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Water, environment, and health nexus: understanding the risk factors for waterborne diseases in communities along the Tano River Basin, Ghana

Saeed Ibn Idris Kofi Yeboah[a,b,*], Prince Antwi-Agyei[a,b], Amos T. Kabo-Bah[a,b] and Nana Osei Bonsu Ackerson[a,b]

[a] Department of Civil and Environmental Engineering, University of Energy and Natural Resources, P.O. Box 214, Sunyani, Ghana
[b] Regional Centre for Energy and Environmental Sustainability (RCEES), University of Energy and Natural Resources, P.O. Box 214, Sunyani, Ghana
*Corresponding author. E-mail: saeed.yeboah@uenr.edu.gh

SIIKY, 0000-0002-8088-4920

ABSTRACT

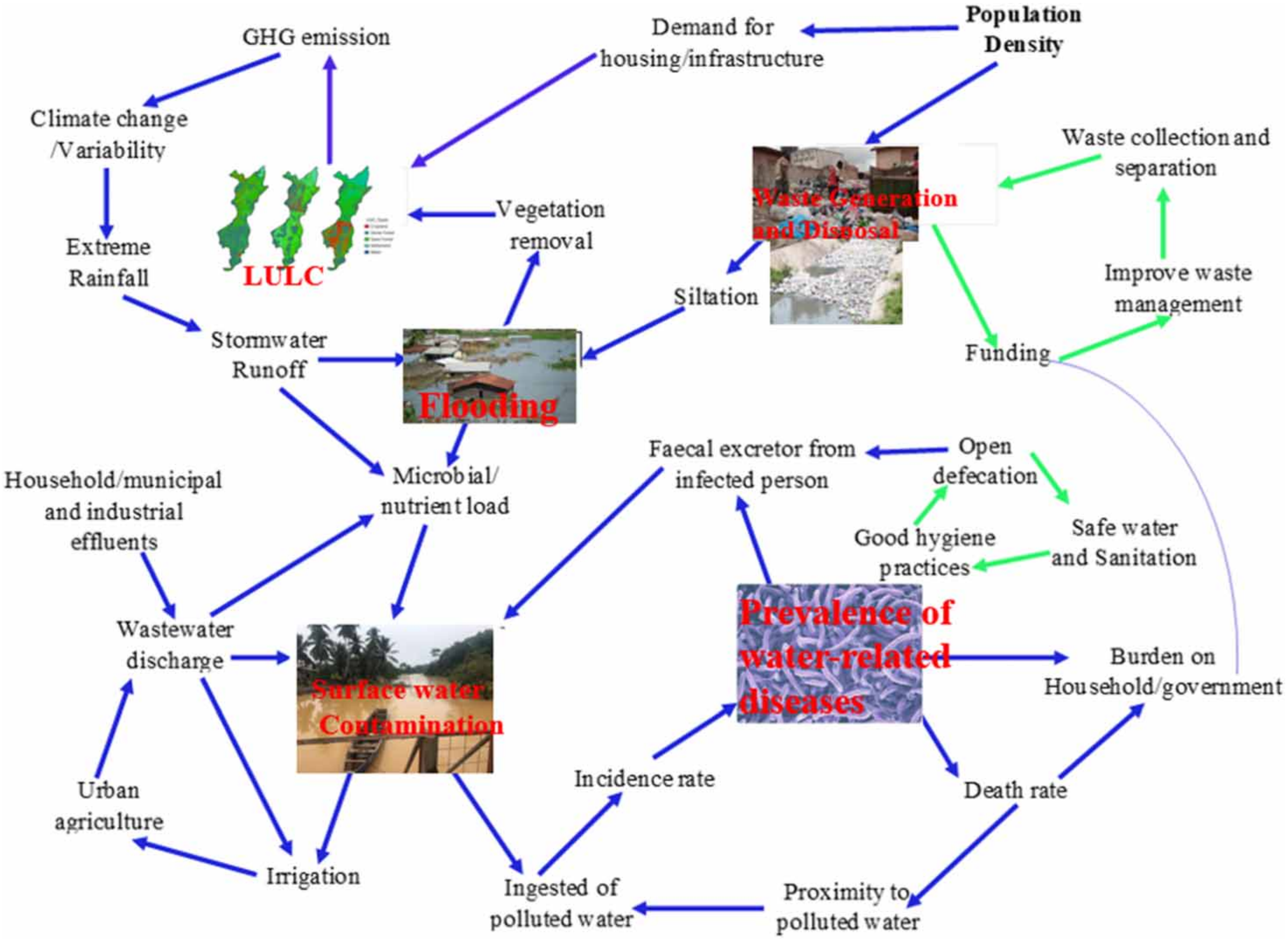
Freshwater pollution is a major concern in Ghana, directly impacting human health. However, the underlying drivers of exposure and risks are not comprehensively understood, emphasizing the severity and impact of these diseases. This study assessed the interaction between water and human health, specifically focusing on the risk factors for waterborne diseases and the drivers of water pollution among residents near the Tano River Basin, Ghana. A sample size of 400 households was selected from five communities within the basin based on their proximity to the Tano River. In addition, the study combined both spatial and non-spatial data sources to map potential flood zones for the basin. The study found that inadequate sanitation, poor hygiene practices, and contamination from illegal mining were the primary causative factors of waterborne diseases. Additionally, floods and improper waste management significantly contributed to disease outbreaks. The flood susceptibility analysis indicated that areas highly susceptible to flooding cover 21.2% of the basin, predominantly in the southern part. The results highlight the urgent need for comprehensive interventions to address the drivers of waterborne diseases. This study will contribute to the local authorities in developing plans to prevent waterborne diseases and mitigate their economic and public health impacts.

Key words: Ghana, public health, Tano River Basin, waste management, water and sanitation, water pollution

HIGHLIGHTS

- Identified primary contributors: inadequate sanitation, poor hygiene, and illegal mining contamination.
- High flood risk zones cover 21.2%, mainly in the southern region.
- Integrated spatial and non-spatial data for flood zone mapping.
- Floods and waste mismanagement exacerbate waterborne disease incidence.
- Urgent need for comprehensive interventions highlighted; policy recommendations for authorities provided.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Water is a crucial resource for aquatic ecosystems and provides numerous health benefits. However, water pollution can destroy ecosystems and spread waterborne diseases, resulting in significant economic consequences. Natural factors like climate change and natural disasters, as well as human activities, influence the state of water resources (Charnley *et al.* 2022). Waterborne diseases are often associated with communities that have limited access to clean water and sanitation facilities. Despite advancements in access to clean water and sanitation in some regions, waterborne diseases continue to be a major burden, particularly in vulnerable areas of Africa and Asia (Mabhaudhi *et al.* 2019).

Global trends like rapid population growth, urbanization, and environmental changes such as climate change and land use alterations exacerbate the scarcity and pollution of freshwater resources worldwide. Waterborne diseases remain a significant burden globally, mainly due to the inadequate investment in clean water and sanitation infrastructure despite the growing threats posed by climate change disasters, conflicts between transboundary countries and among competitive users, drought, and frequent flooding (Ntajal *et al.* 2020). In 2019 alone, diarrhea claimed the lives of over 370,000 children under five, with water, sanitation, and hygiene-related infections contributing to an estimated 21,000–143,000 deaths worldwide (Charnley *et al.* 2022).

In addition to water access and sanitation, land use, waste management, and water pollution are significant contributors to waterborne disease exposure and risks (Ntajal *et al.* 2020; Brattig *et al.* 2021). Moreover, changes in land use patterns, driven by urbanization and agricultural expansion, alter hydrological dynamics and increase the likelihood of surface water contamination (McGrane 2016).

Natural disasters, particularly floods, pose additional threats by disrupting water and sanitation infrastructure and contaminating water sources with sewage and other pollutants (Islam *et al.* 2021). For instance, flood events can contaminate surface water and sewage-disposal systems, leading to outbreaks of waterborne diseases when the contaminated water sources are ingested (Walika *et al.* 2023). The rapid spread of waterborne pathogens during floods underscores the vulnerability of communities dependent on surface water sources and inadequate sanitation facilities. However, there is limited research on how these factors interact to influence pathogen levels in surface water, highlighting the need for further investigation to mitigate health risks.

In Ghana, despite improvements in access to drinking water and sanitation, communities in flood-prone areas, such as the Tano River catchment in Bono, Bono East, Western Ghana, and parts of Côte d'Ivoire, experience frequent outbreaks of diarrheal diseases (Honlah *et al.* 2019). In 2016, the incidence of diseases like cholera, typhoid, and dysentery in these regions was approximately 25.6 and 26.5% (Honlah *et al.* 2019). Inadequate sanitation, poor hygiene, and water contamination are some of the underlying causative factors. Waterborne diseases generally have different causes and underlying drivers influencing the outbreaks.

Despite advancements in understanding the direct links between water quality, sanitation, and hygiene (WASH) and waterborne diseases, gaps remain in comprehending how complex interactions among these factors, alongside broader environmental changes, influence disease dynamics (UNICEF & WHO 2022). This study aims to address these gaps by investigating the drivers of waterborne diseases in the Tano River catchment area. Specifically, it examines the interaction between water quality and human health, focusing on identifying and understanding the risk factors for waterborne diseases among residents near the Tano River Basin, Ghana. The findings will support local authorities in formulating effective strategies to prevent disease outbreaks and mitigate their adverse impacts on public health and the economy.

2. MATERIALS AND METHODS

2.1. Descriptions of the study area

The Tano River Basin is a crucial water resource in Ghana, holding significant socioeconomic value. The Ghana Water Company Limited (GWCL) has constructed dams at Tanoso, Sefwi Wiawso, and Elubo along the river to treat and distribute drinking water to over 2.4 million people in the Bono, Bono East, Ahafo, and Western Regions (Water Resources Commission & Ghana Country Water 2019; Obiri *et al.* 2021). The Tano River has a basin area of approximately 15,000 km^2, shared between Ghana and Cote D'Ivoire (Larbi *et al.* 2022). This river supports various activities such as irrigation, bathing, and drinking and also serves as a recipient of raw pollutants.

Over the past 37 years (1981–2019), the Tano basin has experienced annual rainfall ranging from 1,136.7 to 2,156.0 mm (Nasirudeen *et al.* 2021). Peak rainfall seasons occur in May/June and October/November. Although the duration of rainfall has decreased, its intensity has increased, with cumulative rainfall rising by 4.7 mm per decade from 1980 to 2021 (GMet 2021). The annual temperature in the area ranges between 23.0 and 32.0 °C, with variations of 3–5 °C from the mean during the daytime (Nyantakyi *et al.* 2020). Major rainy seasons are from May to June, while minor rainy seasons occur from March to April and September to October (WRC 2017).

Flooding is a recurrent issue in the Tano River Basin, with a more than 10% chance of flooding due to extremely high rainfall each year (Larbi *et al.* 2022). Intermittent droughts also affect the Tano catchment (Nasirudeen *et al.* 2021), reducing water volume and increasing pollutant concentrations in stagnant waters, which can contaminate drinking water during floods (Marchionni *et al.* 2020).

Pollution from domestic and industrial discharges significantly affects the Tano River and its tributaries (Asare-Donkor & Adimado 2016; Banunle & Fei-Baffoe 2018; Nyantakyi *et al.* 2020).

WASH-related diseases are a critical concern in this region. Frequent outbreaks of diseases such as cholera, typhoid, and dysentery are linked to inadequate water, sanitation, and hygiene infrastructure. Communities near the Tano River are particularly vulnerable due to their dependence on the river for various activities and their exposure to pollution and flooding. To explore the dynamics of waterborne diseases, five communities within the Tano River catchment were selected for household surveys: Tanoso, Techiman, Sefwi Wiawso, Asemkrom, and Elubo. These communities were chosen based on their proximity to the main river drains (within a 100 m buffer), influencing their interaction with the river, exposure to frequent floods, and risk of waterborne diseases (Amoueyan *et al.* 2020). The proximity to the river increases the likelihood of exposure to polluted water, thereby heightening the risk of WASH-related diseases. The study also aims to understand the complex interactions between environmental factors and human health outcomes, focusing on the drivers of waterborne diseases in the Tano River Basin.

2.2. Methodological approach

2.2.1. Sampling and sample size estimation for household surveys

To collect data on the exposure to and risks of waterborne diseases, household surveys were conducted in April and May 2023. The five communities chosen for the survey were selected based on their proximity to the main Tano River. According to the Ghana Water Resource Commission, the Tano River Basin is home to approximately 2.4 million people who live and work along the basin. To ensure a fair representation of the sampled population, the (Yamane 1967) formula was used to determine the appropriate sample size of the study by projecting the sample frame as 400 across all the existing regions along the Tano River Basin of Ghana.

$$n = \frac{N}{1 + N(e)^2} \quad (1)$$

where n is the sample of the study, N is the total target population of 2,400,000 (WRC 2017; Obiri *et al.* 2021), and α is the confidence level, 0.05.

Therefore, a sample size (n) of 400 households was estimated for the survey. Respondents' anonymity was assured, and their consent was obtained using custom consent forms. With a target sample size of 400, all selected households consented to participate. The sample was evenly distributed among the five purposively selected communities (Techiman, Tanoso, Safwi Waoso, Asemkrom, and Elubo) within the Tano River catchment area. In each community, 80 households were randomly chosen to participate based on their proximity to the main Tano River. These communities shared similar physical, socio-cultural, and economic characteristics, making individual household differences less relevant to the study. The survey was digitally coded and administered using the KoBoCollect tool. It was designed to cover key topics, including access to water and sanitation, risks of waterborne diseases, and underlying factors contributing to water pollution, such as floods and household waste management practices. However, to comprehensively understand the drivers of water pollution within the Tano River Basin, a multifaceted methodology was employed. Initially, a thorough review of existing literature about water pollution drivers, specifically focusing on studies relevant to the region, was conducted. This literature review served as a foundation for identifying key factors influencing water quality. Primary data from the structured questionnaire interviews and surveys with stakeholders were also integrated (Figure 1). Secondary data from governmental agencies, environmental reports, and research articles were also gathered to complement the analysis.

2.2.2. Respondents survey

A cross-sectional study was employed for the study. A survey using questionnaires was conducted with inhabitants in the community to assess their knowledge of water-related diseases. Information about the public awareness of current water management practices and the incidence of water-related diseases was evaluated. Four hundred (400) questionnaires were administered to the selected community respondents.

The study examined various demographic and socioeconomic factors, including gender, education level, age group, religion, duration of community residence, and occupation. Factors such as water and sanitation facilities, waste management methods and practices, waterborne disease prevalence, and potential drivers of Tano River water pollution, personal hygiene, and food safety behaviors were also assessed. To ensure the questionnaire's effectiveness, it underwent review and testing on various households from different river basins in the Bono Region of Ghana. Feedback from this trial run was utilized to refine the questionnaire, focusing on question clarity, language comprehension, relevance to environmental realities, time needed for completion, and sensitivity of inquiries. These insights guided the final questionnaire revisions. Survey questions were constructed using Kobocollect version V2023.1.2, a mobile and web-based data collection tool developed by the Harvard Humanitarian Initiative (HHI). Kobocollect integrates natural language processing features for survey question analysis. Before the interview, each participant was provided with a consent form to ensure full comprehension of the study and its requirements. Upon completion and understanding of the consent form, the interview proceeded as planned.

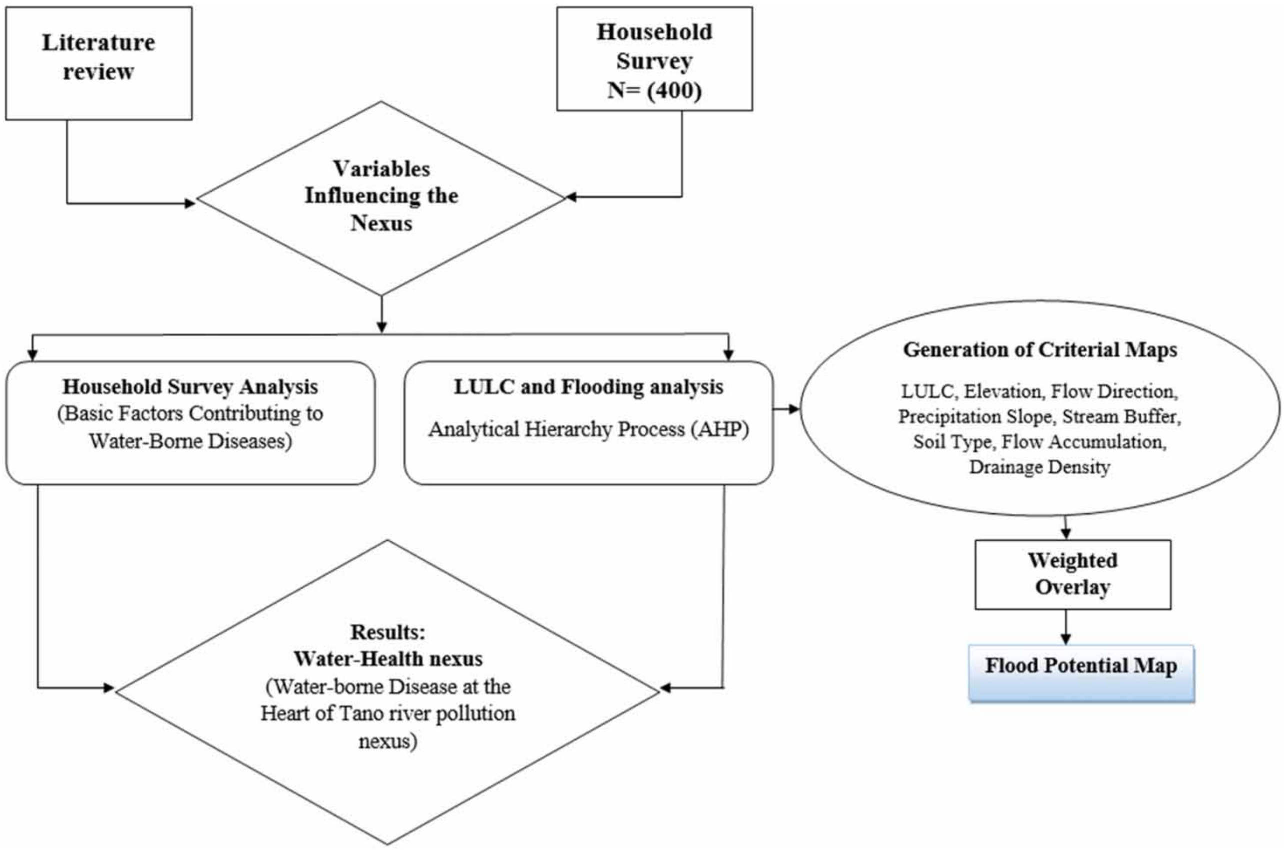


Figure 1 | Methodological framework of the study.

2.3. Input data for flood potential mapping

The study utilized both spatial and non-spatial data sources. Sentinel-2 imagery was employed, providing images with a spatial resolution of 10–60 m across 13 bands. This satellite imagery was used to extract vegetation cover. Additionally, topographic data from the Shuttle Radar Topographic Mission (SRTM), with a 30-m spatial resolution, were used to create a depressionless digital elevation model (DEM) (refer to Supplementary Sheet). Other derived datasets included flow accumulation, flow direction, drainage basin, and slope. These datasets were essential for analyzing flood risk and understanding the spatial characteristics of the study area.

2.3.1. Spatial data and collection source

Materials used for the flood assessment were obtained from Sentinel archives acquired from the USGS, SRTM, and TAMSAT satellite data. All thematic data preparation tasks were carried out using ENVI and ArcGIS software (Roy & Saha 2016). TAMSAT daily rainfall data was downloaded from the TAMSAT website using TAMSAT data extractor. CSV files were then downloaded and analyzed. This was done using time series selection per pixel and choosing the GPS coordinates matching with the location of the weather data on the ground to be able to compare satellite and ground station data. Rainfall intensity and land use change maps were also derived for the flood susceptivity map.

2.3.2. Analytic hierarchy process

The study utilized the analytic hierarchy process (AHP) to tackle intricate issues with multiple criteria. This method evaluates decisions using mathematical techniques that incorporate the preferences of decision-makers or groups within a specific field, considering selected factors. As the approach relies on expert judgment to ascertain the relative importance of factors, comparison matrices were established for both geophysical and vulnerability factors, organized according to the parameters' level of significance (Jalayer *et al.* 2014; Mukherjee & Singh 2020; Ullah & Id 2020) (refer to Supplementary Sheet).

2.3.3. Parameter selection and data processing

Nine parameters were selected for flood risk assessment, including elevation, slope, flow direction, flow accumulation, drainage basin, land use/land cover change, soil type, distance to river, and rainfall intensity. All parameters were resampled to 30 by 30-m grid data and classified into five flood risk classes ranging from very low to very high risk. Detailed processing methodologies were applied to each parameter, including DEM correction, flow direction raster construction, flow accumulation analysis, drainage basin delineation, land use/land cover classification, and soil type classification. Elevation and slope were analyzed to understand their impact on flooding, with DEM data obtained from the USGS website and processed using ArcGIS tools. Flow direction analysis was conducted using the flow direction tool in ArcGIS to establish flow patterns, and flow accumulation was calculated to delineate drainage networks. Drainage basins were delineated to identify flood-prone areas, and land use/land cover change was mapped using Sentinel 2 imagery through supervised classification. Soil type data were derived from the iSDAsoil dataset to assess water-holding capacities. Each parameter's classification was conducted to facilitate flood risk assessment and management. A matrix was developed for the AHP to evaluate the relative importance of factors, with factors including LULC, elevation, flow direction, precipitation, slope, stream buffer, soil type, flow accumulation, and drainage density. Pairwise comparisons were made between factors to determine their relative importance, with normalized principal eigenvectors calculated for each factor. The matrix provided a systematic approach to weighting factors based on their significance in flood risk assessment (refer to Supplementary Sheet).

2.4. Data analysis

Data entry was performed using Kobocollect, followed by analysis and tabulation using SPSS software Version 26 (SPSS Inc., Chicago, Illinois). Descriptive statistics, including frequencies and percentages, were used to summarize all variables. To evaluate the association between socio-demographics and the incidence of waterborne diarrhea disease, the Chi-square test was applied at a 95% significance level. The study also utilized spatial and non-spatial data to assess flood risk in the Tano River Basin. Flood assessment is crucial for understanding waterborne disease risk factors and pollution pathways, as flooding can exacerbate contamination of water sources, spread pathogens, and amplify the impact of inadequate sanitation and hygiene practices on public health. Spatial analysis techniques such as satellite imagery, digital elevation models, and hydrological analysis were employed to map flood zones within the Tano River Basin and assess their impact on waterborne disease outbreaks. In addition, demographic characteristics such as age, educational level, and years of residence in the community were subsequently tabulated to assess respondents' perceptions of the major causes of pollution in the Tano River catchment. Descriptive statistics and the Chi-square (χ^2) test were utilized to describe patterns of variability and to test for independence. The Chi-square test statistic was calculated using Equation (2) (McHugh 2013), as follows:

$$X^2 = \sum_{i=1}^{r} \sum_{j=1}^{c} \frac{(o_{ij} - e_{ij})^2}{e_{ij}} \quad (2)$$

where o_{ij} is the observed count; and e_{ij} is the expected count.

3. RESULTS AND DISCUSSION

3.1. Characteristics of study respondents

Overall, the survey included 400 respondents, with 64.5% being males and 35.5% being females (Table 1). The respondents had an average age of 34 years, ranging from 18 to 67 years. Two respondents reported having some form of visual impairment disability. In terms of religious affiliation, the majority of respondents (67.4%) identified as Christian. Marital status exhibited significant variation, with Safwi Waoso having the highest percentage of married respondents (78.75%), while Elubo had the lowest (52.50%). The education levels of respondents varied across communities, with Junior High School/Middle School being the most common attainment in all communities except Elubo, where Primary education had the highest representation (38.75%). The communities showed a relatively stable and long-term residency pattern, with the highest proportions of residents falling within the 20–25 years age category in Techiman, Tanoso, Safwi Waoso, and Asemkrom.

Table 1 | Respondents demographic characteristics

Variable	Items of measurement	Techiman (%)	Tanoso (%)	Safwi Waoso (%)	Asemkrom (%)	Elubo (%)	Total (%)	Average
Gender (%)	Male	57 (71.25)	70 (87.50)	42 (52.50)	45 (56.25)	44 (55.00)	258	51.6 ± 11.845
	Female	23 (28.75)	10 (12.50)	38 (47.50)	35 (43.75)	36 (45.00)	142	28.4 ± 11.845
Age (years)	18–25	12 (15.00)	13 (16.25)	10 (12.50)	17 (21.25)	11 (13.75)	63	12.6 ± 2.702
	26–35	33 (41.25)	40 (50.00)	37 (46.25)	46 (57.50)	35 (43.75)	191	38.2 ± 5.070
	36–45	23 (28.75)	15 (18.75)	26 (32.50)	13 (16.25)	25 (31.25)	102	20.4 ± 5.983
	46–60	6 (7.50)	11 (13.75)	3 (3.75)	4 (5.00)	7 (8.75)	31	6.2 ± 3.114
	More than 60	6 (7.50)	1 (1.25)	4 (5.00)	0 (0.00)	2 (2.50)	13	2.6 ± 2.408
Marital status (%)	Married	56 (70.00)	50 (62.50)	63 (78.75)	42 (52.50)	53 (66.25)	264	52.8 ± 7.727
	Single	16 (20.00)	22 (27.50)	8 (10.00)	20 (25.00)	10 (12.50)	76	15.2 ± 6.099
	Divorced	3 (3.75)	6 (7.50)	1 (1.25)	8 (10.00)	6 (7.50)	24	4.8 ± 2.775
	Widowed	3 (3.75)	1 (1.25)	0 (0.00)	7 (8.75)	5 (6.25)	16	3.2 ± 2.864
	Engaged	0 (0.00)	0 (0.00)	5 (6.25)	3 (3.75)	0 (0.00)	8	1.6 ± 2.302
	Separated	2 (2.50)	1 (1.25)	3 (3.75)	0 (0.00)	6 (7.50)	12	2.4 ± 2.302
Education level (%)	None	13 (16.25)	7 (8.75)	18 (22.50)	17 (21.25)	13 (16.25)	68	13.6 ± 4.336
	Primary	16 (20.00)	14 (17.50)	10 (12.50)	17 (21.25)	31 (38.75)	88	17.6 ± 7.956
	Junior High School/Middle School	41 (51.25)	46 (57.50)	48 (60.00)	40 (50.00)	22 (27.50)	197	39.4 ± 10.286
	Senior High School	3 (3.75)	5 (6.25)	1 (1.25)	2 (2.50)	5 (6.25)	16	3.2 ± 1.789
	Vocational/Technical	4 (5.00)	6 (7.50)	2 (2.50)	4 (5.00)	7 (8.75)	23	4.6 ± 1.949
	Tertiary Education	3 (3.75)	2 (2.50)	1 (1.25)	0 (0.00)	2 (2.50)	8	1.6 ± 1.140
Religion (%)	Christian	51 (63.75)	69 (86.25)	72 (90.00)	77 (96.25)	68 (85.00)	337	67.4 ± 9.813
	Muslim	24 (30.00)	10 (12.50)	4 (5.00)	1 (1.25)	10 (12.50)	49	9.8 ± 8.843
	Others	5 (6.25)	1 (1.25)	4 (5.00)	2 (2.50)	2 (2.50)	14	2.8 ± 1.643
Years of living in community (%)	1–5	5 (6.25)	2 (2.50)	4 (5.00)	1 (1.25)	4 (5.00)	16	3.2 ± 1.643
	6–10	3 (3.75)	7 (8.75)	2 (2.50)	6 (7.50)	2 (2.50)	20	4 ± 2.345
	11–15	2 (2.50)	3 (3.75)	5 (6.25)	2 (2.50)	2 (2.50)	14	2.8 ± 1.304
	16–20	15 (18.75)	6 (7.50)	4 (5.00)	5 (6.25)	8 (10.00)	38	7.6 ± 4.393
	20–25	39 (48.75)	22 (27.50)	39 (48.75)	45 (56.25)	33 (41.25)	178	35.6 ± 8.706
	More than 25 years	16 (20.00)	40 (50.00)	26 (32.50)	21 (26.25)	31 (38.75)	134	26.8 ± 9.257
Occupation	Farming	63 (78.75)	70 (87.50)	58 (72.50)	60 (75.00)	66 (82.50)	317	63.4 ± 4.775
	Trading	8 (10.00)	2 (2.50)	5 (6.25)	5 (6.25)	10 (12.50)	30	6 ± 3.082
	Public servant	3 (3.75)	1 (1.25)	4 (5.00)	0 (0.00)	1 (1.25)	9	1.8 ± 1.643
	Unemployed	2 (2.50)	5 (6.25)	10 (12.50)	3 (3.75)	3 (3.75)	23	4.6 ± 3.209
	Others	4 (5.00)	2 (2.50)	3 (3.75)	12 (15.00)	0 (0.00)	21	4.2 ± 4.604
Type of farming activities	Crop farming	40(10.0)	38(9.50)	37 (9.25)	41(10.25)	51 (12.75)	207	41.4 ± 5.595
	Livestock rearing	16(4.0)	29(7.25)	13 (3.35)	14(3.50)	9 (2.25))	81	16.2 ± 7.560
	Both	7(1.75)	3 (0.75)	8(2.0)	5(1.25)	6(1.5)	29	5.8 ± 1.924

3.2. Factors contributing to waterborne diseases

3.2.1. Access to water and sanitation facilities

The majority of respondents reported having access to water, though the main drinking water sources varied (Table 2).

The primary sources of water at home were piped water from the Ghana Water Company supply (36%) and borehole water supply (30.75%), while bottled and sachet water were the main sources of drinking water outside the homes (96.5%). Despite the availability of piped water, a notable proportion of respondents reported using unimproved drinking water sources such as untreated rivers or streams (7.75%) and hand-dug wells (14%). All households using piped water confirmed its direct use for drinking and cooking without additional treatments (100%, $N = 144$).

Regarding sanitation facilities, public toilets, including water closets (WCs with septic tanks), Kumasi ventilated improved pit latrines (KVIPs), and VIPs, were predominantly used in the communities, except in Asemkrom, where shared pit latrine toilets were mainly used, alongside open defecation practices. These public toilets accounted for approximately 52.5% of facilities in Techiman, 41.25% in Tanoso, 38.75% in Safwi Woaso, 15% in Asemkrom, and 32.5% in Elubo. Household ventilated improved pit latrines were less prevalent, ranging from 5 to 15% across the communities. Septic tanks were found in 4–7.5% of households, while pour flush systems were observed in 3–11% of communities (Table 3).

Despite the availability of public sanitation facilities, their poor maintenance and deplorable conditions, especially in Techiman, Tanoso, Safwi Woaso, and Elubo, discouraged their usage, contributing to open defecation practices, particularly in Asemkrom. Respondents had to pay usage fees for access to sanitation services, further discouraging usage due to poor maintenance. Although public toilets aimed to provide communal sanitation facilities, a significant proportion of respondents disliked them due to poor maintenance (62%), foul odor and flies (71%), or required payment (23%), contributing to open defecation practices. A respondent at Asemkrom stated, '*I would love to use the public sanitation facilities, but they are always in terrible condition and poorly maintained. It's discouraging, and that's why people resort to open defecation*'.

Further analysis revealed that while self-reported open defecation was rare in the communities, it was significantly practised in and around the Tano River, posing a significant risk of water pollution with fecal indicator bacteria concentrations and increasing waterborne disease risks when ingested. Reasons for opting for open defecation included

Table 2 | Respondents access to water and sanitation

Variable	Number ($N = 400$)	Percentage (%)
Source of drinking water at home for respondents		
Borehole water	123	30.75
Sachet	33	8.25
Bottle water	9	2.25
Untreated/unboiled Tano river/stream	31	7.75
Boiled River Tano	4	1.00
Hand-dug well	56	14.00
Pipe-borne water (GWC)	144	36.00
Source of drinking water outside home for respondents ($N = 386$)		
Sachet bags	344	89.12
Plastic bottles	42	10.88
Drinking water consumption per person/day (L)		
Less than 0.5	38	9.5
0.5–1.0	86	21.5
1.01–1.50	56	14
1.51–2.0	42	10.5
2.01–2.50	123	30.75
2.51–3.0	46	11.5
3.01–3.50	9	2.25

Table 3 | Types of sanitation facilities and practices in the study communities along the Tano River Basin

Sanitation facilities and practices	Techiman (%)	Tanoso (%)	Safwi Waoso (%)	Asemkrom (%)	Elubo (%)	Total (%)
Shared pit latrine	16 (20.0)	19 (23.8)	10 (12.5)	20 (25)	17 (21.3)	82 (20.5)
Household VIP	6 (7.5)	5 (6.3)	6 (7.5)	13 (16.3)	15 (18.8)	45 (11.3)
Septic tank	4 (5)	5 (6.3)	7 (8.8)	7 (8.8)	6 (7.5)	29 (7.3)
Pour flush	3 (3.6)	2 (2.5)	6 (7.5)	11 (13.8)	3 (3.8)	25 (6.3)
Public toilet (WC/KVIP/pit)	42 (52.5)	33 (41.3)	31 (38.8)	12 (15.0)	26 (32.5)	144 (36.0)
Dig and burry	4 (5.0)	10 (12.5)	13 (16.3)	2 (2.5)	6 (7.5)	35 (8.8)
Open defecation practices	5 (6.3)	6 (7.5)	7 (8.8)	15 (18.8)	7 (8.8)	40 (10.0)

no payment involved (40%), comfort (such as receiving fresh air during the process) (32%), soil enrichment for crop growth (9%), and readily available and accessible usage (19%). Detailed reasons (advantages) for the choice of excreta disposal options are summarized in Table 4. A respondent from Elubo expressed concern about the potential pollution of the Tano River with fecal waste. '*I will not be surprised if the entire Tano River is polluted with faeces; have you asked yourself where all those using septic tanks discharge their waste to in Elubo? The trucks discharge them in the bush, and they all flow back to the Tano River*', said a 47-year-old respondent from Elubo.

Concerns were raised about potential pollution of the Tano River with fecal waste, with respondents noting that waste from septic tanks was often discharged into the bush, ultimately finding its way back to the river. Given the prevalence of open defecation and exposure to pathogens through poor hygiene practices, improving access to advanced and hygienic sanitation systems, such as ventilated improved pit latrines and pour flush systems, is crucial for enhancing public health outcomes and reducing waterborne diseases in the communities. Addressing the prevalence of open defecation through targeted interventions and awareness campaigns will be essential for achieving sustainable sanitation practices in the Tano River Basin communities.

Efficient management of wastewater originating from sanitation, laundry, cooking, and bathing is imperative for safeguarding public health. Survey findings revealed that approximately one-third (33.5%) of households primarily discharged their wastewater into nearby gutters, while 63.3% disposed of it in open spaces surrounding their homes, attracting pests like houseflies and rodents. Moreover, 2.5% directed wastewater through drainage into soak pits. Unfortunately, these disposal methods were identified as contributors to water and food contamination due to poor hygiene practices, floodwater, and pest activity. Such practices pose significant health risks by exposing individuals to pathogens and toxic substances present

Table 4 | Respondents' reasons for the preferred toilet facility and practices

Excreta disposal option	Respondent reasons/advantages associated with the option
Open defecation	a. No payment is involved, cheap and readily available. b. Fresh air is received during the process. c. It is more comfortable to use free-range.
Household latrine (KVIP, septic tank, pour flush)	a. It improves good health and personal hygiene. b. Prevent snake bite. c. Can be used anytime, especially at night. d. There is easy access to the facility. e. It reduces the spread of diseases in the community. f. There is privacy.
Dig and bury method	a. It produces manure, enriching the soil for crop production.
Shared pit latrine	a. Cannot afford public toilet cost where payment is involved.
Public toilet (WC/KVIP/pit, etc.)	a. It has reduced open defecation and reduce diseases outbreak in the community.

in raw Tano River water. Notably, only 10% of households utilized designated public waste collection sites designated by local authorities or the Ghana Zoom Lion Company Limited, with 47% resorting to open dumping, often followed by burning (Table 5).

Similarly, 3% of households utilized ‘house-to-house’ private waste collection services. However, many respondents disposed of their waste outside their homes, with only a small minority (20%) not doing so (Table 5). Despite being prevalent in the communities, these waste disposal options were deemed unsustainable due to delays in transferring waste to final dumping sites. This perpetuates indiscriminate open dumping habits (47%), posing significant hygiene and health challenges, in addition to drain siltation. A follow-up interview revealed that household wastes were often thrown outside homes and nearby bushes due to limited waste containers nearby and complaints about the cost of waste disposal. According to Miezah *et al.* (2015), improper waste disposal can have adverse effects on human health, highlighting the need to raise awareness and streamline waste management practices. Hence, there is a need to streamline and sensitize people on environmental problems to prevent the consequences. The practice of open dumping risks polluting the Tano River, while waste burning exacerbates air pollution and potentially contributes to river water pollution and global warming. For instance, the open burning of plastic waste can lead to air pollution with harmful health effects due to heavy metal additives (Twumasi 2017).

In identifying contributing factors to water pollution within the basin, household surveys identified illegal mining and poor solid waste disposal as major contributors to Tano River pollution (refer to Table 5). Additionally, building houses on watercourses and lack of law enforcement were deemed relevant by almost all the respondents. Residents’ behavior also emerged as a significant factor (52.5%). Stormwater runoff was highlighted as another contributor to water pollution through flooding. Waste generated by households and various community dump sites reportedly impacted the Tano River Basin, indicating that reported pollution causes were largely related to land use activities for mining and improper waste disposal, influenced by inadequate law enforcement and community behavior.

Table 5 | Household waste management method and practice

Variables	Frequency	(%)
Dispose of household waste outside your home		
Yes	320	80.0
No	80	20.0
Waste management methods are mostly practiced in the respondents’ area		
Public waste collection points	40	10.0
Burning	160	40.0
Private house-to-house collection service	12	3.0
Open dumping	188	47.0
Respondents wastewater management practices		
Discharge on open space outside homes	253	63.3
Direct dumping into the gutter	134	33.5
Channel through drainage into a pit (soak pit)	10	2.5
Septic tank	3	0.8
Major causes of Tano River catchment pollution[a]		
Illegal mining activities	386	96.5
Solid waste disposal	348	87.0
Lack of law and enforcement	299	74.8
Behavior of people	333	83.3
Stormwater flows	319	79.8
Building houses on watercourses	210	52.5
Poor drainage systems	169	42.3
Open defecation due to lack of public toilets	208	52.0

[a]Multiple responses allowed.

3.2.2. Major causes of Tano River catchment pollution

The study identified several significant causes of pollution in the Tano River catchment area when stratified by respondent demographic factors such as age, educational level, and years of living in the community. The findings are summarized in Table 6.

Illegal mining activities showed a significant correlation with age (Pearson $R = 52.687$, p-value $= 0.001$), educational level (Pearson $R = 31.307$, p-value $= 0.001$), and years of living in the community (Pearson $R = 14.556$, p-value $= 0.006$) (Table 6). The correlation between illegal mining and demographic variables highlights its pervasive impact on water quality. Illegal mining operations introduce pollutants like heavy metals and sedimentation into waterways, posing serious health risks to downstream communities (Obiri-Yeboah *et al.* 2021). This contamination can lead to chronic diseases and acute health crises among local populations reliant on river water for drinking and domestic use (Fernández-Luqueño *et al.* 2013). The study result is not surprising as similar findings have been reported in various regions of Ghana where illegal mining is prevalent, confirming the consistent risk posed by mining-related pollutants (Zhang *et al.* 2016; White *et al.* 2020; Kazapoe *et al.* 2023). Effective interventions are needed, including stringent enforcement of mining regulations and community education on the health impacts of illegal mining activities.

The study also found a strong association between improper solid waste disposal and demographic factors such as age (Pearson $R = 162.525$, p-value $= 0.001$), educational level (Pearson $R = 266.533$, p-value $= 0.001$), and years of living in the community (Pearson $R = 76.151$, p-value $= 0.001$). These results suggest that improper solid waste management is a widespread issue recognized across various demographic segments, exacerbating the pollution problem. Inadequate disposal methods allow solid waste to leach contaminants into water sources, creating breeding grounds for waterborne pathogens (Mamhobu-Amadi *et al.* 2019). Previous studies have shown that solid waste disposal is a significant contributor to water pollution in many developing countries (Henry *et al.* 2006; Pekdogan *et al.* 2024; Sharma *et al.* 2024). Public education campaigns are essential to educate the community on proper waste management practices, which can significantly reduce pollution-related health risks. Developing sustainable waste management systems and encouraging community participation in waste segregation and recycling can also mitigate these risks (Owusu-Ansah *et al.* 2022; Bhattacharya *et al.* 2024).

Table 6 | Chi-square test of association of the major causes of Tano River catchment pollution

		Age		Educational level		Years of living community	
Variables	**Category**	**Pearson *R***	***p*-value**	**Pearson *R***	***p*-value**	**Pearson *R***	***p*-value**
Illegal mining activities	Yes	52.687	0.001	31.307	0.001	14.556	0.006
	No						
Solid waste disposal	Yes	162.525	0.001	266.533	0.001	76.151	0.001
	No						
Lack of law and enforcement	Yes	134.789	0.012	178.456	0.020	156.432	0.015
	No						
Behavior of people	Yes	225.896	0.001	229.506	0.01	106.696	0.001
	No						
Stormwater flows	Yes	291.614	0.001	324.567	0.001	198.654	0.002
	No						
Building houses on watercourses	Yes	34.789	0.107	65.432	0.035	98.321	0.002
	No						
Poor drainage systems	Yes	45.678	0.074	87.543	0.073	123.456	0.046
	No						
Open defecation due to lack of public toilets	Yes	56.789	0.009	76.432	0.007	134.567	0.095
	No						

A significant relationship was found between the lack of law enforcement and age (Pearson $R = 134.789$, p-value $= 0.012$), educational level (Pearson $R = 178.456$, p-value $= 0.020$), and years of living in the community (Pearson $R = 156.432$, p-value $= 0.015$) (Table 6). Weak governance and regulatory enforcement, as indicated by demographic perceptions, contribute significantly to environmental degradation and health hazards. Ineffective enforcement of environmental laws allows unchecked pollution from multiple sources, undermining efforts to maintain water quality standards (Hill 2017). His finding aligns with other studies indicating that weak enforcement of environmental regulations leads to increased pollution and health risks (Owusu-Ansah *et al.* 2022; Bhattacharya *et al.* 2024). This underscores the critical role that governance and regulatory frameworks play in mitigating pollution and highlights the community's perception of inadequate enforcement as a major concern. Effective enforcement of environmental laws, coupled with community involvement in monitoring activities, can enhance compliance and reduce pollution for the attainment of clean sanitation in line with the sustainable development goals as well as the Ghana national sanitation policies. Behavioral factors related to pollution showed a significant correlation with age (Pearson $R = 225.896$, p-value $= 0.001$), educational level (Pearson $R = 229.506$, p-value $= 0.01$), and years of living in the community (Pearson $R = 106.696$, p-value $= 0.001$). This indicates that community behaviors significantly impact pollution levels, necessitating targeted educational and behavioral interventions. Educating the community on the impact of their actions and promoting sustainable practices can lead to significant improvements. Stormwater flows were significantly associated with age (Pearson $R = 291.614$, p-value $= 0.001$), educational level (Pearson $R = 324.567$, p-value $= 0.001$), and years of living in the community (Pearson $R = 198.654$, p-value $= 0.002$).

These results highlight the impact of urban runoff and inadequate stormwater management on river pollution. Building houses on watercourses showed significant correlations with educational level (Pearson $R = 65.432$, p-value $= 0.035$) and years of living in the community (Pearson $R = 98.321$, p-value $= 0.002$), though not significantly with age (Pearson $R = 34.789$, p-value $= 0.107$). This suggests that better education could potentially mitigate the adverse effects of such constructions. Strict enforcement of zoning laws and relocation programs are essential to prevent residential areas from being constructed on critical watercourses. Poor drainage systems were significantly correlated with years of living in the community (Pearson $R = 123.456$, p-value $= 0.046$) but not significantly with age (Pearson $R = 45.678$, p-value $= 0.074$) or educational level (Pearson $R = 87.543$, p-value $= 0.073$). According to the studies of Hill (2017) and Khan (2000), urban expansion disrupts natural drainage patterns, increasing surface runoff and carrying pollutants into water bodies. This highlights the need for infrastructural improvements and community involvement in maintaining drainage systems. Investing in modern drainage infrastructure can prevent blockages and overflows, thereby reducing pollution. Open defecation due to a lack of public toilets was significantly correlated with age (Pearson $R = 56.789$, p-value $= 0.009$), educational level (Pearson $R = 76.432$, p-value $= 0.007$), and years of living in the community (Pearson $R = 134.567$, p-value $= 0.095$). Providing adequate public sanitation facilities and ensuring their maintenance can significantly improve public health and reduce pollution. The implementation of community-led total sanitation (CLTS) programs can mobilize communities to eliminate open defecation practices and improve sanitation facilities.

3.2.3. Common illnesses experienced by respondents

The study revealed several common illnesses experienced by the respondents, highlighting significant health challenges linked to environmental and sanitation issues in the community. Malaria was most widespread, affecting 51% of the population, followed by acute respiratory tract infections (ARTIs) reported by 45%, characterized by symptoms such as cough, sore throat, and runny nose (Figure 2). Intestinal worms affected 27% of respondents, while rheumatism disease and eye infections each affected 18%. Diarrheal disease was reported by 13%, with skin diseases also affecting 18%. Acute urinary infections and anemia had lower prevalence rates at 3% each. The high prevalence of malaria can be attributed to the improper management of wastewater, particularly the discharge of wastewater into gutters and open spaces. These practices create breeding grounds for mosquitoes, which are known carriers of malaria. The stagnant water resulting from poor waste management provides a conducive environment for mosquito breeding, leading to an increased risk of malaria transmission. Also, improper waste management practices, such as open dumping and burning, can release harmful airborne pollutants and particulate matter into the atmosphere. Inhaling or getting into contact with these pollutants can irritate the eye and the respiratory system and contribute to respiratory tract infections. The ARTI may also be consistent with the health effects of pollution from the mining activities around the river basin catchment. The respiratory problems reported by the respondents, such as coughing and shortness of breath, are common symptoms of exposure to dust particles, which are present in the dust generated by both illegal mining activities.

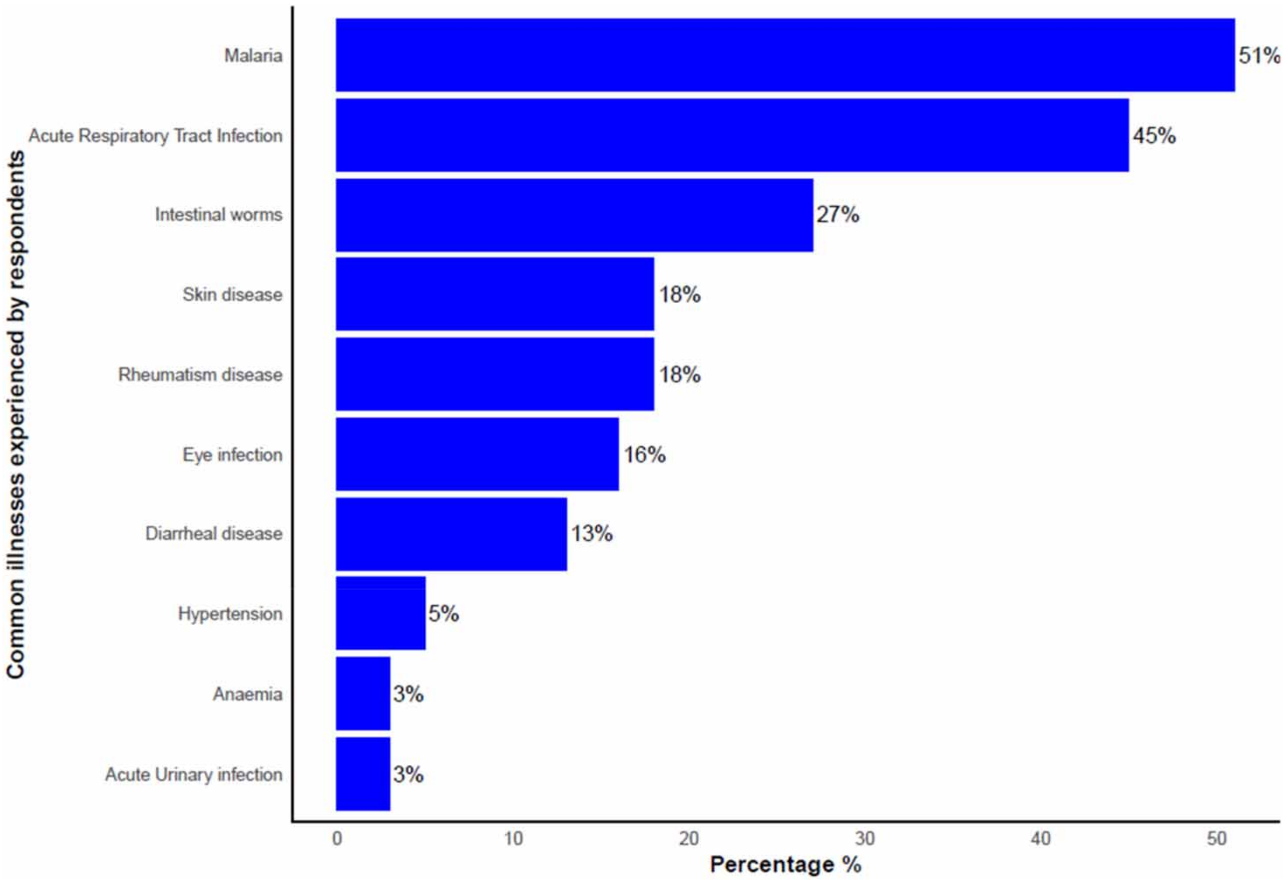


Figure 2 | Common illnesses experienced by respondents.

Furthermore, improper waste disposal and poor sanitation practices can lead to the contamination of water sources with fecal matter containing parasitic worms. Consuming or coming into contact with contaminated water can result in the transmission of intestinal worms, leading to gastrointestinal infections and related health issues such as diarrheal disease among others. Although hypertension, acute urinary infection, and anemia illnesses were reported by a relatively small percentage of respondents and their direct association with waste management practices is not clearly outlined, it is important to note that the overall poor sanitation conditions and potential water pollution resulting from improper waste disposal can contribute to a range of health issues, including those related to cardiovascular health and infections. For example, rheumatism disease was experienced by 18% of the respondents' yet inadequate waste management practices may indirectly contribute to the prevalence of rheumatism disease through factors such as exposure to damp environments and the proliferation of disease-carrying vectors. The prevalence of diseases such as malaria (water-related diseases linked to stagnant water and poor sanitation conditions), respiratory tract infections, intestinal worms (water-based diseases transmitted through contaminated water sources), and skin diseases underscores the need for improved waste disposal methods, proper sanitation, the prevention of water pollution, and the implementation of sustainable waste management strategies. Eisenberg *et al.* (2001) and UNICEF & WHO (2022) classify skin diseases and eye infections as water-washed diseases exacerbated by poor personal hygiene and inadequate clean water access. Diarrheal disease aligns as a waterborne illness, likely due to water contaminated with pathogens like bacteria, viruses, or parasites (Eisenberg *et al.* 2001).

3.2.4. Risk factors for diarrhea diseases among respondents

In this study, the incidence of diarrhea was documented at 13 cases per 100 respondents (52 out of 400 respondents) (Table 7), closely resembling the findings of a study conducted in Asia (Al-Abbad & Bella 1990). South America exhibits some of the highest rates of morbidity and mortality due to diarrheal diseases, with an estimated 500,000 cases and 7,900

Table 7 | Analysis of variables associated with self-reported diarrhea illness by respondents

Variable	Total	No illness ($N = 348$)	Illness ($N = 52$)	Odds ratio	95% CI[a]	p-value
Source of drinking water at home						
Borehole water	123	119	4	0.45	0.14–1.47	0.283
Sachet	33	30	3	1.34	0.35–5.17	0.955
Bottle water	9	8	1	1.68	0.19–14.76	0.958
Untreated/unboiled Tano river/stream	31	12	19	21.22	8.07–55.80	<0.001
Boiled River Tano	4	2	2	13.4	1.70–105.41	0.029
Hand-dug well	56	43	13	4.05	1.66–9.90	0.003
Pipe-borne water (GWC)	144	134	10	1.0	0.40–2.48	0.985
Drinking water consumption per person/day (L)						
Less than 0.5	38	30	8	1.78	0.70–4.57	0.340
0.5–1.0	86	77	9	0.78	0.33–1.86	0.731
1.01–1.50	56	50	6	0.8	0.30–2.17	0.853
1.51–2.0	42	35	7	1.34	0.51–3.52	0.744
2.01–2.50	123	107	16	1	0.48–2.10	0.891
2.51–3.0	46	42	4	0.64	0.20–2.02	0.612
3.01–3.50	9	7	2	1.91	0.36–10.02	0.78
Sanitation facilities and practices						
Shared pit latrine	82	73	9	1.14	0.47–2.77	0.941
Ventilated improved pit latrine	45	40	5	1.16	0.39–3.42	0.899
Public toilet (WC/KVIP/pit)	144	130	14	1	0.46–2.18	0.876
Septic tank	29	24	5	1.93	0.64–5.87	0.395
Pour flush	25	22	3	1.27	0.34–4.77	0.799
Dig and bury	35	29	6	1.92	0.68–5.42	0.34
Open defecation practices	40	30	10	3.1	1.25–7.64	0.020
Dispose of household waste outside your home						
Yes	320	302	18	1	0.51–1.96	0.769
No	80	46	34	12.4	6.47–23.76	<0.001
Waste management methods mostly practiced in the respondents' area						
Public waste collection points	40	33	7	1.45	0.58–3.64	0.590
Burning	160	141	19	0.92	0.48–1.75	0.930
Private house-to-house collection service	12	10	2	1.37	0.28–6.62	0.932
Open dumping	188	164	24	1	0.55–1.83	0.912
Respondents' wastewater management practices						
Discharge on open space outside homes	253	227	26	1	0.56–1.78	0.946
Direct dumping into the gutter	134	108	25	2	1.10–3.63	0.03
Channel through drainage into a pit (soak pit)	10	9	1	0.97	0.12–7.97	0.867
Septic tank	3	1	0	0.64	0.20–2.02	0.564
Wash hands before eating with soap						
Always	315	302	13			<0.001
Mostly	60	36	24	12	5.79–24.84	
Sometimes	23	10	13	27	7.32–99.23	
Never/rarely	2	0	2	1	0.03–34.78	

(*Continued.*)

Table 7 | Continued

Variable	Total	No illness ($N = 348$)	Illness ($N = 52$)	Odds ratio	95% CI[a]	*p*-value
Wash hands after toilet with soap						
Always	83	80	3			0.002
Mostly	55	47	8	10.67	3.19–35.61	
Sometimes	145	121	24	16.67	8.12–34.29	
Never/rarely	117	100	17	8.5	3.86–18.72	
Wash hands when coming from outside						
Always	31	25	6			0.001
Mostly	69	56	13	8.67	2.78–27.08	
Sometimes	100	83	17	9.83	3.42–28.25	
Never/rarely	200	184	16	7.75	2.81–21.41	
Buy from street vendors						
Rarely	34	29	5			<0.001
Sometimes	87	68	19	9.5	3.28–27.49	
Mostly	119	103	16	11.5	3.84–34.67	
Always	160	148	12	19	5.98–60.24	

[a]=95% Confidence Interval

deaths, representing a prevalence rate of 31% (Clasen *et al.* 2007). Studies from Africa indicate varying prevalence rates, with Kenya at 19%, Uganda at 22%, and Tanzania at 9% (Tumwine *et al.* 2002). Many of the significant risk factors identified in this study align with previous research findings.

The analysis highlights several significant associations between various factors and health outcomes. Among the key findings, individuals relying on untreated or unboiled water from the Tano River or stream exhibit notably higher odds of illness (OR 21.22, 95% CI: 8.07–55.80) compared with other sources of water such as with access to pipe-borne water (GWC).

Moreover, sanitation practices play a pivotal role, with open defecation showing a substantially higher odds ratio for illness (OR 3.1, 95% CI: 1.25–7.64), underscoring the importance of adequate sanitation infrastructure. Additionally, handwashing habits significantly influence health outcomes, with consistent handwashing before eating associated with reduced odds of illness (OR 0.001, 95% CI: <0.001–0.002), while inconsistent handwashing after toilet use correlates with elevated risks (OR 16.67, 95% CI: 8.12–34.29). Many of the most significant risk factor findings in this study are consistent with results from other studies.

The association between the use of untreated or unboiled water from rivers or streams and a higher risk of diarrheal diseases is well-documented. Previous research in regions with similar water sources has shown that untreated surface water often contains pathogens that lead to gastrointestinal diseases (Mourad 2004; Mara 2017). The boiled Tano River water, although safer than untreated water, still presented a significantly elevated risk in the study communities. This could be due to inconsistent boiling practices, as noted in studies by Cohen & Colford (2017) and Liu *et al.* (2020), who highlight that improper boiling may not eliminate all pathogens. According to Cohen & Colford (2017), pathogens such as *E. coli O157:H7* cells can survive boiling or microwaving at viable temperatures in a study of the effects of boiling drinking water on diarrhea and pathogens. The analysis also suggests that factors beyond water quantity, such as water quality and hygiene practices, play significant roles in determining disease risk. This finding supports previous studies that emphasize the need for reliable and consistent water treatment methods in these communities (Yoada *et al.* 2014).

Sanitation practices were another significant factor. Open defecation, identified as a major risk in our study ($OR = 3.1$, $p = 0.02$), has been repeatedly linked to higher incidences of diarrheal diseases. The increased risk of diarrheal diseases associated with open defecation is consistent with findings from Ogundele *et al.* (2018) who identified poor sanitation as a major contributor to the spread of diarrheal diseases. This finding also aligns with global research recording the impact of poor sanitation on public health (Owoeye & Adedeji 2013; Andrés *et al.* 2021). However, the lack of significant associations with other sanitation facilities might indicate variability in the quality and maintenance of these facilities, which is consistent with findings from Prüss-Ustün *et al.* (2014) who noted that the effectiveness of sanitation facilities heavily depends on their proper use and maintenance.

Handwashing habits also showed significant associations with health outcomes. The protective effect of consistent handwashing before eating (OR 0.001, 95% CI: $<$0.001–0.002) and the increased risk associated with inconsistent handwashing after toilet use (OR 16.67, 95% CI: 8.12–34.29) are in line with studies by Zhang *et al.* (2016). White *et al.* (2020) and Zhang *et al.* (2016) demonstrated that handwashing is a critical intervention for preventing over 30% of diarrheal diseases. These findings suggest that hygiene education and the availability of handwashing facilities are crucial for improving health outcomes.

Furthermore, our study found that improper waste disposal was associated with a higher risk of illness (OR 12.4, 95% CI: 6.47–23.76), consistent with findings by Yoada *et al.* (2014). That improper waste disposal can contaminate the environment and serve as a breeding ground for disease vectors. Similarly, direct dumping of wastewater into gutters, which increases the risk of illness (OR 2, 95% CI: 1.10–3.63), has been shown to contaminate water sources and spread waterborne diseases (Ogundele *et al.* 2018). Previous research, as highlighted by Clasen *et al.* (2007), has established a correlation between diarrhea and exposure to wastewater or inadequate sanitation facilities. Areas with stagnant water accumulation provide conducive environments for microbial proliferation, potentially serving as infection reservoirs, as noted by Adhikari *et al.* (2023). Furthermore, studies indicate that microorganisms thriving in such conditions pose a heightened risk to vulnerable demographics, including children, pregnant women, the elderly, and individuals with compromised immune systems, compared with other household members (Clasen *et al.* 2007).

In contrast to previous studies where handwashing showed significant associations with reduced illness risk, our study yielded consistent results. The association between handwashing and reduced risk of illness was robust, with statistically significant findings observed across all analyses. This underscores the importance of proper hand hygiene practices, particularly the use of soap, in mitigating the risk of diarrheal diseases. The significant association persisted even after adjusting for potential confounding factors, affirming the substantial role of handwashing in preventing waterborne illnesses in our study population. Several factors may contribute to the strong association observed in our study. Firstly, the emphasis on handwashing with soap as a key hygiene intervention may have led to higher compliance rates among our participants. Cultural norms and public health campaigns promoting hand hygiene practices could have influenced behavior, resulting in better adherence to recommended handwashing techniques. Additionally, the availability of soap and water may have facilitated consistent handwashing behaviors among our study population, further enhancing the protective effect against diarrheal diseases. Our findings underscore the effectiveness of handwashing with soap as a simple yet powerful preventive measure against waterborne illnesses. Public health interventions aimed at promoting hand hygiene should prioritize the provision of soap and water access, along with educational efforts to encourage proper handwashing practices. By addressing barriers to hand hygiene and promoting behavioral change, we can significantly reduce the burden of diarrheal diseases and improve overall community health outcomes (Adhikari *et al.* 2023). Further research is warranted to explore the long-term impact of sustained handwashing interventions and their implications for reducing the transmission of waterborne pathogens.

The association between consuming food from outside sources and increased illness risk (OR 1.7) observed in our study is consistent with findings from previous research. Epidemiological data indicate that a significant proportion of foodborne illness outbreaks, approximately 44%, are linked to restaurants, hotels, and other catering establishments. This association may be attributed to various factors, including inadequate food handling practices and insufficient hygiene standards, particularly in establishments operated by immigrants from developing countries who may lack adequate training in food safety protocols (Angulo *et al.* 2006). Despite the prevalence of foodborne illness outbreaks associated with eating from outside sources, limited research has been conducted on this topic. For instance, a local study identified a popular fast-food outlet as the source of numerous salmonellosis outbreaks linked to chicken shawarma, highlighting the potential for food poisoning due to suboptimal cooking practices. Our findings suggest that individuals who consume food from outside sources may face an increased risk of foodborne illnesses, emphasizing the importance of food safety measures in commercial food establishments. The findings presented in this study are based on self-reported instances of diarrhea, which, while providing valuable insights, lack the advantage of microbiological confirmation. Conversely, alternative study methodologies may offer more precise diagnostic capabilities but often suffer from significant underreporting of illness. This issue is particularly evident in approaches reliant on physician-reported surveillance and is compounded by a steep decline in reporting over time in prospective studies. Moreover, the necessity of collecting stool samples in many cultural contexts may serve as a disincentive for individuals to report diarrheal episodes. Consequently, we contend that the study design employed in our research yields a more accurate estimate of the population prevalence of diarrheal disease compared with alternative methodologies.

3.3. Susceptibility map

The spatial distribution of geophysical-based flood risk and vulnerability maps was generated for the Tano River Basin at a 30-m resolution. Generally, high- and very-high-risk flood susceptibility zones are situated in areas near the river banks with lower elevations. In the geophysical-based flood risk maps, high-risk areas are predominantly found in water bodies and around water resources, covering approximately 21.2% of the area. A land cover map provides spatial information on various types/classes of physical coverage of the earth's surface, such as forests and lakes. This map was created by identifying and classifying the pixels in the Landsat 8 image. Each pixel in the image was assigned to a specific class based on the statistical characteristics of the pixel brightness values using supervised classification. This classification method relies on selecting sample pixels in an image that are representative of specific classes.

Land cover, such as vegetation, significantly impacts the soil by acting as water storage. From the flood hazard map (Figure 3), the spatial variability of hazards in the area is evident. The flood hazard map model's results seem to align with ground truth observations. Increasing the slope of the basin's level decreases the likelihood of penetration, which can result in a decrease in the time of concentration (Mahmood 2019). The map indicates that the southern and central parts of the Tano Basin exhibit very high susceptibility to flooding, covering approximately 14.9% (2,599.7 km^2) of the area. An additional 6.3% (1,096.4 km^2) of the area is identified as having a high susceptibility to flooding. Conversely, some areas will be less endangered by flooding, with moderate and low-risk prone areas covering 16.3% (2,844.4 km^2) and 33.5% (5,840.6 km^2) of the area, respectively. Moderate-risk areas are evenly distributed across the Tano Basin, while low-risk areas are concentrated in the northern part of the basin. Overall, areas highly susceptible to flooding cover 21.2% of the entire area, indicating that a significant portion of the southern part of the basin is at risk of flooding, making these areas unsafe for occupancy. Flood incidences are more likely to affect areas with high urban growth, as shown in Figure 3(b), particularly in the southern part of the basin. This susceptibility is attributed to several factors, including the presence of numerous stream networks, high slope angles, low elevated areas, land use changes, and developments in the Tano River

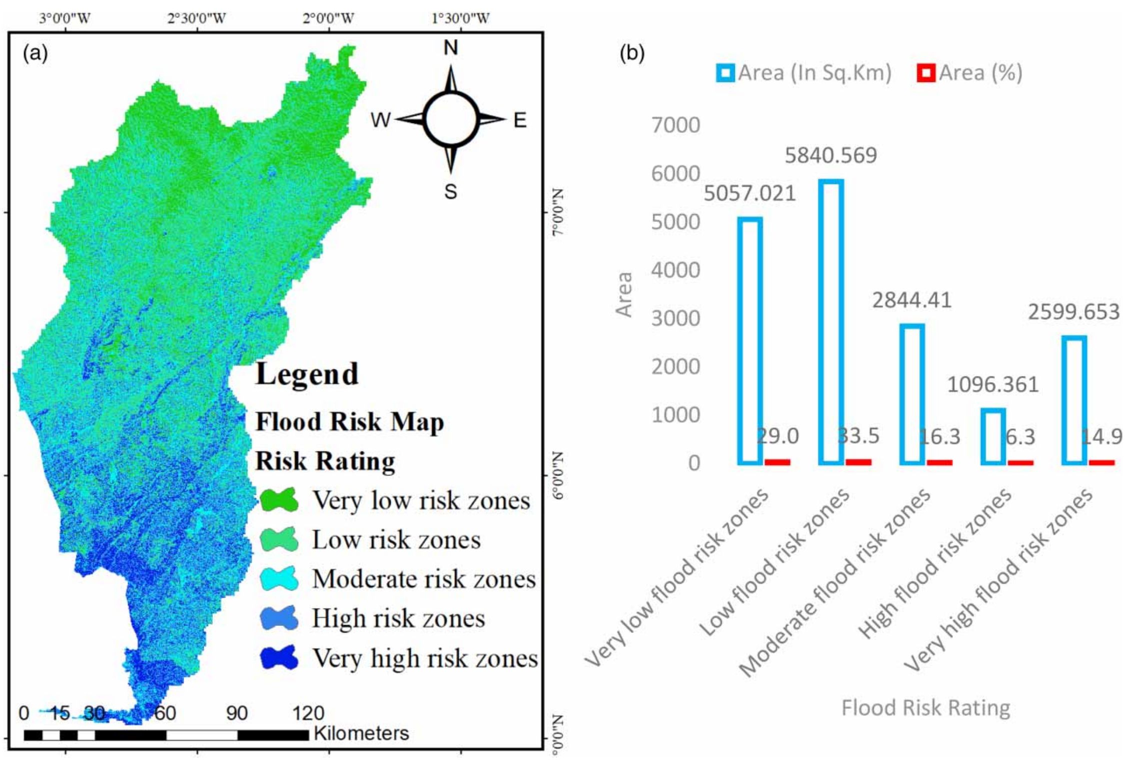


Figure 3 | (a) Flood susceptibility map and (b) areas of flood zone classes for Tano River Basin.

Basins. The high proportion of built-up areas in the southern portion increases their vulnerability to flooding during periods of high precipitation (Ullah & Id 2020).

3.4. Exposure pathways and risks of waterborne diseases

The study shed light on crucial insights provided by respondents, highlighting that the consumption of contaminated water, especially among those who consume untreated Tano River water due to inadequate hygiene and sanitation practices, contributes significantly to the prevalence of diseases like diarrheal illness. Scarce access to water and sanitation facilities, compounded by substandard hygiene habits among households, was identified as a key factor leading to water contamination through unsafe wastewater disposal and open defecation practices. Moreover, a majority of respondents disclosed that household wastewater is occasionally utilized for backyard irrigation to fulfill the growing food demand. However, these irrigation practices, alongside the use of livestock manure and fertilizers, result in wastewater laden with nutrients and chemical residues, consequently polluting the Tano River. Additionally, the influx of urban migrants into vacant areas bordering the river has led to the establishment of informal settlements. Proximity to the river heightens their exposure to polluted water, particularly during floods, exacerbating drinking water contamination and the prevalence of waterborne diseases. Industrial waste discharge from factories along the river introduces harmful pollutants and toxic substances, further degrading water quality. Construction activities disturb the soil and lead to increased sedimentation in the river, affecting its clarity and ecosystem health. Illegal mining operations, often unregulated, result in heavy metal contamination and siltation, severely impacting the river's health. Lastly, open defecation along the riverbanks introduces pathogens and fecal matter directly into the water, posing immediate health risks to the communities relying on the river for their water supply.

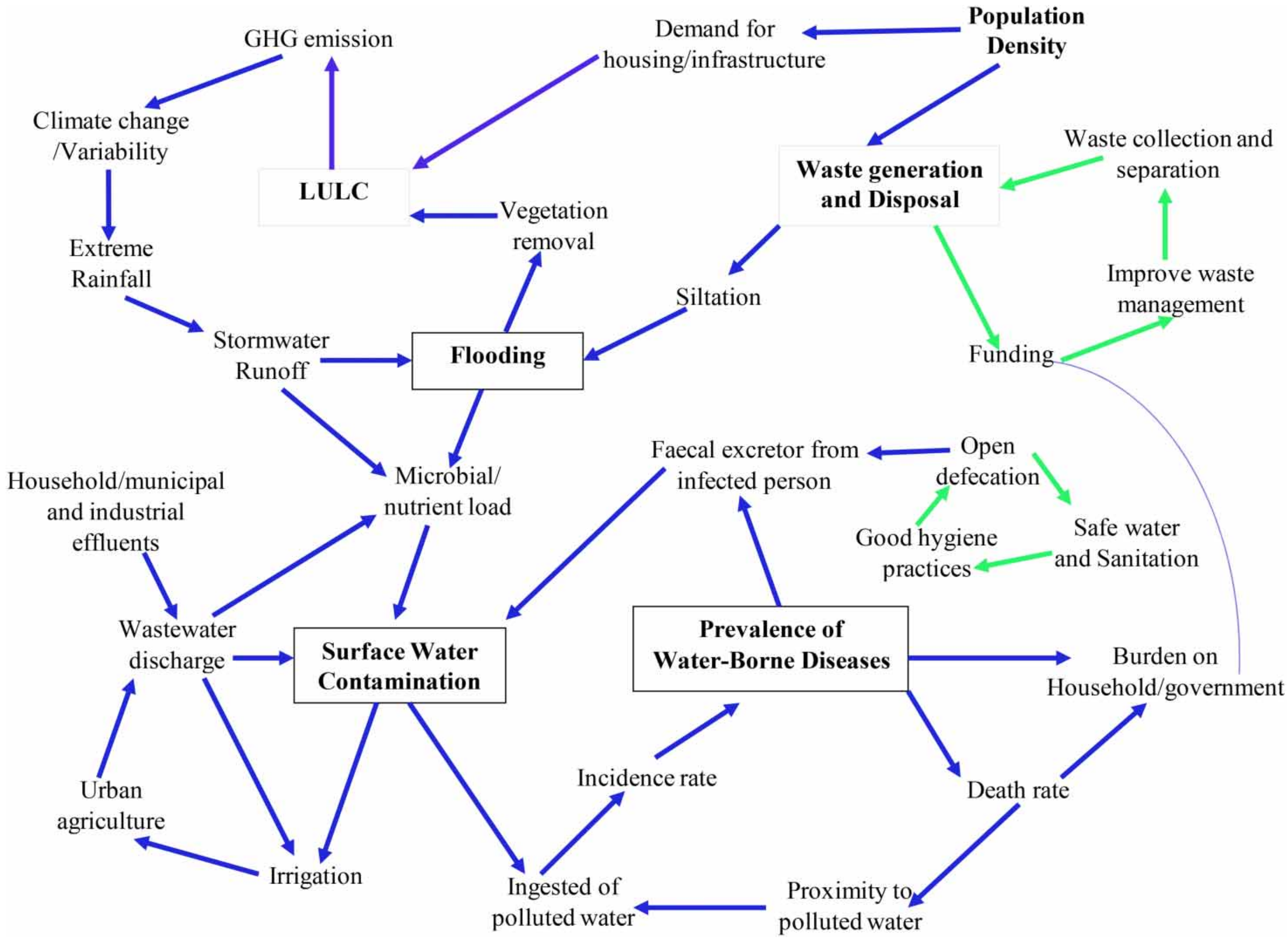


Figure 4 | Exposure pathways and risks of waterborne diseases – influences of floods, LULC, and waste management.

Limited access to healthcare services, especially in rural settings, may exacerbate the prevalence of diseases among infected individuals (Honlah *et al.* 2019). Long-term repercussions may encompass a reduction in population growth, albeit interventions by the government and time-related factors could disrupt this trajectory. Insights gleaned from the literature indicate that the actual number of unreported cases of waterborne and flood-related fatalities in Ghana surpasses documented statistics due to inadequate record-keeping practices and social stigmatization at both household and district levels.

The Tano River has undergone significant alterations due to the demand for housing and infrastructure, resulting in shifts in land use land cover (LULC), as evidenced by Larbi (2023). Illegal mining activities and the rising urban population density contribute to solid waste generation, which, if not properly managed, exacerbates drain siltation and localized flash floods during short periods of intense rainfall. These factors collectively elevate the susceptibility to flooding in approximately 14.9% of the area, totaling 2,599.7 km^2. In essence, the impacts of LULC changes and waste management practices are pivotal in exacerbating devastating flood events within the catchment, thereby polluting the Tano River and fostering outbreaks of waterborne diseases. Figure 4 delineates the exposure pathways and risks associated with waterborne illnesses, elucidating the influences of floods, waste management practices, and LULC alterations. Figure 4 shows how LULC changes and household solid waste disposal strategies within the catchment influence the occurrence of flooding in the study area and are potential causes of microbial water pollution in the Tano River.

4. CONCLUSION

The study investigated the water–health nexus in the Tano River Basin, considering land use dynamics, flooding, and waterborne diseases using a questionnaire survey and GIS application to determine flood-prone areas through the generation of a flood map. The study identified inadequate sanitation, poor hygiene practices, and contamination from illegal mining activities as the primary contributors to waterborne diseases. Additionally, flooding and improper waste management were found to exacerbate these issues. The incidence of diarrhea was recorded at 13 cases per 100 respondents with significant risk factors including untreated water from the Tano River, inadequate sanitation leading to open defecation practices, and inconsistent handwashing after toilet use. Again, the study found that illegal mining, waste disposal, and lack of law enforcement in the Tano River catchment correlated significantly with demographic factors such as age, educational level, and years of living in the community ($p < 0.05$). Furthermore, geospatial analysis revealed that areas highly susceptible to flooding cover 21.2% of the entire area and predominantly in the southernmost part of the basin. This highlights the urgent need for flood protection measures and sustainable soil conservation practices, including the installation of rock berms, ripraps, and enhanced drainage systems. In conclusion, the study recommends immediate action to mitigate these identified risk factors. Stakeholders and local authorities must prioritize the development and implementation of comprehensive strategies aimed at improving water quality and public health. Effective measures include enhancing WASH facilities, implementing stringent waste management practices, and fortifying flood resilience through infrastructure improvements. These findings are instrumental for local authorities in formulating evidence-based policies and interventions to mitigate the economic and public health impacts of waterborne diseases in the Tano River Basin.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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