



Impact of Tidal Flooding on Sanitation Damage and Disease Patterns in Coastal Areas

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ABSTRACT

Tidal flooding (rob) has become a persistent environmental hazard in Indonesia's coastal regions, particularly in Pekalongan City, Central Java, leading to significant degradation of basic sanitation infrastructure and increased health risks. This study aims to analyze the impact of tidal flooding on sanitation facility damage and the shifting patterns of disease among coastal communities. A quantitative cross-sectional design was employed involving 120 households in flood-prone areas of North Pekalongan. Data were collected through structured interviews, direct observation, and secondary health records from local health centers. Variables included sanitation condition, water quality, and incidence of waterborne and environmentally related diseases. Statistical analysis using chi-square and logistic regression revealed a significant relationship between sanitation damage and increased incidence of diarrhea, skin diseases, and acute respiratory infections ($p < 0.05$). Households with damaged sanitation facilities had a 2.8 times higher risk of experiencing diarrhea (OR = 2.8; 95% CI: 1.4–5.6). Approximately 65% of sanitation facilities were found to be damaged or non-functional during flooding periods, leading to contamination of clean water sources. These findings highlight the urgent need for climate-resilient sanitation systems, including flood-adaptive septic tank designs and improved wastewater management in coastal settlements. The study concludes that tidal flooding significantly contributes to sanitation degradation and alters disease patterns in coastal populations.

Keywords: *Tidal Flooding, Sanitation Damage, Coastal Health, Disease Pattern*



INTRODUCTION

Tidal flooding (rob) has increasingly become a recurring phenomenon in Indonesia's coastal regions, driven by a combination of sea-level rise, land subsidence, and broader climate change dynamics. Pekalongan City is among the most severely affected areas, experiencing frequent and prolonged seawater inundation (BPS Kota Pekalongan, 2023). These conditions have led to substantial damage to essential infrastructure, particularly basic sanitation systems such as septic tanks, wastewater drainage networks, and sources of clean water.

At the global level, coastal flooding has been recognized as a major public health risk, especially in developing countries where sanitation systems remain inadequate (Nicholls & Cazenave, 2020). In Indonesia, the increasing frequency and severity of tidal flooding are further exacerbated by significant land subsidence along the northern coast of Java, which intensifies seawater intrusion and flooding events (Abidin et al., 2021). As a result, sanitation systems are placed under increasing pressure, heightening community vulnerability to health-related issues. Recent global assessments further emphasize that climate-induced coastal hazards significantly disrupt water and sanitation systems, increasing exposure to environmental pathogens and amplifying public health risks in low- and middle-income countries (Willetts et al., 2022; Cissé et al., 2019).

Damage to sanitation infrastructure caused by tidal flooding significantly elevates the risk of environmentally related diseases. Contaminated water, often mixed with domestic waste, serves as a transmission medium for pathogenic microorganisms responsible for diarrhea, skin infections, and respiratory illnesses (WHO, 2019). Previous research by Sugiharto et al. (2020) reported higher incidences of diarrhea in tidal flood-affected areas compared to unaffected regions. Similarly, other studies have demonstrated that flooding contributes to groundwater contamination, which directly impacts public health (Ministry of Health of Indonesia, 2023). Emerging evidence also indicates that extreme flooding events accelerate the spread of enteric pathogens and increase the burden of waterborne diseases due to the breakdown of sanitation barriers and contamination of drinking water sources (Levy et al., 2016; WHO, 2023).

Furthermore, recent studies indicate that disruptions to sanitation systems due to flooding are strongly associated with an increase in waterborne and environment-related diseases, particularly among vulnerable populations such as children and the elderly (Prüss-Ustün et al., 2019). Few et al. (2021) also highlighted that repeated flooding in coastal areas can alter disease patterns over time, including a rise in chronic diarrhea and skin conditions resulting from prolonged exposure to contaminated water. In addition, climate variability has been shown to influence the spatial and temporal distribution of infectious diseases, reinforcing the link between environmental change and epidemiological transitions in coastal settings (Carlton et al., 2016).

Despite these findings, most existing studies primarily examine isolated components, such as water quality or individual disease outcomes, without providing an integrated analysis of how sanitation infrastructure damage directly influences shifts in disease patterns. There remains limited empirical evidence that simultaneously links environmental exposure, sanitation system failure, and epidemiological transitions in coastal flood-prone settings. This lack of comprehensive analysis represents a critical research gap, particularly in highly vulnerable coastal regions such as Pekalongan. Therefore, this study aims to analyze the impact of tidal flooding on the deterioration of basic sanitation facilities and its implications for changing disease patterns in coastal communities. By combining environmental, infrastructural, and health-related variables, this study offers a more holistic understanding and contributes to the development of evidence-based, climate-adaptive sanitation policies in coastal regions.



In addition to physical infrastructure damage, tidal flooding also poses long-term socio-economic and public health challenges for coastal communities. Limited access to safe water and proper sanitation services during and after flooding events often forces households to rely on unsafe water sources and inadequate hygiene practices. This situation not only increases immediate health risks but also contributes to the persistence of disease transmission cycles within the community. Moreover, the lack of adaptive infrastructure and early warning systems further exacerbates community vulnerability, particularly in densely populated coastal settlements. Strengthening climate-resilient sanitation systems and integrating public health adaptation strategies are therefore essential to reduce long-term vulnerability and improve community resilience in flood-prone coastal regions (Howard et al., 2020). Therefore, understanding the interaction between environmental hazards, sanitation conditions, and health outcomes is essential for designing effective mitigation strategies and strengthening community resilience in flood-prone coastal areas.

METHODS

This study employed a quantitative approach with a cross-sectional design to examine the association between sanitation facility damage caused by tidal flooding and the incidence of environment-related diseases. The research was conducted in North Pekalongan District, Pekalongan City, Central Java, Indonesia, an area characterized by a high frequency of tidal flooding events. The study population consisted of households located in flood-affected areas. A total of 120 respondents were selected using a purposive sampling technique based on the following inclusion criteria: (1) having resided in the tidal flood-prone area for at least three years, and (2) possessing household sanitation facilities, including septic systems, water sources, and wastewater disposal systems. Data were collected through structured interviews using a pre-tested questionnaire, direct observation of sanitation conditions, and secondary data from local primary healthcare centers (Puskesmas) regarding cases of diarrhea, skin diseases, and acute respiratory infections (ARI). The questionnaire was validated through expert judgment involving two public health specialists, and reliability testing yielded a Cronbach's alpha value of 0.82, indicating good internal consistency.

The independent variable, sanitation condition, was categorized as "adequate" when facilities functioned properly without contamination, and "damaged" when indicators such as septic overflow, contaminated water sources, or non-functional drainage were observed. The dependent variables included the incidence of diarrhea, skin diseases, and ARI reported within the past three months. Data analysis included descriptive statistics, chi-square tests to assess associations, and logistic regression to estimate odds ratios (OR) with 95% confidence intervals (CI). A p-value < 0.05 was considered statistically significant. All analyses were performed using IBM SPSS Statistics version 25. Potential biases, including recall bias and selection bias, were acknowledged. Measures to minimize bias included structured data collection, cross-verification with health records, and consistent sampling criteria. Ethical standards were upheld through informed consent and data confidentiality.

RESULTS

1. Damage to Basic Sanitation Facilities Due to Tidal Flooding

The findings demonstrate that tidal flooding exerts a substantial and measurable impact on household sanitation systems in coastal areas. Of the 120 surveyed households, 78 (65%) experienced sanitation damage, indicating that the majority of affected communities operate under compromised environmental health conditions. The dominant forms of damage overflowing septic tanks (58%), contaminated shallow wells (52%), and dysfunctional drainage systems (47%) suggest systemic



failure in sanitation infrastructure under flood stress. Notably, more than half of respondents (52%) reported deterioration in water quality (e.g., turbidity and odor), reflecting direct contamination pathways between floodwater and domestic waste. This condition significantly increases the probability of pathogen transmission.

Table 1. Distribution of Household Sanitation Conditions

Sanitation Condition	Number (n)	Percentage (%)
Adequate	42	35%
Damaged	78	65%
Total	120	100%

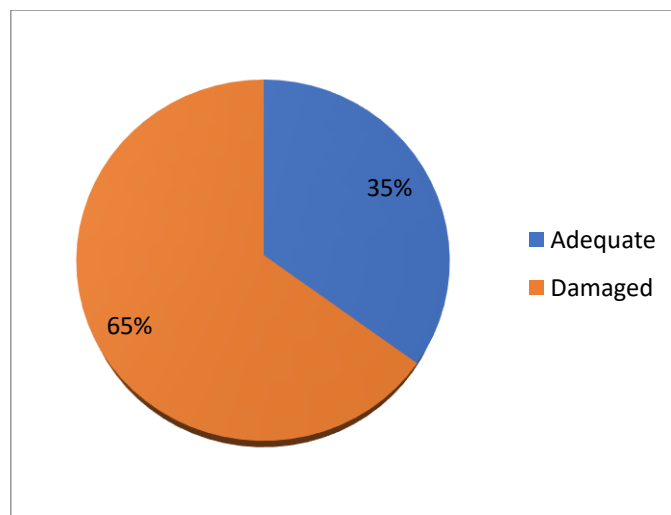


Figure 1. Distribution of Sanitation Conditions

These findings indicate that sanitation damage is not isolated but occurs as an interconnected system failure, amplifying environmental exposure risks.

a) Distribution of Environment-Related Diseases in Coastal Communities

The incidence of environment-related diseases was notably high among affected households, with diarrhea reported in 45% of respondents, followed by skin diseases (38%) and ARI (32%). Households with damaged sanitation facilities consistently showed higher disease prevalence, suggesting a strong environmental determinant. Recurrent infections, particularly skin diseases, further indicate prolonged exposure to contaminated floodwater.

Table 2. Distribution of Reported Diseases

Disease Type	Number of Cases (n)	Percentage (%)
Diarrhea	54	45%
Skin Diseases	46	38%
ARI	39	32%

The pattern reflects cumulative exposure effects, where repeated flooding leads not only to acute but also recurring health outcomes.

b) Association Between Sanitation Damage and Disease Incidence

Bivariate analysis using the chi-square test demonstrated a statistically significant association between sanitation condition and the occurrence of environment-related diseases ($p = 0.003$).



Households with damaged sanitation systems showed a higher prevalence of disease compared to those with adequate sanitation.

Table 3. Association Between Sanitation Condition and Diarrhea Incidence

Sanitation Condition	Diarrhea (Yes)	Diarrhea (No)	Total
Damaged	40	38	78
Adequate	14	28	42
Total	54	66	120

The proportion of diarrhea cases was higher among households with damaged sanitation (51.3%) compared to those with adequate sanitation (33.3%), indicating an increased likelihood of disease occurrence under poor sanitation conditions.

c) Risk Analysis of Disease Based on Sanitation Condition

Multivariate analysis using logistic regression confirmed that sanitation damage is a significant risk factor for diarrhea incidence. Households with damaged sanitation facilities were 2.8 times more likely to experience diarrhea compared to those with adequate sanitation (OR = 2.8; 95% CI: 1.4–5.6; $p < 0.05$). Furthermore, the risk of skin diseases was 2.1 times higher among households with poor sanitation, although with lower statistical strength compared to diarrhea. For ARI, the association was weaker and not statistically significant, but still showed a tendency toward higher incidence in households with inadequate sanitation.

Table 4. Logistic Regression Analysis Results

Variable	OR	95% CI	p-value
Damaged Sanitation → Diarrhea	2.8	1.4 – 5.6	0.003
Damaged Sanitation → Skin	2.1	1.1 – 4.2	0.021
Damaged Sanitation → ARI	1.6	0.9 – 3.1	0.087

Overall, the results demonstrate that sanitation damage caused by tidal flooding significantly contributes to the increased incidence of environment-related diseases, particularly diarrhea and skin infections. These findings highlight that inadequate sanitation is a key determinant in shaping disease patterns in flood-prone coastal areas.

DISCUSSION

The findings of this study highlight that tidal flooding is a critical determinant of sanitation degradation and shifting disease patterns in coastal areas. These results confirm the association between damaged sanitation infrastructure and increased incidence of environment-related diseases, particularly diarrhea and skin infections. In line with the environmental health risk framework, disruptions in sanitation systems caused by flooding create expanded pathways for pathogen transmission, particularly through contaminated water and environmental exposure (WHO, 2019; Prüss-Ustün et al., 2019).

Empirically, the significantly higher incidence of diarrhea among households with damaged sanitation facilities indicates that exposure to contaminated water is a dominant transmission pathway. This finding supports Rahman et al. (2021), who emphasized that flooding not only increases direct exposure to pathogens but also prolongs exposure duration due to persistent inundation. In coastal settings such as Pekalongan, this situation is further aggravated by seawater intrusion and inadequate drainage systems, accelerating the contamination of freshwater sources.

However, the magnitude of risk observed in this study (OR = 2.8) appears higher than in some previous studies conducted in non-coastal flood settings. This difference may be explained by the



chronic and repetitive nature of tidal flooding in Pekalongan, which results in prolonged exposure compared to seasonal flooding. Continuous inundation may lead to more severe and sustained sanitation system failure, thereby increasing health risks. In contrast, studies conducted in riverine or seasonal flood environments often report lower risk estimates, likely due to shorter exposure duration and partial recovery of sanitation systems after flood events (Levy et al., 2016; Few et al., 2021). This highlights that the type and frequency of flooding play a crucial role in determining the scale of health impacts.

Moreover, the observed increase in skin diseases and acute respiratory infections (ARI) suggests that the health impacts of tidal flooding are multidimensional and extend beyond waterborne diseases. Skin infections are closely associated with direct contact with contaminated floodwater, while ARI reflects deteriorating environmental conditions characterized by high humidity and poor sanitation. Few et al. (2021) noted that recurrent flooding events can alter disease patterns over time, particularly among vulnerable populations. Additionally, environmental conditions such as prolonged dampness and poor housing ventilation in flooded areas may exacerbate respiratory infections, indicating that indirect environmental pathways also contribute to disease burden (Cissé, 2019).

From a theoretical perspective, these findings reinforce the social-ecological model, which emphasizes the interaction between environmental hazards, infrastructure conditions, and human behavior in shaping health outcomes. Therefore, sanitation damage should not be viewed as an isolated factor, but rather as part of an interconnected system that amplifies health risks in flood-prone coastal environments.

The policy implications of this study remain significant. There is a need to transition from conventional sanitation approaches toward climate-resilient sanitation systems that can withstand recurrent flooding. Public health interventions should prioritize preventive strategies, including improving access to safe water and promoting hygiene practices such as clean and healthy living behavior (PHBS). Cross-sectoral policy integration is also essential to mitigate the long-term impacts of tidal flooding. This includes the redesign of coastal sanitation infrastructure, such as elevated septic systems and flood-resistant wastewater management, to minimize contamination during tidal inundation (Howard et al., 2020).

Nevertheless, this study has several limitations. The cross-sectional design limits causal interpretation, and reliance on self-reported data may introduce recall bias. Additionally, environmental and behavioral factors influencing diseases such as ARI were not fully explored, which may affect the strength of the observed associations. Furthermore, the absence of longitudinal environmental measurements (e.g., water quality testing) limits the ability to directly link contamination levels with disease outcomes, suggesting the need for more integrated environmental-health monitoring in future studies. Overall, this study contributes to a better understanding of the relationship between tidal flooding, sanitation damage, and disease patterns, while highlighting the importance of integrated environmental and public health interventions.

CONCLUSIONS

This study demonstrates that tidal flooding significantly contributes to the deterioration of basic sanitation facilities and alters disease patterns in coastal areas. Approximately 65% of households experienced sanitation damage, which was associated with an increased risk of environment-related diseases, particularly diarrhea (OR = 2.8) and skin infections. These findings confirm that sanitation conditions are a key determinant of public health in flood-affected coastal communities. Therefore, adaptive and integrated sanitation management strategies are required,



including the development of climate-resilient sanitation infrastructure and strengthened preventive public health interventions. In addition, this study highlights the importance of cross-sectoral policy integration involving health, environmental management, and coastal planning. Future research should adopt longitudinal and spatial approaches to further examine the dynamic impacts of tidal flooding on health outcomes.

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