



SIGn Journal of Social Science

E-ISSN: 2745-374X

jurnal.penerbitsign.com/index.php/sjss/article/view/v7n1-012

Vol. 7 Issue 1: June – November 2026

Published Online: October 5, 2026

Article Title

Flood Risk and Prevention of Environment-Related Diseases: An Adaptive Settlement Sanitation Management Model in Karawang Regency

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How to cite:

Aziz, F. A., Darmawan, W., Noval, M., Alhanif, A. R., & Irwana, I. (2026). Flood Risk and Prevention of Environment-Related Diseases: An Adaptive Settlement Sanitation Management Model in Karawang Regency. *SIGn Journal of Social Science*, 7(1), 202-224. <https://doi.org/10.37276/sjss.v7i1.807>



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ABSTRACT

Flooding affects sanitation functioning in settlements through interactions among environmental pressures, facility conditions, community behavior, governance, and environmental quality. This study aimed to identify sanitation conditions in the context of flood risk, analyze direct and indirect structural relationships among Flood Risk, Sanitation Governance, Sanitation Conditions, Community Behavior, Environmental Health, and Disease Prevention, and formulate an adaptive model for settlement sanitation management. This study used a quantitative descriptive-analytical cross-sectional design with 320 mothers from households in Karangligar Village and Purwadana Village, Karawang Regency. Questionnaire data were analyzed using PLS-SEM in SmartPLS 4.1 through evaluation of the second-order measurement model, structural model, and a bootstrapping procedure with 5,000 subsamples. Flood Risk was significantly related to all endogenous constructs with direct relationships. Sanitation Governance showed the strongest direct relationship with Community Behavior. Sanitation Conditions and Community Behavior showed significant indirect relationships with Disease Prevention through Environmental Health. All significant indirect relationships with Disease Prevention involved Environmental Health. These findings indicate that Environmental Health consistently links flood pressure, institutional capacity, physical sanitation conditions, community behavior, and disease prevention in an adaptive model.

Keywords: *Adaptive Model; Disease Prevention; Environmental Health; Flood Risk; Settlement Sanitation.*

INTRODUCTION

Flooding affects sanitation functioning in settlements by disrupting facilities, services, waste containment, and environmental quality. Water supply, drainage, wastewater, solid waste, and settlement environmental conditions are interrelated components. Disruption to one component is associated with changes in the functioning of other components. Climate-related pressures are also associated with disruptions to sanitation infrastructure and services, environmental pollution, and increased public health risks. At the household level, the resilience of sanitation facilities to flooding is associated with construction quality and maintenance. Extreme wet conditions also affect waste management and increase the risk of waste mixing with the surrounding settlement environment (Hyde-Smith et al., 2022; Kohlitz et al., 2026; Mremi et al., 2026). Sanitation management in flood-prone areas therefore requires functional continuity across all system components.

The relationship between sanitation and disease operates through environmental conditions that influence exposure. Sanitation systems are associated with the capacity to contain pathogens and limit their release, while environmental conditions affect the likelihood of human exposure (Foster et al., 2021). In flood-prone areas, the quality of sanitation facilities interacts with flood exposure, creating differences in the relationship between sanitation facilities and diarrhea prevalence depending on the environmental conditions in which the facilities operate (Kikuchi, 2023). Floodwater also moves contaminants from human, animal, and environmental pathogen sources (Tan et al., 2025). In the Indonesian context, on-site sanitation

safety is linked to the management of containment, emptying, treatment, and disposal throughout the sanitation service chain (Odagiri et al., 2021). Environmental Health therefore has an important function in the relationship between sanitation conditions and Disease Prevention.

The continuity of sanitation functioning in flood-prone areas is also associated with community behavior and institutional capacity. Environmental maintenance, facility use, solid waste management, compliance, sanitation awareness, and clean and healthy living behavior are associated with environmental sanitation conditions (Sekarningrum et al., 2023). At the institutional level, cross-sector coordination, participation, monitoring, funding, and policy implementation support sanitation management. Collaborative governance requires coordination and structured relationships among actors so that their respective capacities contribute to collective action. Adaptive sanitation management also requires organization, learning, flexibility, and community involvement in responding to socio-ecological change (Sofiyah & Suryawan, 2025; Asril et al., 2026). Settlement resilience is associated with relationships among households, communities, infrastructure, and local government (Satterthwaite et al., 2020). Sanitation management in flood-prone settlements therefore involves environmental pressures, physical conditions, community behavior, institutional capacity, and environmental health.

This analysis draws on three conceptual perspectives with distinct functions. General Systems Theory explains that a system's characteristics emerge from the organization of relationships among its components (Bertalanffy, 2015). The social-ecological resilience perspective emphasizes the capacity to maintain function, learn, and adjust responses to disturbances (Walker & Salt, 2012). Institutional and collective action theory explains how rules, participation, monitoring, coordination, and actor capacity establish and maintain collective arrangements (Ostrom, 1990). These three perspectives also explain technology's role in sanitation management. Climate-resilient sanitation requires service continuity, operational adjustment, limitation of failure consequences, and functional recovery. Facility resilience is also associated with construction, maintenance, financing, regulation, and monitoring (Cunningham et al., 2024; Kohlitz et al., 2026). Technology's function is therefore linked to institutional capacity, community behavior, and environmental conditions.

The literature reviewed encompasses three major areas of inquiry. The first examines sanitation resilience to flooding and climate-related pressures through facility failure, technological flexibility, maintenance, and management systems (Hyde-Smith et al., 2022; Cunningham et al., 2024; Kohlitz et al., 2026; Mremi et al., 2026). The second examines sanitation-health relationships through pathogen release, environmental exposure, sanitation service-chain safety, fecal exposure, and flood-related disease (Foster et al., 2021; Odagiri et al., 2021; Kikuchi, 2023; Tan et al., 2025). The third addresses governance, participation, community behavior, and settlement

resilience in environmental management ([Satterthwaite et al., 2020](#); [Sekarningrum et al., 2023](#); [Sofiyah & Suryawan, 2025](#); [Asril et al., 2026](#)). These areas of research demonstrate the need for an integrated analysis of flood pressure, institutional capacity, physical sanitation conditions, community behavior, environmental health, and disease prevention.

The research model comprises six constructs, each with a distinct conceptual function. Flood Risk represents environmental pressure. Sanitation Governance represents institutional capacity. Sanitation Conditions represent the physical components of sanitation. Community Behavior represents community practices in sanitation management. Environmental Health represents environmental conditions associated with exposure. Disease Prevention represents the outcome orientation. The literature reviewed largely addresses sanitation resilience, sanitation-health relationships, and social-institutional dimensions as separate areas. An integrated analysis of the six constructs is therefore needed to explain their interrelationships, particularly Environmental Health's role in indirect relationships with Disease Prevention.

This study's novelty lies in the empirical configuration of direct and indirect relationships generated by the integrated assessment of the six constructs. Particular attention is given to Environmental Health's consistent indirect relationship with Disease Prevention. This empirical contribution explains differences in the relationships among environmental pressure, institutional capacity, physical sanitation conditions, community behavior, Environmental Health, and Disease Prevention. The resulting configuration is subsequently used to formulate an adaptive model of settlement sanitation management. The study's scientific contribution is strengthening a systems-based approach to sanitation in flood-prone settlements. Its practical contribution is a conceptual-empirical basis for sanitation management that responds to flood pressure while supporting functional continuity.

This study aimed to identify settlement sanitation conditions in the context of flood exposure by considering the population's social and demographic characteristics and the representation of sanitation dimensions in Karawang Regency. It also analyzed direct and indirect structural relationships among Flood Risk, Sanitation Governance, Sanitation Conditions, Community Behavior, Environmental Health, and Disease Prevention, with particular attention to Environmental Health. The third objective was to formulate an adaptive model of settlement sanitation management that integrates flood pressure, governance capacity, physical sanitation conditions, community behavior, environmental health, and prevention of environment-related diseases.

METHOD

This study used a quantitative descriptive-analytical cross-sectional design. Data collection and processing were conducted from May to August 2026 (Creswell & Creswell, 2022). The study was conducted in Karangligar Village, Telukjambe Barat Subdistrict, and Purwadana Village, Telukjambe Timur Subdistrict, Karawang Regency. Both villages are flood-prone settlements and were selected as study locations to examine relationships between flood pressure and sanitation functioning. The study population comprised households located in flood-prone areas of the two villages. The study selected 320 mothers from these households through purposive sampling based on their involvement in domestic activities, household sanitation management, and family health. The respondents had diverse occupations, which were recorded as part of their social and demographic characteristics.

The primary quantitative data were obtained through a structured questionnaire that measured respondent characteristics and perceptions of indicators representing six latent constructs (Neuman, 2014). Respondent characteristics included maternal age, education, occupation, family income, household size, child sex and age, exclusive breastfeeding, and a history of diarrhea or acute respiratory infection (ARI) during or after flooding. Flood Risk was measured through inundation duration, flood depth, extent of the affected area, and flood frequency. Sanitation Conditions were measured through drainage, wastewater management, access to sanitary latrines, access to clean water, and solid waste management. Sanitation Governance was measured through cross-sector coordination, monitoring and evaluation, community participation, funding, and policy. Community Behavior was measured through environmental maintenance, compliance, sanitation awareness, and clean and healthy living behavior. Environmental Health was measured through vector density, environmental pollution, environmental cleanliness, and water quality. Disease Prevention was measured by reductions in dengue hemorrhagic fever (DHF), ARI, skin diseases, leptospirosis, and diarrhea. Within the research model, Disease Prevention functioned as the outcome orientation.

Data collection also included field observations using a checklist to assess the physical condition of clean water sources, latrines, drainage, solid waste management, and wastewater disposal. The study conducted limited in-depth interviews with representatives of the Regional Disaster Management Agency, Health Office, Public Works and Spatial Planning Office, Community Health Center, and village officials. The observations and interviews supplemented information on physical sanitation conditions, governance, and institutional conditions. Estimation of the structural relationships among the six constructs was based on the quantitative questionnaire data.

The analysis included descriptive statistics and partial least squares structural equation modeling (PLS-SEM) using SmartPLS 4.1. PLS-SEM was used to analyze

multiple latent constructs, direct and indirect relationships, and a hierarchical measurement structure (Hair et al., 2017; Hair & Alamer, 2022). The measurement model was analyzed as a second-order reflective model. Convergent validity was assessed using outer loadings and average variance extracted (AVE). Reliability was evaluated using Cronbach's alpha and composite reliability (CR). The evaluation of each dimension considered outer loading, AVE, reliability, and construct coverage (Hair et al., 2019; Hair & Alamer, 2022). Discriminant validity was evaluated using the heterotrait-monotrait ratio (HTMT) with a threshold of 0.85 and the Fornell-Larcker criterion by comparing the square root of AVE with interconstruct correlations. The variance inflation factor (VIF) was used to evaluate collinearity in the measurement model.

Structural model evaluation included path coefficients, R^2 and Adjusted R^2 , effect size f^2 , the standardized root mean square residual (SRMR), and predictive assessment. At the construct level, Q^2 was used to assess predictive accuracy. Values of approximately 0.25 and 0.50 were used as reference points for medium and high predictive accuracy, respectively (Hair et al., 2019). At the indicator level, out-of-sample prediction was assessed using PLSpredict and Q^2 predict. The predictive power of PLSpredict was evaluated by comparing the RMSE or MAE of PLS-SEM with a linear model benchmark (Hair et al., 2019; Hair & Alamer, 2022). Structural relationships were tested using a bootstrapping procedure with 5,000 subsamples, directional hypotheses, a one-tailed test, and a 5% significance level. The tests included direct relationships as well as single and serial indirect relationships. The adaptive model was formulated from descriptive statistics, measurement model quality, structural relationships, fundamental theories, and evidence from previous studies.

RESULTS AND DISCUSSION

A. Respondent Characteristics and the Measurement Structure of Sanitation Constructs in Flood-Prone Settlements

The characteristics of the 320 respondents describe the social and demographic profile of households in flood-prone settlements in Karawang Regency. The largest age group was 36 to 50 years, comprising 143 respondents (44.7%), followed by those aged 18 to 35 years, comprising 112 respondents (35.0%). Senior high school or vocational high school was the most common educational attainment, reported by 247 respondents, or 77.2%. By occupation, homemakers constituted the largest group, with 262 respondents or 81.9%. Most families had monthly incomes of IDR 2,000,000 to IDR 4,000,000, accounting for 203 respondents or 63.4%. Households with four to five members accounted for 189 respondents or 59.1%. These characteristics describe the social and economic conditions of the households in which sanitation facilities are used and maintained.

Table 1. Frequency Distribution of Respondent Demographic Characteristics

Characteristic	Category	Frequency (f)	Percentage (%)
Maternal Age	Early Adulthood (18–35 years)	112	35.0
	Middle Adulthood (36–50 years)	143	44.7
	Late Adulthood (>50 years)	65	20.3
Maternal Educational Attainment	No Formal Schooling	4	1.3
	Elementary School or Equivalent	5	1.6
	Junior High School or Equivalent	42	13.1
	Senior High School/Vocational High School or Equivalent	247	77.2
	Higher Education	22	6.9
Maternal Occupation	Homemaker	262	81.9
	Employee	39	12.2
	Self-Employed	5	1.6
	Laborer	2	0.6
	Other	12	3.8
Family Income	< IDR 2,000,000	10	3.1
	IDR 2,000,000–4,000,000	203	63.4
	> IDR 4,000,000	107	33.4
Household Size	Small Family (≤ 3 people)	107	33.4
	Medium-Sized Family (4–5 people)	189	59.1
	Large Family (≥ 6 people)	24	7.5
Child Sex	Boy	169	52.8
	Girls	151	47.2
Child Age	Infants (0–11 months)	42	13.1
	Children Aged 12–23 Months	41	12.8
	Children Aged 24–59 Months	237	74.1
Exclusive Breastfeeding	Exclusively Breastfed	260	81.3
	Not Exclusively Breastfed	60	18.8
History of Diarrhea/ARI	During or After Flooding	8	2.5
	Never	312	97.5

Source: *Descriptive Statistical Analysis, SPSS 26 (2026).*

The child profile showed that 169 children, or 52.8%, were male and 151, or 47.2%, were female. Children aged 24 to 59 months made up the largest age group, with 237 children, or 74.1%. Infants aged 0 to 11 months accounted for 42 children (13.1%), while children aged 12 to 23 months accounted for 41 (12.8%). Exclusive breastfeeding was reported for 260 children (81.3%). Eight children, or 2.5%, had a history of diarrhea or ARI during or after flooding. This profile complements the household characteristics in the study area. In flood-prone settings, the relationship between sanitation facilities and childhood diarrhea

is associated with flood exposure and the characteristics of the facilities used (Kikuchi, 2023).

Sanitation Conditions were represented by five physical dimensions: drainage, wastewater management, access to sanitary latrines, access to clean water, and solid waste management. Flood Risk was represented by inundation duration, flood depth, extent of the affected area, and flood frequency. Sanitation Governance comprised cross-sector coordination, monitoring and evaluation, community participation, funding, and policy. Community Behavior comprised environmental maintenance, compliance, sanitation awareness, and clean and healthy living behavior. Environmental Health comprised vector density, environmental pollution, environmental cleanliness, and water quality. Disease Prevention was measured by reductions in DHF, ARI, skin diseases, leptospirosis, and diarrhea. Measurement model evaluation showed how strongly each dimension represented its construct.

Table 2. Second-Order Measurement Model Evaluation

Construct	Dimension	Outer Loading	VIF	Cronbach's Alpha	Reliabilitas Composite (CR)
Flood Risk (AVE = 0.704)	Inundation Duration	0.899	4.156	0.858	0.905
	Flood Depth	0.862	3.590		
	Extent of Affected Area	0.850	2.617		
	Flood Frequency	0.738	2.565		
Sanitation Conditions (AVE = 0.582)	Drainage	0.865	2.461	0.689	0.791
	Wastewater Management	0.847	2.525		
	Access to Sanitary Latrines	0.789	1.149		
	Access to Clean Water	0.675	1.270		
	Solid Waste Management	0.605	1.416		
Sanitation Governance (AVE = 0.641)	Cross-Sector Coordination	0.901	3.252	0.858	0.898
	Monitoring and Evaluation	0.856	2.989		
	Community Participation	0.839	2.815		
	Funding	0.771	2.560		
	Policy	0.603	1.834		
Community Behavior (AVE = 0.742)	Environmental Maintenance	0.937	4.433	0.882	0.920
	Compliance	0.871	3.416		
	Sanitation Awareness	0.864	3.488		
	Clean and Healthy Living Behavior	0.763	1.576		
Environmental Health (AVE = 0.662)	Vector Density	0.905	3.425	0.836	0.886
	Environmental Pollution	0.816	2.387		
	Environmental Cleanliness	0.799	3.403		
	Water Quality	0.723	4.188		

Construct	Dimension	Outer Loading	VIF	Cronbach's Alpha	Reliabilitas Composite (CR)
Disease Prevention (AVE = 0.632)	Reduction in DHF	0.904	4.299	0.858	0.895
	Reduction in ARI	0.860	4.816		
	Reduction in Skin Diseases	0.800	2.692		
	Reduction in Leptospirosis	0.711	2.927		
	Reduction in Diarrhea	0.677	2.219		

Source: *Second-Order SEM-PLS Analysis, SmartPLS 4.1 (2026).*

Flood Risk had an AVE of 0.704, Cronbach's alpha of 0.858, and composite reliability of 0.905. Inundation duration had the highest outer loading (0.899), followed by flood depth (0.862), extent of the affected area (0.850), and flood frequency (0.738). These values indicate that duration, depth, affected-area extent, and frequency strongly represent flood risk. Flood exposure is linked to household sanitation system functioning through construction quality and maintenance. Extreme wet conditions are also associated with waste management and facility vulnerability to environmental contamination (Kohlitz et al., 2026; Mremi et al., 2026). The measurement structure of Flood Risk aligns with its role as an environmental pressure in the model.

Sanitation Conditions had an AVE of 0.582, Cronbach's alpha of 0.689, and composite reliability of 0.791. Drainage had an outer loading of 0.865, followed by wastewater management (0.847) and access to sanitary latrines (0.789). Access to clean water had an outer loading of 0.675, while solid waste management had a loading of 0.605. These differences indicate how each dimension contributes to Sanitation Conditions. The five dimensions represent physical sanitation facilities and management associated with containment, waste management, disposal, and exposure control within household sanitation systems (Odagiri et al., 2021).

Sanitation Governance had an AVE of 0.641, Cronbach's alpha of 0.858, and composite reliability of 0.898. Cross-sector coordination had the highest outer loading (0.901), followed by monitoring and evaluation (0.856), community participation (0.839), funding (0.771), and policy (0.603). These values indicate strong contributions from coordination, monitoring and evaluation, and community participation to Sanitation Governance. Community Behavior had an AVE of 0.742, Cronbach's alpha of 0.882, and composite reliability of 0.920. Environmental maintenance had the highest outer loading in the entire model at 0.937, followed by compliance at 0.871, sanitation awareness at 0.864, and clean and healthy living behavior at 0.763. This structure empirically distinguishes institutional capacity from community behavior in sanitation management.

Environmental Health had an AVE of 0.662, Cronbach's alpha of 0.836, and composite reliability of 0.886. Vector density had the highest outer loading (0.905),

followed by environmental pollution (0.816), environmental cleanliness (0.799), and water quality (0.723). Disease Prevention had an AVE of 0.632, Cronbach's alpha of 0.858, and composite reliability of 0.895. Reduction in DHF had an outer loading of 0.904, followed by reduction in ARI (0.860), skin diseases (0.800), leptospirosis (0.711), and diarrhea (0.677). Environmental Health represents conditions associated with exposure, whereas Disease Prevention represents the outcome orientation. In flood-prone settings, the relationship between sanitation facilities and health conditions reflects interactions between facilities and the environmental conditions in which exposure occurs (Kikuchi, 2023).

Overall, 23 of the 27 dimensions had outer loadings of at least 0.708. Four dimensions had values below 0.708: access to clean water (0.675), solid waste management (0.605), policy (0.603), and reduction in diarrhea (0.677). AVE values ranged from 0.582 to 0.742, and composite reliability ranged from 0.791 to 0.920. These values indicate convergent validity and construct-level composite reliability (Hair et al., 2019). VIF values ranged from 1.149 to 4.816. Several dimensions had VIF values above 3, while all remained below 5. These results indicate variation in collinearity across dimensions and should be interpreted alongside each construct's measurement structure.

Discriminant validity demonstrated empirical separation among the six constructs. HTMT values for all construct pairs ranged from 0.468 to 0.684 and satisfied the 0.85 criterion. The Fornell-Larcker criterion was also met because the square root of the AVE for each construct exceeded its correlations with other constructs. For Sanitation Conditions, for example, the square root of AVE was 0.763, which was higher than its strongest correlation, 0.531, with Flood Risk. These results indicate adequate empirical separation among Sanitation Conditions, Environmental Health, Community Behavior, Sanitation Governance, Flood Risk, and Disease Prevention. HTMT was used to assess discriminant validity in the PLS-SEM evaluation (Hair et al., 2019).

After evaluating the measurement model, the analysis proceeded to the structural relationships among the constructs. Sanitation Conditions represent the physical component, Community Behavior represents social practices, Sanitation Governance represents institutional capacity, Environmental Health represents exposure-related conditions, Flood Risk represents environmental pressure, and Disease Prevention represents the outcome orientation. These distinct functions provide the substantive basis for interpreting direct and indirect relationships among the constructs.

B. Direct Relationships among Constructs in Sanitation Management in Flood-Prone Settlements

The model showed different levels of explained variance across the endogenous constructs. Disease Prevention had an R^2 of 0.479 and an Adjusted

R^2 of 0.470. Environmental Health had an R^2 of 0.456, Community Behavior 0.427, and Sanitation Conditions 0.338. These values indicate the proportion of variance explained by the constructs associated with each endogenous construct. Effect sizes also showed different relative contributions. The relationship between Sanitation Governance and Community Behavior had the highest f^2 (0.226). The relationship between Flood Risk and Sanitation Conditions had an f^2 of 0.185. The relationships between Sanitation Conditions and Community Behavior and between Sanitation Conditions and Disease Prevention each had an f^2 of 0.000. The combination of R^2 , f^2 , and path coefficients was used to assess the model's explanatory performance for the structural relationships (Hair et al., 2019; Hair & Alamer, 2022).

Predictive assessment yielded Q^2 values of 0.411 for Community Behavior, 0.397 for Environmental Health, 0.396 for Disease Prevention, and 0.323 for Sanitation Conditions. All values were above 0.25 and below 0.50, indicating medium predictive accuracy (Hair et al., 2019). At the indicator level, most $Q^2_{predict}$ values ranged from 0.059 to 0.401, while access to sanitary latrines was -0.007. Positive $Q^2_{predict}$ values for most indicators indicate predictive relevance. The predictive power of PLSpredict was further evaluated by comparing prediction errors from PLS-SEM with those from the linear model benchmark (Hair et al., 2019; Hair & Alamer, 2022).

The SRMR was 0.100 for both the saturated and estimated models. This value reflects the difference between the empirical correlations and those implied by the model. Structural model interpretation considered SRMR alongside R^2 , predictive accuracy, effect sizes, path coefficients, and the statistical significance of interconstruct relationships, in accordance with the characteristics of PLS-SEM estimation (Hu & Bentler, 1999; Hair et al., 2019).

Table 3. Hypothesis Testing Results for Direct Relationships

Hypothesis	Interconstruct Relationship	Path Coefficient (β)	t-Statistic	p-Value	Decision
H1	Flood Risk → Sanitation Conditions	0.399	8.133	< 0.001	Supported
H2	Flood Risk → Community Behavior	0.320	4.347	< 0.001	Supported
H3	Flood Risk → Environmental Health	0.356	5.636	< 0.001	Supported
H4	Flood Risk → Disease Prevention	0.181	2.728	0.003	Supported
H5	Sanitation Governance → Sanitation Conditions	0.272	4.801	< 0.001	Supported
H6	Sanitation Governance → Community Behavior	0.428	6.602	< 0.001	Supported

Hypothesis	Interconstruct Relationship	Path Coefficient (β)	t-Statistic	p-Value	Decision
H7	Sanitation Governance → Environmental Health	0.093	1.387	0.083	Not Supported
H8	Sanitation Governance → Disease Prevention	0.246	3.495	< 0.001	Supported
H9	Sanitation Conditions → Environmental Health	0.146	2.351	0.009	Supported
H10	Sanitation Conditions → Community Behavior	0.012	0.178	0.429	Not Supported
H11	Sanitation Conditions → Disease Prevention	0.003	0.049	0.480	Not Supported
H12	Community Behavior → Environmental Health	0.239	3.338	< 0.001	Supported
H13	Community Behavior → Disease Prevention	0.132	1.536	0.062	Not Supported
H14	Environmental Health → Disease Prevention	0.293	3.831	< 0.001	Supported

Source: SEM-PLS Bootstrapping Results, SmartPLS 4.1 (2026).

Of the 14 direct relationships tested, 10 were statistically significant. Flood Risk was significantly related to Sanitation Conditions, Community Behavior, Environmental Health, and Disease Prevention. Sanitation Governance was significantly related to Sanitation Conditions, Community Behavior, and Disease Prevention. Sanitation Conditions and Community Behavior were each significantly related to Environmental Health. Environmental Health was also significantly related to Disease Prevention. Four relationships were not statistically significant: Sanitation Governance with Environmental Health, Sanitation Conditions with Community Behavior, Sanitation Conditions with Disease Prevention, and Community Behavior with Disease Prevention.

Flood Risk was related to Sanitation Conditions ($\beta = 0.399$), Environmental Health ($\beta = 0.356$), Community Behavior ($\beta = 0.320$), and Disease Prevention ($\beta = 0.181$). All four relationships were statistically significant. These results indicate that Flood Risk is associated with physical sanitation components, community behavior, environmental health conditions, and Disease Prevention. Flood exposure is associated with the capacity of household sanitation systems to maintain function. Extreme weather events are also associated with fecal sludge management, facility overflow, and environmental contamination (Kohlitz et al., 2026; Mremi et al., 2026).

The relationships between Flood Risk and several constructs also reflect the interdependence between sanitation infrastructure and services. Climate-related pressures are associated with infrastructure, services, waste transportation, and other urban components. Settlement resilience is also influenced by relationships among households, communities, infrastructure, and government capacity

(Satterthwaite et al., 2020; Hyde-Smith et al., 2022). The resilience perspective explains responses to environmental disturbances through physical, social, and institutional capacities (Walker & Salt, 2012). H1 through H4 therefore show relationships between Flood Risk and several major components of settlement sanitation management.

Sanitation Governance showed its strongest direct relationship with Community Behavior ($\beta = 0.428$). This was the largest direct path coefficient in the entire model. Sanitation Governance was also significantly related to Sanitation Conditions ($\beta = 0.272$) and Disease Prevention ($\beta = 0.246$). Its relationship with Environmental Health was $\beta = 0.093$ with a p-value of 0.083. These findings indicate stronger relationships between Sanitation Governance and both community behavior and management conditions. Rules, coordination, monitoring, and participation are important components in organizing collective action and maintaining collective arrangements (Ostrom, 1990).

Cross-sector coordination and community participation connect policy with community action in management processes involving multiple institutions (Asril et al., 2026). Administrative capacity and infrastructure reliability are distinct but interrelated components of public service performance (Fitri et al., 2025). Adaptive sanitation management also requires organization, flexibility, learning, and community involvement in responding to socio-ecological dynamics (Sofiyah & Suryawan, 2025). H5, H6, and H8 therefore show relationships between Sanitation Governance and physical sanitation conditions, community behavior, and Disease Prevention.

Sanitation Conditions were significantly related to Environmental Health ($\beta = 0.146$). Their relationships with Community Behavior ($\beta = 0.012$) and Disease Prevention ($\beta = 0.003$) were not significant. On-site sanitation safety encompasses containment, emptying, management, disposal, and exposure control. The physical functioning of sanitation facilities is therefore associated with the environmental conditions in which sanitation management occurs (Odagiri et al., 2021). Basic sanitation facilities, environmental cleanliness, and management practices are also interrelated within settlement sanitation (Sekarningrum et al., 2023). H9 demonstrates the relationship between physical sanitation conditions and Environmental Health.

Community Behavior was significantly related to Environmental Health ($\beta = 0.239$). The direct relationship between Community Behavior and Disease Prevention was $\beta = 0.132$ with a p-value of 0.062. Environmental maintenance, compliance, sanitation awareness, and clean and healthy living behavior are associated with water conditions, wastewater, solid waste, cleanliness, and vector presence at the household and settlement levels. Findings on maintenance, learning, and adaptation in sanitation management also support relationships

among behavior, sanitation conditions, and environmental health (Sekarningrum et al., 2023; Sofiyah & Suryawan, 2025).

Environmental Health had a direct relationship with Disease Prevention ($\beta = 0.293$). This was the largest coefficient among all direct relationships with Disease Prevention. The corresponding coefficients were 0.246 for Sanitation Governance, 0.181 for Flood Risk, 0.132 for Community Behavior, and 0.003 for Sanitation Conditions. These findings show that Environmental Health had the strongest direct relationship with Disease Prevention among the constructs directly associated with Disease Prevention. Vector density, environmental pollution, environmental cleanliness, and water quality represent environmental conditions associated with exposure. Sanitation disruption during flooding is associated with pollution and waste management, while sanitation service-chain safety is associated with control of fecal exposure (Odagiri et al., 2021; Mremi et al., 2026).

Differences in significance across H7, H10, H11, and H13 show that interconstruct relationships were not uniformly direct. Sanitation Conditions and Community Behavior were each significantly related to Environmental Health, whereas their direct relationships with Disease Prevention were not significant. This pattern provides the empirical basis for examining indirect relationships involving Environmental Health.

C. Environmental Health in Indirect Relationships among Constructs and Disease Prevention

The indirect relationship analysis included both single and serial relationships. Of the 14 indirect relationships tested, seven were statistically significant and seven were not. All significant indirect relationships with Disease Prevention involved Environmental Health, either directly as an intervening construct or as part of a serial relationship. H17 and H24 also involved Environmental Health, but neither was statistically significant. These findings indicate that the significance of indirect relationships varied according to the configuration of the constructs involved.

Table 4. Hypothesis Testing Results for Indirect Relationships

Hypothesis	Indirect Relationship	Coefficient (β)	t-Statistic	p-Value	Decision
H15	Sanitation Conditions → Environmental Health → Disease Prevention	0.043	1.949	0.026	Supported
H16	Sanitation Conditions → Community Behavior → Disease Prevention	0.002	0.151	0.440	Not Supported
H17	Sanitation Conditions → Community Behavior → Environmental Health → Disease Prevention	0.001	0.162	0.435	Not Supported

Hypothesis	Indirect Relationship	Coefficient (β)	t-Statistic	p-Value	Decision
H18	Community Behavior → Environmental Health → Disease Prevention	0.070	2.507	0.006	Supported
H19	Flood Risk → Environmental Health → Disease Prevention	0.104	3.260	0.001	Supported
H20	Flood Risk → Sanitation Conditions → Environmental Health → Disease Prevention	0.017	1.870	0.031	Supported
H21	Flood Risk → Community Behavior → Disease Prevention	0.042	1.415	0.079	Not Supported
H22	Flood Risk → Community Behavior → Environmental Health → Disease Prevention	0.022	2.050	0.020	Supported
H23	Flood Risk → Sanitation Conditions → Disease Prevention	0.001	0.049	0.481	Not Supported
H24	Sanitation Governance → Environmental Health → Disease Prevention	0.027	1.270	0.102	Not Supported
H25	Sanitation Governance → Sanitation Conditions → Environmental Health → Disease Prevention	0.012	1.736	0.041	Supported
H26	Sanitation Governance → Community Behavior → Environmental Health → Disease Prevention	0.030	2.489	0.006	Supported
H27	Sanitation Governance → Community Behavior → Disease Prevention	0.057	1.440	0.075	Not Supported
H28	Sanitation Governance → Sanitation Conditions → Disease Prevention	0.001	0.048	0.481	Not Supported

Source: SEM-PLS Bootstrapping Results, SmartPLS 4.1 (2026).

A comparison of H11 and H15 shows the difference between the direct relationship and the indirect relationship through Environmental Health. In H11, the relationship between Sanitation Conditions and Disease Prevention was $\beta = 0.003$, $p = 0.480$. The relationship between Sanitation Conditions and Disease Prevention through Environmental Health in H15 was $\beta = 0.043$, $p = 0.026$. H16 and H17 were not significant when Community Behavior was included in the indirect relationship originating from Sanitation Conditions. These results show that the relationship between Sanitation Conditions and Disease Prevention was significant when Sanitation Conditions related to Environmental Health, and Environmental Health subsequently related to Disease Prevention.

Sanitation facilities are associated with health through environmental exposure mechanisms. Better facility conditions interact with flood exposure in their relationship with diarrhea prevalence. The health benefits of sanitation

also relate to its capacity to contain pathogens, limit their release, control their movement through the environment, and reduce human exposure ([Foster et al., 2021](#); [Kikuchi, 2023](#)). H15 demonstrates the role of Environmental Health in the relationship between Sanitation Conditions and Disease Prevention.

Community Behavior showed a similar pattern. The direct relationship between Community Behavior and Disease Prevention in H13 was $\beta = 0.132$ with a p-value of 0.062. The relationship between Community Behavior and Disease Prevention through Environmental Health in H18 was $\beta = 0.070$ ($p = 0.006$). Environmental maintenance, compliance, sanitation awareness, and clean and healthy living behavior are associated with water conditions, solid waste, wastewater, cleanliness, and vector presence in the settlement environment. These findings show the relationship between Community Behavior and Disease Prevention through environmental health conditions.

Personal hygiene and environmental exposure are associated with skin health disorders among populations with particular exposure patterns. Improved health knowledge is also associated with facility availability and social support in shaping health practices. Community behavior and environmental sanitation conditions are interrelated at the settlement level ([Sekarningrum et al., 2023](#); [Hasjuni & Hamdan, 2024](#); [Hamdan et al., 2025](#)). These findings support the interpretation of H18 regarding the role of Environmental Health in the indirect relationship between Community Behavior and Disease Prevention.

Flood Risk had several indirect relationships with Disease Prevention. The relationship between Flood Risk and Disease Prevention through Environmental Health in H19 was $\beta = 0.104$ with a p-value of 0.001. This was the largest indirect coefficient in the model. The serial relationship among Flood Risk, Sanitation Conditions, Environmental Health, and Disease Prevention in H20 was $\beta = 0.017$ ($p = 0.031$). The serial relationship among Flood Risk, Community Behavior, Environmental Health, and Disease Prevention in H22 was $\beta = 0.022$ ($p = 0.020$). H21 and H23 were not significant. These differences indicate that Environmental Health was involved in all significant indirect relationships originating from Flood Risk.

Floodwater affects pathogen transmission through interactions among human, animal, and environmental contamination sources. On-site sanitation safety is associated with containment, disposal, and management capacity for limiting fecal exposure. Extreme wet conditions are also associated with fecal sludge management, facility functioning, and environmental contamination. Household sanitation system resilience to flooding is associated with facility construction and maintenance ([Odagiri et al., 2021](#); [Tan et al., 2025](#); [Kohlitz et al., 2026](#); [Mremi et al., 2026](#)). These findings are consistent with the significant relationships observed in H19, H20, and H22.

Sanitation Governance showed different levels of significance across the indirect relationships tested. The relationship between Sanitation Governance and Disease Prevention through Environmental Health in H24 was $\beta = 0.027$ with a p-value of 0.102. The serial relationship among Sanitation Governance, Sanitation Conditions, Environmental Health, and Disease Prevention in H25 was $\beta = 0.012$, $p = 0.041$. The serial relationship among Sanitation Governance, Community Behavior, Environmental Health, and Disease Prevention in H26 was $\beta = 0.030$ ($p = 0.006$). H27 and H28 were not significant. H25 and H26 indicate that the relationship between Sanitation Governance and Disease Prevention operated through its relationships with physical conditions or community behavior together with Environmental Health.

Rules, coordination, monitoring, funding, and participation are elements of collective action capacity in institutional management (Ostrom, 1990). Adaptive sanitation management also involves organization, flexibility, learning, and community participation in responding to socio-ecological dynamics (Sofiyah & Suryawan, 2025). H25 and H26 show relationships between Sanitation Governance and Disease Prevention through Sanitation Conditions or Community Behavior together with Environmental Health.

H15, H18, H19, H20, H22, H25, and H26 were statistically significant, and all involved Environmental Health. H17 and H24 indicate that Environmental Health's involvement produced different statistical patterns depending on the configuration of interconstruct relationships. Overall, Environmental Health showed the greatest consistency as the construct involved in significant indirect relationships with Disease Prevention. The systems perspective explains that a single outcome can be associated with multiple interaction configurations among system components (Bertalanffy, 2015).

The direct and indirect relationships show how Environmental Health functions in the relationships among flood pressure, physical sanitation conditions, community behavior, Sanitation Governance, and Disease Prevention. The resilience perspective also explains functional continuity through interactions among pressure, system conditions, and response capacity (Walker & Salt, 2012). These findings provide the empirical basis for integrating the six constructs into an adaptive model of settlement sanitation management.

D. Integration of Six Constructs into an Adaptive Sanitation Management Model for Flood-Prone Settlements

The adaptive settlement sanitation management model integrates six constructs according to their respective functions. Flood Risk represents environmental pressure. Sanitation Governance represents institutional capacity. Sanitation Conditions represent physical sanitation components. Community Behavior represents social practices. Environmental Health represents

environmental conditions associated with exposure. Disease Prevention represents the outcome orientation. Direct and indirect interconstruct relationships provide the empirical basis for this integration.

Flood Risk represents environmental pressure associated with Sanitation Conditions, Community Behavior, Environmental Health, and Disease Prevention. H1 through H4 show significant relationships with all four constructs. Sanitation management in flood-prone areas requires facilities and services to remain functional during flood events and during service recovery. Interdependence between sanitation infrastructure and services highlights the importance of service continuity. Climate-resilient sanitation technologies also require flexibility, limitation of failure consequences, and recovery capacity ([Hyde-Smith et al., 2022](#); [Cunningham et al., 2024](#)). Information on Flood Risk therefore informs adjustments to physical, social, institutional, and environmental health management.

Sanitation Conditions comprise drainage, wastewater management, sanitary latrines, clean water, and solid waste management. H9, H15, H20, and H25 show relationships between Sanitation Conditions, Environmental Health, and Disease Prevention. The health function of sanitation facilities is associated with maintaining services, managing waste, limiting contaminant release, and protecting environmental quality in settlements. On-site sanitation safety depends on technology, installation, emptying, maintenance, monitoring, and local government support. Flood resilience is also associated with construction quality and maintenance of household systems ([Odagiri et al., 2021](#); [Kohlitz et al., 2026](#)). Management of physical sanitation components therefore requires facility resilience and functional continuity during flood events.

Sanitation Governance comprises cross-sector coordination, monitoring and evaluation, community participation, funding, and policy. H5, H6, and H8 show relationships between Sanitation Governance and Sanitation Conditions, Community Behavior, and Disease Prevention. H25 and H26 show indirect relationships through Sanitation Conditions or Community Behavior together with Environmental Health. Collaborative governance integrates the capacities of governmental and nongovernmental actors in management processes involving multiple institutions ([Asril et al., 2026](#)). Rules, monitoring, participation, and collective action also support institutional management ([Ostrom, 1990](#)). Within the adaptive model, Sanitation Governance aligns decisions, resources, facility management, community behavior, and environmental health needs.

Community Behavior comprises environmental maintenance, compliance, sanitation awareness, and clean and healthy living behavior. H12, H18, H22, and H26 show relationships between Community Behavior, Environmental Health, and Disease Prevention. Facility use and maintenance are associated with water conditions, solid waste, wastewater, cleanliness, and vector presence at household

and settlement levels. Participation, organization, learning, flexibility, and the capacity to act are components of adaptive sanitation management under changing socio-ecological conditions ([Sofiyah & Suryawan, 2025](#)). Community Behavior is therefore associated with facility use and environmental quality in settlements.

Environmental Health had the largest direct relationship with Disease Prevention in H14 and was involved in all significant indirect relationships in H15, H18, H19, H20, H22, H25, and H26. Vector density, environmental pollution, environmental cleanliness, and water quality indicate environmental conditions associated with sanitation functioning and community behavior. The relationship between sanitation and health risk operates through pathogen release and environmental exposure. Flooding also affects transmission through interactions among humans, animals, and the environment ([Foster et al., 2021](#); [Tan et al., 2025](#)). Environmental Health therefore functions as an evaluation component linking sanitation management conditions with Disease Prevention.

Disease Prevention represents the outcome orientation in the adaptive model. Flood Risk, Sanitation Governance, and Environmental Health had significant direct relationships with Disease Prevention. Sanitation Conditions and Community Behavior had significant indirect relationships with Disease Prevention through Environmental Health. The systems perspective explains that system-level characteristics arise from the organization of relationships among components ([Bertalanffy, 2015](#)). Disease Prevention is therefore associated with the combination of environmental pressure, institutional capacity, physical sanitation conditions, community behavior, and environmental health.

Adaptive sanitation management encompasses flood-pressure monitoring, institutional coordination, facility maintenance, strengthening community behavior, Environmental Health evaluation, and adjusting management actions. The resilience perspective emphasizes the capacity to maintain function, learn, and adjust responses to disturbances ([Walker & Salt, 2012](#)). Flood Risk provides information on the intensity of environmental pressure. Sanitation Governance regulates decisions and resources. Sanitation Conditions and Community Behavior represent physical and social components of management implementation. Environmental Health provides evaluation indicators. Disease Prevention represents the management's outcome orientation.

Sanitation technology is an implementation component of managing physical sanitation conditions. Technology selection considers flood resilience, containment and treatment capacity, contamination control, maintenance requirements, service continuity, hydrological characteristics, and local management capacity. Sanitation resilience to climate-related pressures depends on the combination of technological features, hazard type, and context of use ([Cunningham et al., 2024](#)). A bio septic tank is one technological alternative for locations that meet the

relevant technical, hydrological, treatment, maintenance, and service-continuity requirements.

The adaptive model integrates environmental pressure, institutional capacity, physical sanitation conditions, community behavior, Environmental Health, and Disease Prevention. Settlement resilience depends on relationships among households, communities, infrastructure, and local government. Context-specific management also requires integrating structural, managerial, and behavioral factors ([Satterthwaite et al., 2020](#); [Muchlis et al., 2025](#)). Integration of the six constructs establishes sanitation functional continuity and environmental health conditions as major components of sanitation management in flood-prone settlements.

CONCLUSIONS AND SUGGESTIONS

Settlement sanitation conditions in the study area included drainage, wastewater management, access to sanitary latrines, clean water, and solid waste management in households exposed to flood pressure. Flood Risk was significantly related to Sanitation Conditions, Community Behavior, Environmental Health, and Disease Prevention. Sanitation Governance showed its strongest direct relationship with Community Behavior. Sanitation Conditions and Community Behavior were significantly related to Environmental Health and showed significant indirect relationships with Disease Prevention through Environmental Health. All significant indirect relationships tested with Disease Prevention involved Environmental Health.

The adaptive model integrates Flood Risk as environmental pressure, Sanitation Governance as institutional capacity, Sanitation Conditions as the physical component, Community Behavior as social practice, Environmental Health as a linking and evaluation component, and Disease Prevention as the outcome orientation. Adaptive management encompasses flood-pressure monitoring, institutional coordination, maintaining sanitation functioning, strengthening community behavior, evaluating environmental health conditions, and adjusting management actions. The study's empirical novelty is the consistent involvement of Environmental Health in all significant indirect relationships with Disease Prevention.

Future research should test the model in flood-prone areas with different hydrological, social, and institutional characteristics. Further measurement development should integrate epidemiological data, water quality, environmental contamination, and vector indicators. Longitudinal assessment is also needed to examine changes in flood pressure, sanitation functioning, environmental health conditions, and Disease Prevention over time. Future technology studies should compare sanitation alternatives based on functional resilience, contamination-control capacity, maintenance requirements, costs, and suitability for local conditions.

At the implementation and policy levels, sanitation management in flood-prone areas should integrate flood-pressure mapping with drainage-system maintenance, wastewater management, latrines, clean water, solid waste management, strengthened community behavior, and monitoring of water quality, environmental cleanliness, pollution, and vector density. Cross-sector coordination should align planning, funding, maintenance, monitoring, and evaluation with the need to sustain sanitation functioning during flooding. Environmental Health serves as an evaluation component linking policy, facilities, community behavior, and Disease Prevention. Sanitation technologies, including bio septic tanks that meet local technical, hydrological, cost, and maintenance-capacity requirements, form part of physical sanitation management within the adaptive sanitation model.

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