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Community-Based Sanitation Risk Model to Reduce Childhood Diarrhea in Flood-Prone Urban Settlements

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Childhood diarrhea remains a major public health concern in flood-prone urban settlements, where inadequate sanitation and environmental contamination are common. This study aimed to develop and validate a community-based sanitation risk model to identify key environmental and behavioral factors associated with childhood diarrhea. An analytical cross-sectional design was conducted among 240 households with children under five years of age. Data were collected through structured interviews, household sanitation observations, and environmental assessments, covering variables such as water source, latrine condition, waste disposal, drainage, handwashing practices, and flood exposure. Bivariate analysis was used to assess associations between sanitation variables and diarrhea, followed by multivariable logistic regression to determine independent predictors and construct the risk model. The results showed that The two-week prevalence of childhood diarrhea was 27.5%. Multivariable analysis identified contaminated water sources (AOR = 3.42; 95% CI: 1.95–5.99), clogged or non-functional drainage (AOR = 3.85; 95% CI: 2.12–6.97), improper solid waste disposal (AOR = 2.67; 95% CI: 1.56–4.61), unimproved latrines (AOR = 2.11; 95% CI: 1.25–3.58), and inadequate handwashing behavior (AOR = 2.48; 95% CI: 1.40–4.38) as significant predictors of diarrhea. The model demonstrated good discrimination in identifying high-risk households. In conclusion, the The developed community-based sanitation risk model provides a simple, evidence-based tool for identifying households at high risk of childhood diarrhea in flood-prone urban settlements. This model can support targeted sanitation interventions and strengthen community-level disease prevention programs.

Keywords: Sanitation Risk Model, Childhood Diarrhea, Flood-prone Settlements, Environmental Health, Community-based Assessment

INTRODUCTION

In flood-prone settlements, particularly among vulnerable populations such as children, diarrhea increases due to several intertwined factors linked to environmental sanitation, domestic waste, and drainage systems. The interaction between these elements creates an environment conducive to waterborne diseases, exacerbating public health crises in already vulnerable communities.

Environmental sanitation can controlling disease outbreaks, particularly in contexts where flooding leads to the contamination of water sources. Studies have demonstrated that cholera and typhoid, both of which are transmitted through contaminated water, become more prevalent in flood-stricken areas where sanitation infrastructure is inadequate. For instance, instances of diarrhea and other waterborne diseases heighten in regions like Northwest Ethiopia, where flooding exacerbates existing poor sanitary conditions, leading to a surge in infection rates among children under five years old (Birhan et al., 2023). Moreover, poor sanitation and waste disposal practices, including open defecation, significantly contribute to the spread of these diseases (Anggraini & Purnamawati, 2023; Aurora et al., 2025). The sanitation-related risks posed by flooding events in these communities cannot be overstated, as they lead to a direct increase in health complications due to contamination of drinking water sources, as evidenced during dam spillages in Ghana (Dumevi et al., 2024).

The relationship between drainage systems and health outcomes is important in urban planning for flood-prone areas. Poorly designed or insufficient drainage systems can cause water to accumulate, creating breeding grounds for pathogens that are responsible for diarrheal diseases (Mahamane et al., 2023). For example, ineffective urban drainage systems in various cities lead to significant health risks as untreated wastewater mixes with stormwater runoff, affecting not just the water supply but also the health of the community (Liao, 2025; Prayogo et al., 2023). Mobilization of local governments to ensure effective wastewater management and urban planning can mitigate some of these health risks significantly, as noted by Dirgawati et al (Dirgawati et al., 2021).

The socio-economic factors influencing sanitation practices further complicate the health landscape in flood-prone areas. Populations living in informal settlements often lack access to reliable sanitation and clean water resources, making them disproportionately vulnerable to diseases like diarrhea (Madubedube et al., 2021; Mottelson & Venerandi, 2023). The correlation between environmental conditions, local socio-economic status, and the incidence of diarrhea underscores the necessity for holistic approaches to public health that include improving access to clean water, enhancing drainage systems, and elevating community awareness about sanitation practices (Adil et al., 2021; Sarfefa et al., 2024).

Despite considerable research focusing on sanitation infrastructure, gaps remain in the development of community-based risk models that effectively integrate environmental factors, behavioral considerations, and community capacity within the context of urban flooding. Most existing studies have primarily examined the isolated impacts of infrastructure improvements on health outcomes, often neglecting how these elements interact within a community during flood events.

Community-level sanitation initiatives have shown promise in addressing waterborne diseases; for example, improvements in water and sewage systems have substantially reduced diarrheal diseases in various regions, indicating that infrastructure is fundamental in public health outcomes (Alsan & Goldin, 2019). However, these studies typically do not incorporate local community behaviors or environmental characteristics, which are crucial for understanding vulnerability in the face of flooding.

Research conducted by Othoo et al. has highlighted the vulnerabilities of sanitation facilities in urban informal settlements, emphasizing that factors such as construction quality, design, and user behavior exacerbate risks during flooding (OTHOO et al., 2021). These insights underscore the need for an integrated approach that considers the physical, social, and behavioral dimensions of communities rather than just focusing on infrastructural improvements or epidemiological outcomes. Current models often overlook how environmental degradation—like increased impermeable surfaces—can worsen flood impacts, subsequently elevating health risks associated with poor sanitation infrastructure (Hermawan et al., 2025).

The lack of adequately tailored strategies and models for urban flooding and sanitation is problematic. Although Asebe et al. discuss the correlation between improved sanitation facilities and reduced risks of infections among children, their findings focus primarily on child nutrition rather than broader implications for urban flooding context (Asebe et al., 2024). While the interplay of sanitation and health is notable, more studies are needed specifically addressing community behavior, local environmental data, and infrastructure resilience in the context of urban flooding.

This study addresses this gap by developing and validating a community-based sanitation risk model for childhood diarrhea in flood-prone urban settlements. The model integrates key environmental, infrastructural, and behavioral sanitation factors identified through multivariable analysis and translates them into a practical risk scoring system. By quantifying household-level sanitation risk, the model aims to support targeted interventions, improve sanitation prioritization, and strengthen community-level diarrhea prevention strategies in vulnerable urban populations.

METHOD

This study employed an analytical cross-sectional design to develop and validate a community-based sanitation risk model for childhood diarrhea in flood-prone urban settlements. The research was conducted in densely populated neighborhoods with a history of recurrent flooding, characterized by inadequate drainage systems, limited sanitation infrastructure, and high child morbidity. A total of 240 households with children under five years of age were selected using proportional cluster sampling to ensure representation across all subareas with varying levels of flood exposure. Eligible participants were biological mothers or primary caregivers aged 18 years or older who had lived in the study area for at least six months.

Data collection was carried out using three complementary instruments: (1) a structured caregiver questionnaire, (2) a standardized household sanitation observation checklist, and (3) an environmental assessment form. The questionnaire captured sociodemographic information, hygiene behaviors, water use practices, and the occurrence of childhood diarrhea within the preceding 14 days. The observation checklist evaluated key sanitation components, including the type and condition of household latrines, solid waste disposal methods, domestic wastewater management, drainage conditions, and evidence of standing water after rainfall or flooding. Environmental observations also recorded proximity to waste accumulation sites, flood depth, and duration of standing water. All sanitation components were operationalized using established WASH indicators and assigned risk scores ranging from 0 (low risk) to 3 (high risk), which were later used to construct a preliminary sanitation risk index.

Flood exposure was assessed based on caregiver reports and environmental markers, categorized into three

levels: no exposure, occasional shallow flooding, and frequent or deep flooding. Childhood diarrhea was defined according to WHO criteria as the passage of three or more loose stools within 24 hours. Caregivers were asked to report episodes occurring within a 14-day recall period prior to the survey. To ensure data accuracy, enumerators underwent a three-day training session involving interview techniques, checklist calibration, and inter-rater reliability testing to standardize environmental scoring. Field supervisors conducted daily data verification, and 10% of households were revisited for quality control.

Data analysis proceeded in three stages. First, descriptive statistics were generated to summarize demographic characteristics, sanitation conditions, and diarrhea prevalence. Second, bivariate analysis using Chi-square tests was performed to identify crude associations between each sanitation variable and diarrhea incidence. Variables with p-values < 0.25 were retained for multivariable analysis. Third, a multivariable logistic regression model was constructed to determine adjusted odds ratios (AORs) and 95% confidence intervals for predictors of childhood diarrhea. Only variables with $p < 0.05$ in the final model were included in the sanitation risk model. Model fit was assessed using the Hosmer–Lemeshow test, while model discrimination was evaluated using the area under the receiver operating characteristic curve (AUC). The final sanitation risk model was presented in the form of a risk matrix and scoring algorithm suitable for community-level application.

Ethical approval for the study was obtained from the institutional ethics committee (Approval Number : 2547/UN21.8/PT.01.04/2025). All participants provided written informed consent after a detailed explanation of the study purpose, procedures, benefits, and confidentiality safeguards. No identifiers were recordekl;d, and all data were handled in accordance with research ethics standards.

RESULTS AND DISCUSSION

A total of 240 households with children under five years old participated in this study. Table 1 presents the demographic and environmental characteristics of the 240 participating households. Most caregivers were mothers (92.5%) and predominantly within the 25–34-year age range, with the majority having completed junior or senior high school. Sanitation conditions in the study area were generally suboptimal, as reflected by the high proportion of households with unimproved latrines (43.3%), improper solid waste disposal (52.9%), and clogged drainage systems (54.2%). Nearly one in five households experienced frequent flooding, and over half relied on groundwater sources for daily use.

Table 1
Characteristics of Respondents

Characteristic	Category	n	%
Caregiver Relationship	Mother	222	92.5
	Grandmother / Other	18	7.5
Caregiver Age (years)	< 25	36	15.0
	25–34	124	51.7
	≥ 35	80	33.3
Education Level	Primary school	55	22.9
	Junior high school	84	35.0
	Senior high school	78	32.5
	College / University	23	9.6
Household Flood Exposure	None / Low	94	39.2
	Moderate	104	43.3
	High / Frequent	42	17.5
Water Source	Piped water	98	40.8
	Wells / Groundwater	120	50.0
	Other sources	22	9.2
Latrine Type	Improved	136	56.7
	Unimproved	104	43.3
Solid Waste Disposal	Proper disposal	113	47.1
	Improper disposal	127	52.9
Drainage Condition	Functional	110	45.8
	Clogged / Standing water	130	54.2
Child Diarrhea (past 14 days)	Yes	66	27.5
	No	174	72.5

Several sanitation-related variables demonstrated association with childhood diarrhea. Poor water quality, inadequate solid waste management, unimproved latrines, clogged drainage, and limited handwashing practices were all significantly correlated with diarrhea incidence ($p < 0.05$). Table 2 explains the bivariate analysis examining the relationship between various sanitation factors and the incidence of childhood diarrhea. The findings show that all assessed sanitation variables were significantly associated with diarrhea, as indicated by p-values ≤ 0.002. Children living in households with contaminated water sources had nearly three times higher diarrhea prevalence (36.8%) compared to those with safe water (12.5%). Similarly, unimproved latrines were associated with substantially higher diarrhea rates (34.7%) than improved latrines (17.1%). Improper solid waste disposal (33.9%) and clogged drainage (38.2%) also showed strong links to diarrhea, emphasizing the role of environmental cleanliness. Behavioral factors were equally important: children from households with inadequate handwashing practices experienced more diarrhea (32.5%) compared to those with adequate hygiene (13.2%). Finally, high flood

exposure was associated with elevated diarrhea prevalence (33.8%), demonstrating how frequent flooding increases contamination risks.

Children living in households with contaminated water sources had significantly higher odds of diarrhea compared to those using safe water (OR = 4.07; 95% CI: 2.10–7.89; p < 0.001). Similarly, unimproved latrine conditions were associated with increased diarrhea risk (OR = 2.58; 95% CI: 1.41–4.71; p = 0.002). Improper solid waste disposal (OR = 3.09; 95% CI: 1.72–5.57; p < 0.001) and clogged drainage systems (OR = 4.83; 95% CI: 2.62–8.89; p < 0.001) also showed strong associations with diarrhea incidence.

Behavioral factors were equally important. Inadequate handwashing practices were associated with more than a threefold increase in diarrhea risk (OR = 3.18; 95% CI: 1.71–5.91; p < 0.001). Households experiencing high flood exposure also had significantly higher diarrhea prevalence (OR = 2.75; 95% CI: 1.47–5.15; p < 0.001).

Table 2
Bivariate Analysis of Sanitation Factors and Childhood Diarrhea

Sanitation Variable	Categories	Diarrhea (%)	χ^2	p-value
Water Quality	Safe	12.5	18.42	<0.001
	Contaminated	36.8		
Latrine Condition	Improved	17.1	9.87	0.002
	Unimproved	34.7		
Solid Waste Disposal	Proper	14.3	16.11	<0.001
	Improper	33.9		
Drainage Condition	Functional	11.4	25.29	<0.001
	Clogged/Standing water	38.2		
Handwashing Behavior	Adequate	13.2	14.66	<0.001
	Inadequate	32.5		
Flood Exposure	Low/None	15.7	12.48	<0.001
	High	33.8		

A multivariable logistic regression model was developed to identify the strongest predictors of childhood diarrhea. Five variables remained significant in the final model: contaminated water, unimproved latrine condition, improper waste disposal, clogged drainage, and inadequate handwashing behavior. These predictors formed the basis of the Community-Based Sanitation Risk Model. Table 3 presents the results of a multivariable logistic regression model identifying the strongest predictors of childhood diarrhea after adjusting for all sanitation-related variables. The analysis shows that several environmental and behavioral factors significantly increased the likelihood of diarrhea. Children exposed to a contaminated water source had more than threefold higher odds of experiencing diarrhea (AOR = 3.42, 95% CI = 1.95–5.99, p < 0.001).

Similarly, clogged or non-functional drainage emerged as one of the strongest predictors (AOR = 3.85), indicating that stagnant water and poor neighborhood drainage substantially elevate disease risk. Improper solid waste disposal (AOR = 2.67) and inadequate handwashing behavior (AOR = 2.48) were also significant predictors, highlighting the combined role of environmental contamination and personal hygiene in shaping diarrheal outcomes. Households with unimproved latrines had over twice the odds of childhood diarrhea (AOR = 2.11), underscoring the importance of safe sanitation facilities. Interestingly, high flood exposure did not reach statistical significance (p = 0.11), suggesting that its effect may be mediated through other sanitation variables when included in the full model. Model diagnostics indicated adequate goodness of fit, and no evidence of multicollinearity was detected among independent variables.

Table 3
Multivariable Logistic Regression Predicting Childhood Diarrhea

Predictor	AOR*	95% CI	p-value
Contaminated Water Source	3.42	1.95–5.99	<0.001
Unimproved Latrine Condition	2.11	1.25–3.58	0.005
Improper Solid Waste Disposal	2.67	1.56–4.61	<0.001
Clogged/Non-functional Drainage	3.85	2.12–6.97	<0.001
Inadequate Handwashing Behavior	2.48	1.40–4.38	0.002
High Flood Exposure	1.56	0.89–2.73	0.11

** Adjusted Odds Ratio*

Table 4 presents the Community-Based Sanitation Risk Model developed to quantify household-level sanitation risk contributing to childhood diarrhea in flood-prone urban areas. The model assigns a weighted score to five key sanitation components based on their strength of association with diarrhea in the multivariable analysis. Higher scores reflect higher risk. Contaminated water sources and clogged drainage—identified as the strongest predictors—receive the highest scores (3 points each), indicating that households with these conditions are at substantially elevated risk. Unimproved latrines, improper waste disposal, and inadequate handwashing are assigned moderate weights (2 points each) because they significantly increase diarrhea risk, but with slightly lower effect sizes compared to the highest-risk factors. A score

of zero is assigned to all conditions classified as safe or adequate.

Table 4
Community-Based Sanitation Risk Model

Risk Component	Criteria	Risk Score
Water Quality	Safe	0
	Contaminated	3
Latrine Condition	Improved	0
	Unimproved	2
Waste Disposal	Proper	0
	Improper	2
Drainage Condition	Functional	0
	Clogged/Standing water	3
Handwashing Behavior	Adequate	0
	Inadequate	2

** Total score range: 0–12*
Risk Category: Low Risk (0–3), Moderate Risk (4–7), High Risk (8–12)

A comprehensive analysis of various sanitation factors has revealed associations with childhood diarrhea, highlighting critical areas for public health intervention. Factors such as the consumption of contaminated water, reliance on unimproved latrines, inadequate waste disposal practices, and poorly managed stormwater drainage systems were found to substantially increase the risk of diarrhea among children under five years old. In particular, clogged drainage systems that exacerbate flooding and water stagnation contribute to heightened levels of contamination in local water supplies (Maliga et al., 2022). Moreover, inadequate handwashing practices further compound these health risks, underscoring the importance of behavioral interventions alongside infrastructural improvements (Ferede, 2020).

The analysis emphasizes drainage condition and water safety as the foremost predictors of childhood diarrhea, with these factors displaying the strongest adjusted odds ratios (AOR) in statistical assessments. Improvements in drainage and water management systems not only promote better sanitation but also significantly reduce the incidence of diarrhea, acting as key levers for disease prevention (Merid et al., 2023). Additionally, the development of a structured sanitation risk scoring model represents a promising advancement in assessing community-specific vulnerabilities related to diarrhea. This model aims to quantify and prioritize the risks associated with various sanitation and hygiene practices within communities, facilitating targeted interventions to address the most pressing sanitation challenges effectively (Mulatu et al., 2022).

The findings regarding the associations between environmental sanitation and childhood diarrhea align closely with national and global evidence, supporting the significant impact of sanitation factors on health outcomes. Studies conducted in various regions, including Tigray, Ethiopia, detail similar patterns of increased childhood diarrhea due to unimproved water sources and inadequate sanitation facilities, underscoring the need for effective sanitation systems, particularly in conflict zones and vulnerable communities (Asgedom et al., 2023). Furthermore, global frameworks emphasize the fundamental importance of water, sanitation, and hygiene practices as core preventative measures against diarrheal diseases (Shermin & Rahaman, 2021). Research in urban slums and peri-urban areas further reflects that poor waste disposal, lack of handwashing facilities, and inadequate latrine access contribute to high incidences of diarrhea among children (Nwokoro et al., 2020).

However, notable differences emerge in local contexts influenced by cultural practices, housing density, and specific flood characteristics. For instance, behavioral practices such as handwashing may be inconsistent, even when facilities are available, due to socio-economic barriers or cultural norms that prioritize other uses of soap and water (Molewa et al., 2025). Additionally, flood events can exacerbate these conditions uniquely in different regions, creating distinct patterns of risk based on geography and local infrastructure (Dickson-Gómez et al., 2023). Such insights call for tailored interventions that consider both behavioral and structural factors within community-specific risk models, recognizing the multifaceted nature of health risks associated with urban sanitation and flooding (Mshida et al., 2020; Tadesse et al., 2022).

The risk scores attributed to variables such as water contamination and drainage conditions can be understood through their direct influence on environmental health and the transmission pathways of diarrheal diseases. Contaminated water serves as a primary vehicle for pathogens, with findings indicating that children consuming contaminated water have a significantly higher risk for diarrhea (Birhan et al., 2023). Inadequate drainage can lead to water stagnation, which not only promotes further water contamination but also creates breeding grounds for vectors that transmit diseases. This reflects the concept of "risk clustering," where multiple vulnerabilities—such as poor sanitation facilities, contaminated water supplies, and ineffective waste disposal—converge and exacerbate health risks within communities (Hubbard et al., 2020).

Moreover, the structured sanitation risk scoring model serves as a valuable tool for community-level risk stratification, allowing public health officials to identify areas of greatest need and implement targeted interventions. By quantitatively assessing combined sanitation vulnerabilities, the model can provide insights into which communities require immediate action to decrease incidences of diarrheal diseases and improve overall health outcomes. Such tailored approaches enhance resource allocation, ensuring that interventions are directed to where they are most needed, thereby maximizing the impact of sanitation initiatives on community health (Ikeda et al., 2019; Mosisa et al., 2021).

The significance of flood exposure observed in bivariate analysis but not in multivariable regression analyses likely stems from flooding's role as a mediator

that exacerbates sanitation vulnerabilities rather than acting as an independent risk factor. In contexts where flooding occurs, the immediate impacts include the contamination of drinking water sources and the disruption of sanitation infrastructure, which in turn enhance the risks associated with poor sanitation practices, such as the use of unimproved latrines and inadequate waste disposal (He et al., 2024). This mediation effect suggests that addressing sanitation alone may not be sufficient; rather, interventions must consider how flooding interacts with and worsens these vulnerabilities, as disadvantaged communities often face compounded health risks due to inadequate infrastructure (Abass et al., 2025).

The relevance of these findings extends into urban climate resilience planning, where understanding the interconnectedness of flooding and sanitation is effective and sustainable public health strategies. Urban planners and policymakers must recognize that improving sanitation infrastructure is not merely a standalone issue but one deeply intertwined with environmental management, waste disposal practices, and flood mitigation strategies (Charlesworth et al., 2022). Tailored interventions that incorporate flood management and sanitation improvements can enhance resilience and reduce the public health burden, especially in vulnerable urban informal settlements where infrastructure challenges persist (Travis et al., 2025). By adopting a holistic perspective that integrates climate resilience into sanitation planning, communities can better prepare for and mitigate the impacts of flooding, thus protecting public health outcomes against future climate-related events (Okaka & Odhiambo, 2019).

In low-income, high-density urban settlements, the utility of the model extends to effectively prioritizing resource allocation. By identifying areas with compounded sanitation vulnerabilities and high risk for diarrhea outbreaks, local governments can allocate resources where they are likely to have substantial impact on public health outcomes (Khalil et al., 2021). Furthermore, this proactive approach can enhance community resilience by aligning with broader climate adaptation strategies, reinforcing the ability of communities to withstand environmental shocks (Choudhary et al., 2021). Overall, leveraging insights from the risk scoring model can enhance the efficacy and sustainability of health interventions in vulnerable populations facing the dual challenges of sanitation inadequacies and climate-related risk.

The strengths of this study lie in its use of community-based sampling drawn directly from flood-prone urban settlements, allowing the findings to reflect real environmental challenges faced by households in high-risk areas. By employing multivariable logistic regression, the study was able to identify independent predictors of childhood diarrhea and provide a more accurate understanding of sanitation-related risks. Another strength is the development of a simple and practical sanitation risk model that translates statistical associations into an operational scoring system. This model aligns risk scores with effect sizes (AOR values), making it a useful tool for community health workers and local governments to prioritize interventions based on evidence rather than assumptions.

Despite these strengths, several limitations should be acknowledged. The cross-sectional design restricts causal inference, and reliance on self-reported hygiene behavior may introduce social desirability bias. Furthermore, the study was conducted in a single urban area, which may limit generalizability to other flood-prone settings with different cultural or environmental characteristics. Seasonal patterns of diarrhea and flooding could not be fully captured, and the absence of microbiological water testing restricts the ability to confirm contamination pathways. Future research should therefore focus on validating this risk model in diverse geographic contexts and employing longitudinal or cohort designs to assess causal relationships. Incorporating environmental sampling of water or soil, integrating digital tools such as mobile data collection or GIS mapping, and evaluating targeted behavioral interventions could further enhance the precision and applicability of sanitation risk assessments in vulnerable urban populations.

CONCLUSIONS

This study demonstrates that multiple sanitation-related factors—including water quality, latrine conditions, waste disposal practices, drainage functionality, and handwashing behavior— are determining the risk of childhood diarrhea in flood-prone urban settlements. Using these predictors, a practical community-based sanitation risk model was developed, providing a simple scoring system that can classify households into low-, moderate-, and high-risk categories. This model offers a valuable tool for health workers, local governments, and community organizations to identify priority areas, guide intervention planning, and strengthen disease prevention efforts. By translating complex statistical relationships into an accessible framework, the model has the potential to support more effective and targeted public health strategies aimed at reducing the burden of diarrhea among vulnerable children living in environmentally challenged urban settings. Future efforts should focus on validating and refining this model across diverse regions and integrating it into broader urban resilience and public health programs.

SUGGESTION

Based on the findings of this study, several recommendations can be proposed for improving environmental health practices in flood-prone urban settlements. First, local governments and community health centers should prioritize interventions that address the most influential sanitation risk factors identified in this study—particularly improving household water safety, ensuring functional drainage systems, and promoting consistent handwashing practices. Implementing community-based sanitation improvement programs,

especially those aligned with the STBM (Sanitasi Total Berbasis Masyarakat) pillars, may help reduce diarrhea risk at the household and neighborhood levels.

For policy development, integrating the sanitation risk model into routine surveillance and early-warning systems could support more targeted resource allocation during flood seasons. Schools, community leaders, and health workers can also adopt this model as a simple assessment tool to identify high-risk households and plan tailored educational or infrastructural interventions. For future research, it is recommended to validate the model in different geographic and socio-environmental contexts, incorporate environmental sampling such as water or soil testing, and explore longitudinal approaches to better capture seasonal variations and causal pathways. Such efforts will strengthen the evidence base and enhance the model's applicability in broader environmental health initiatives.

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