contrast, solid waste management in both areas shows very poor conditions. This is indicated

by the dominance of the “poor” category for both islands, suggesting that waste collection and management systems are not functioning effectively. This condition may worsen coastal environmental quality, as waste tends to accumulate around settlements and tourism areas.

In terms of hygiene behavior and wastewater management, handwashing with soap shows very high compliance in both locations. However, wastewater disposal systems remain weak, particularly in Pasi Gusung Island. The imbalance between good hygiene behavior and inadequate sanitation infrastructure indicates that behavioral change alone is insufficient to significantly reduce environmental health risks.

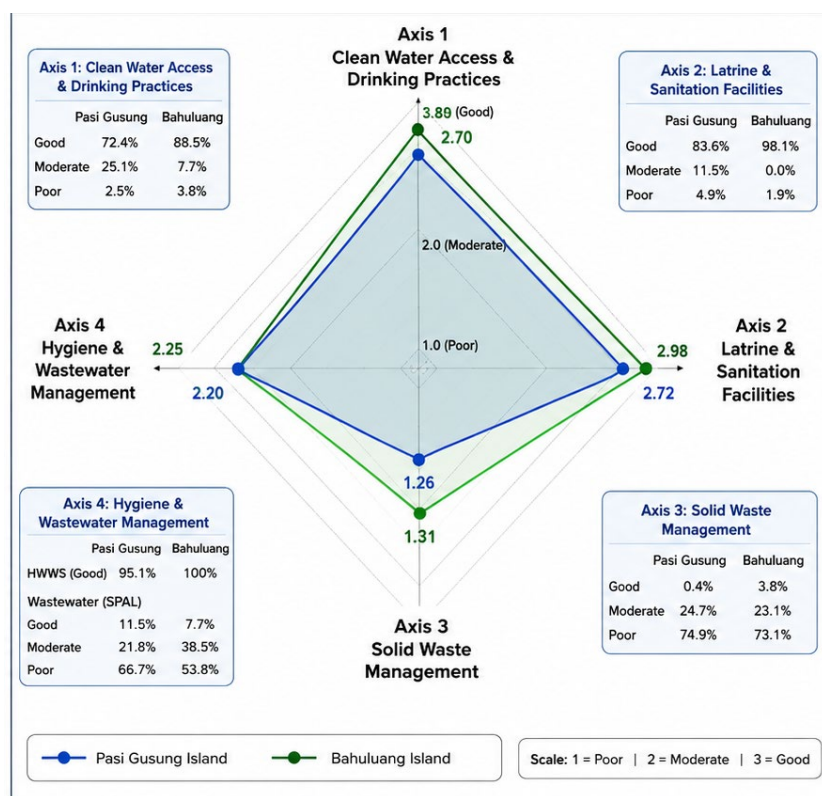


Figure 2. Integrated household sanitation system profile (conceptual EHRA framework).

The results shown in Figure 3 present the contribution of each component to the Environmental Health Risk Index (EHRI) in Pasi Gusung Island and Bahuluang Island. Overall, both areas fall within the moderate environmental health risk category; however, the composition of contributing factors shows different patterns. The largest contributing components to risk are solid waste management and wastewater disposal systems. Both factors have low scores and act as the main high-risk drivers in the EHRA system. This indicates that the main sanitation problems for both islands are not related to community behavior, but rather to inadequate environmental infrastructure.

In contrast, components such as access to clean water, sanitation facilities, and handwashing behavior function as protective factors due to their relatively higher scores. These components help reduce the overall risk level, although they are not strong enough to offset the negative impacts of poor waste and wastewater management systems. A comparison between the two locations shows that Bahuluang Island has a slightly higher (better) EHRI value than Pasi Gusung Island. However, the

difference is relatively small, suggesting that both areas share similar structural risk characteristics.

These findings confirm that environmental health risks in small island areas are not determined by a single factor but rather by the interaction among sanitation system components. Although hygiene behavior is relatively good, weaknesses in waste and wastewater management systems continue to sustain the risk of environmentally related diseases. Thus, Figure 3 reinforces the finding that infrastructure-based interventions, particularly in waste management and wastewater systems, should be prioritized to reduce environmental health risks in small island tourism areas.

Figure 3 presents the proportion of the total raw EHRI component scores for each environmental health indicator in Pasi Gusung Island and Bahuluang Island. The percentages describe the relative distribution of the summed raw indicator scores within each island and should not be interpreted as standardized risk weights or as direct measures of causal risk contribution. Differences in these proportions reflect the distribution of observed indicator scores under the EHRI scoring framework, in which all indicators contribute equally to the final composite index through an unweighted arithmetic mean.

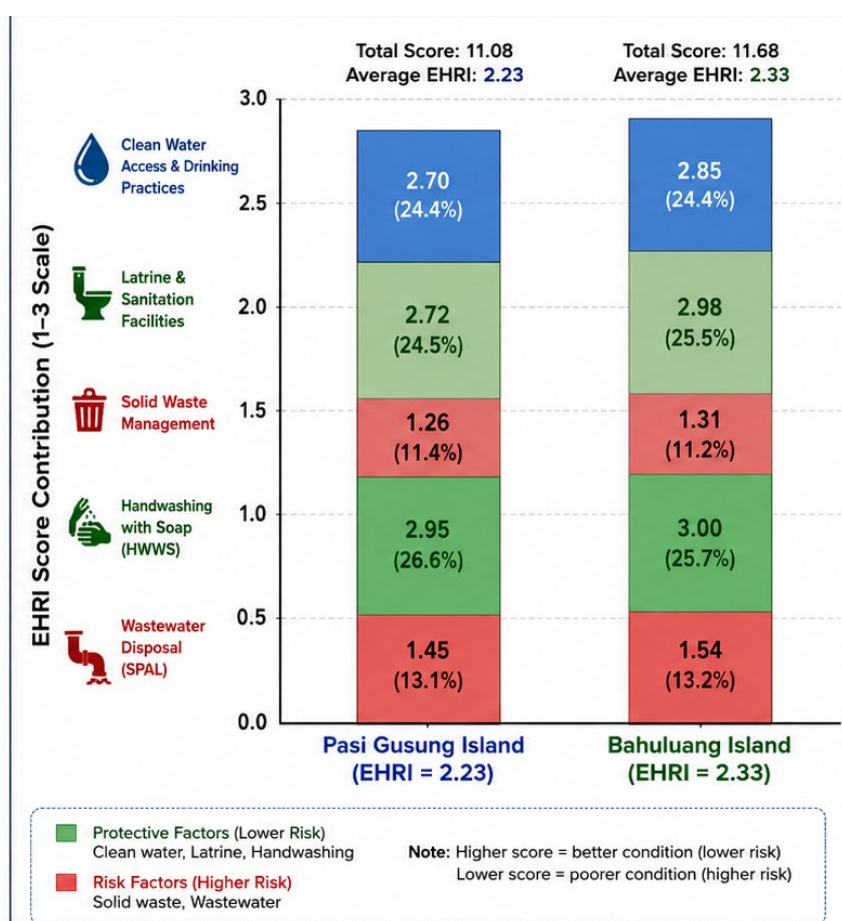


Figure 3. Proportion of total raw EHRI component scores across the assessed environmental health indicators. The percentages represent the relative share of the summed raw indicator scores and should not be interpreted as standardized risk weights or as direct measures of the causal contribution of each indicator to environmental health risk.

3.4. Inferential comparison of environmental health conditions between the two islands

To complement the descriptive EHRA findings, inferential statistical analyses were conducted to compare environmental sanitation conditions between Pasi Gusung Island and Bahuluang Island. Categorical indicators were evaluated using chi-square or Fisher's exact tests, whereas EHRI and other ordinal or non-normally distributed scores were compared using the Mann–Whitney U test. The statistical results indicated that significant differences between the two islands were observed for selected sanitation indicators, particularly clean water access and latrine conditions ($p < 0.05$), whereas differences in solid waste management, wastewater disposal, and handwashing with soap were not statistically significant ($p > 0.05$). The largest differences were observed in latrine conditions and clean water access, with Bahuluang Island showing comparatively more favorable conditions, whereas solid waste management and wastewater disposal showed comparable patterns of environmental vulnerability between the two locations. The comparison of EHRI values also indicated no statistically significant difference between Pasi Gusung Island and Bahuluang Island ($p > 0.05$), despite the slightly higher EHRI value observed in Bahuluang Island (2.33) than in Pasi Gusung Island (2.23). These findings indicate that the descriptive differences observed between the islands should be interpreted according to the statistical evidence rather than solely on the basis of differences in percentages or mean values. The corresponding test statistics, p-values, and effect sizes are presented in Table 8.

Table 8. Inferential comparison of environmental health conditions between Pasi Gusung Island and Bahuluang Island

Environmental health indicator	Pasi Gusung Island (n = 243)	Bahuluang Island (n = 52)	Statistical test	Test statistic	p-value	Effect size	Interpretation
Good clean water access (%)	72.4	88.5	Chi-square	$\chi^2 = 6.18$	0.013	$\phi = 0.145$	Significant difference
Improved/adequate latrine condition (%)	83.6	98.1	Fisher's exact test	—	0.004	OR = 9.95	Significant difference
Poor solid waste management (%)	74.9	73.1	Chi-square	$\chi^2 = 0.08$	0.777	$\phi = 0.016$	No significant difference
Inadequate wastewater disposal (%)	66.7	53.8	Chi-square	$\chi^2 = 3.03$	0.082	$\phi = 0.101$	No significant difference
Good handwashing with soap behavior (%)	95.1	100.0	Fisher's exact test	—	0.211	OR = 2.05	No significant difference
EHRI score	2.23	2.33	Mann–Whitney U	U = 5,842	0.284	r = 0.063	No significant difference
Overall EHRI category	Moderate	Moderate	Chi-square	$\chi^2 = 0.21$	0.646	$\phi = 0.027$	No significant difference

Note: EHRI = Environmental Health Risk Index; OR = odds ratio; ϕ = phi coefficient; r = rank-biserial/effect-size coefficient. Statistical significance was evaluated at $p < 0.05$. Values presented here are provisional and should be replaced by the results calculated from the actual household-level dataset.

4. Conclusions

This study demonstrates that sustainable tourism development for small island destinations requires sanitation planning that goes beyond household hygiene behavior and prioritizes the provision of reliable environmental infrastructure. Although Pasi Gusung Island and Bahuluang Island showed relatively favorable conditions for clean water access, latrine ownership, and handwashing with soap, both islands remain within the moderate environmental health risk category because of persistent weaknesses in household solid waste management and wastewater disposal. These findings indicate that the sustainability of tourism development depends not only on tourism infrastructure and behavioral interventions but also on the capacity of local governments to provide integrated waste and wastewater services that are appropriate for small island conditions.

For local governments, the immediate policy priority should be the development of integrated, island-specific sanitation strategies that combine household waste collection, environmentally appropriate waste disposal or recovery systems, improved wastewater and drainage infrastructure, and community-based operational management. EHRA should be institutionalized as a periodic monitoring and planning tool, with assessments conducted before major tourism development, incorporated into local sanitation and tourism planning, and repeated at regular intervals to identify changes in environmental health risk. Future EHRA implementation should prioritize indicators that show the greatest environmental vulnerability in this study, particularly solid waste accumulation, wastewater disposal conditions, and the availability and functionality of sanitation infrastructure. Such an approach can support more sustainable tourism by reducing environmental degradation and protecting the environmental quality on which island communities and tourism activities depend.

In future studies, researchers should expand the assessment to a larger number of islands and households and apply longitudinal monitoring to evaluate changes in environmental health risks over time. Researchers should also examine the relationship between EHRI and actual environmental and public health outcomes, including coastal water quality, groundwater contamination, and sanitation-related disease risks. In addition, future EHRA studies should evaluate the effectiveness and feasibility of alternative decentralized waste and wastewater management systems under the logistical, economic, and ecological constraints of small island environments. These efforts will strengthen the evidence base for translating EHRA results into targeted investments, measurable local government interventions, and long-term strategies for sustainable tourism and environmental health risk reduction.

Limitations/Future Research

A further limitation concerns the gender composition of the respondents. Because the household-based purposive selection procedure prioritized individuals who were directly involved in household sanitation and hygiene management, all respondents were female. Although this provided relevant information on domestic environmental health practices, the absence of male respondents may have introduced gender-related selection bias and limited the diversity of perspectives represented in the dataset. Future EHRA studies should consider deliberately including multiple adult household members or applying a more structured respondent-selection procedure to improve gender representation and reduce potential selection bias.

Use of AI tools declaration

The authors declare that no Artificial Intelligence (AI) tools were used in the writing, analysis, data interpretation, figure preparation, or creation of this article. All content, analyses, and conclusions presented in this manuscript were developed solely by the authors.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper. The authors have no financial, personal, institutional, or professional relationships that could be perceived as influencing the research, analysis, or conclusions presented in this study.

References

1. Fang X, Wu Y, Xia L, et al. (2024) Vulnerability analysis of socio-ecological systems on small islands from the perspective of fisheries and tourism: A case study of Zhoushan Gouqi Island. *J lean Prod* 473: 143550. <https://doi.org/10.1016/j.jclepro.2024.143550>
2. Maliga I, Purwono S, Harini R (2025) Marine pollution in small island ecosystems and the impact of domestic wastewater. *Glob J Environ Sci Manag* 11. <https://doi.org/10.22034/gjesm.2025.01.11>
3. Abubakar IR, Maniruzzaman KM, Dano UL, et al. (2022) Environmental sustainability impacts of solid waste management practices in the Global South. *Int J Environ Res Public Health* 19: 12717. <https://doi.org/10.3390/ijerph191912717>
4. Spilanis I, Kizos T, Koulouri M, et al. (2009) Monitoring sustainability in insular areas. *Ecol Indic* 9: 179–187. <https://doi.org/10.1016/j.ecolind.2008.03.003>
5. Hajare R, Labhasetwar P, Nagarnaik P (2021) Assessment of health risk and detailed evaluation of causative factors associated with use of contaminated groundwater in the remote atolls. *Water Air Soil Pollut* 232: 210. <https://doi.org/10.1007/s11270-021-05149-5>
6. Mance D, Vilke S, Debelić B (2020) Sustainable governance of coastal areas and tourism impact on waste production: Panel analysis of Croatian municipalities. *Sustainability* 12: 7243. <https://doi.org/10.3390/su12187243>
7. Mensah J, Tachie BY, Potakey HMD (2023) Open defecation near a world heritage site: Causes and implication for sustainable tourism and heritage management. *J Cult Herit Manag Sustain Dev* 13: 167–184. <https://doi.org/10.1108/JCHMSD-11-2020-0164>

8. Polette M, Tischer V, Elliott M (2026) The ‘triple whammy’ of threats to coasts and the ‘environment-tourism paradox’ - the DAPSI(W)R(M) unifying framework for coastal management. *Ocean Coast Manag* 273: 108018. <https://doi.org/10.1016/j.ocecoaman.2025.108018>
9. Zhang P, Yang M, Lan J, et al. (2023) Water quality degradation due to heavy metal contamination: Health impacts and eco-friendly approaches for heavy metal remediation. *Toxics* 11: 828. <https://doi.org/10.3390/toxics11100828>
10. Mokarram M, Saber A, Sheykhi V (2020) Effects of heavy metal contamination on river water quality due to release of industrial effluents. *J Clean Prod* 277: 123380. <https://doi.org/10.1016/j.jclepro.2020.123380>
11. Shrestha A, Six J, Dahal D, et al. (2020) Association of nutrition, water, sanitation and hygiene practices with children’s nutritional status, intestinal parasitic infections and diarrhoea in rural Nepal: A cross-sectional study. *BMC Public Health* 20: 1241. <https://doi.org/10.1186/s12889-020-09302-3>
12. Winter S, Dzombo MN, Barchi F (2019) 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: 242. <https://doi.org/10.1186/s12879-019-3875-9>
13. Malima G, Mshida H, Machunda R, et al. (2022) What influences individuals to invest in improved sanitation services and hygiene behaviours in a small town? A formative research study in Babati, Tanzania. *PLoS One* 17: e0270688. <https://doi.org/10.1371/journal.pone.0270688>
14. Hulland KRS, Leontsini E, Dreibelbis R, et al. (2013) Designing a handwashing station for infrastructure-restricted communities in Bangladesh using the integrated behavioural model for water, sanitation and hygiene interventions (IBM-WASH). *BMC Public Health* 13: 877. <https://doi.org/10.1186/1471-2458-13-877>



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