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Integrating Primary Health Care and WASH Indicators for Spatial Prioritization of Diarrhoeal Disease Risk in Rural Eastern Indonesia

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ABSTRACT

Introduction: The objective of this study is to map the distribution of diarrhoeal disease and identify priority sub-districts for targeted prevention in Manggarai District through integration of diarrhoea incidence rate and WASH indicators. The integration of these indicators into a spatial risk framework provides a practical basis for strengthening diarrhoea prevention at the primary care level.

Methods: This study employed a descriptive quantitative approach with spatial mapping using Quantum Geographic Information System (QGIS) application. Data of diarrhoea incidence rate and poor WASH indicators (access to improved sanitation, clean water coverage, and handwashing with clean water behavior) from 12 sub-districts from Manggarai Health Profile 2023 and Manggarai Health Office Report 2023 were used. The sub-districts were classified into low, moderate, and high-risk priority level using scoring system and equal interval classification method.

Results: West Cibal, North Rahong, and Cibal were classified into high-priority sub-districts characterized by high diarrhoea incidence rate (≥4.12 cases per classification range) and poor WASH indicators. Conversely, Langke Rembong, North Satar Mese, and Wae Ri'i exhibited low diarrhoea incidence rate with optimal WASH coverage. Anomalies were found in Lelak, where high diarrhoea incidence persisted despite good WASH access, indicating possible hidden risk factors.

Conclusion: The observed spatial patterns showed that inadequate water and sanitation infrastructure, combined with poor hygiene practices, are key drivers of diarrhoeal transmission. The coexistence of high disease burden and weak WASH conditions highlights inequalities in primary health care and environmental service provisioin. By integrating epidemiological, environmental, and behavioral data, this study provides a spatial framework to support targeted diarrhoea prevention and strengthen primary health care planning in resource-limited areas.

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INTRODUCTION

There has been an epidemiological transition in the leading causes of death globally from infectious diseases to non-communicable diseases (NCDs). According to the WHO, NCDs accounted for approximately 75% of all deaths worldwide in 2021, with cardiovascular diseases, cancers, chronic respiratory diseases, and diabetes comprising the majority of this burden (1). Despite this global transition, communicable diseases particularly diarrhea, remain a public health concern, particularly among children (2). In 2020, diarrhea ranked sixth as the leading cause of death globally. In Southeast Asia, diarrhea was the second most common infectious disease in 2000, and although its ranking decreased to sixth in 2021, it remains a leading cause of death in children under five, with an estimated 443,832 deaths per year globally (2). In addition to dehydration due to fluid and electrolyte loss, complications such as systemic bacterial infections also increase the risk of death, particularly among children with malnutrition, weakened immune systems, and HIV infection (2).

In Indonesia, diarrhea remains endemic in several regions, particularly affecting children in rural areas and areas with limited access to health services. This disease often triggers outbreaks and remains a leading cause of death in children under five (3,4). Manggarai Regency is one of the regions facing serious challenges in controlling diarrhea. Located in a rural area in the western part of East Nusa Tenggara (NTT) Province, the region remains difficult to reach, with limited health infrastructure and a high dependence on limited natural water sources. (5). In 2023, a total of 1,650 diarrhoea cases were reported across all age groups, with the highest incidence in Satar Mese Sub-District (219 cases) (6). Due to limited resources, the main challenge in Manggarai is not only the high number of diarrhea cases, but also low access to adequate sanitation facilities, clean water, and poor hygiene and healthy living behaviors among the community (5,7).

Globally, most diarrheal disease risk mapping studies focus on urban and peri-urban areas with relatively adequate infrastructure. In contrast, research specifically examining the interaction of environmental factors and health behaviors in remote rural areas, such as Manggarai Regency, is limited. Therefore, this study provides a novel contribution through integrated spatial analysis at the sub-district level in the rural context of Eastern Indonesia, using a multi-indicator approach that includes access to clean water, sanitation facilities, and community hygiene behaviors.

Utilizing Geographic Information System (GIS)-based spatial mapping that integrates diarrhea incidence rates with environmental indicators (clean water and sanitation) and health behavior indicators (PHBS) offers a strategic approach to identifying priority areas in resource-constrained environments. From a primary health care (PHC) perspective, this integration reflects key PHC principles, particularly equity, community-based prevention, and cross-sectoral action (8–10). By linking disease burden to modifiable environmental and behavioral determinants, GIS-based analysis serves not only as a descriptive tool but also as a strategic instrument to support evidence-based planning and resource allocation at the primary care level.

This approach addresses a critical knowledge gap regarding how PHC-relevant determinants shape spatial patterns of diarrheal disease in remote and underserved areas. Furthermore, integrating local health data into a spatial decision-making framework has the potential to enhance the capacity of low- and middle-income countries (LMICs) to design targeted, equitable, and contextualized diarrheal prevention strategies. Therefore, this study aims to map the distribution of diarrheal disease and identify priority sub-districts for intervention in Manggarai Regency by integrating data on diarrheal incidence, sanitation access, clean water availability, and community health behaviors within a PHC-oriented analytical framework.

METHOD

Research Type

This study employed a descriptive quantitative design with a geospatial analysis approach. The goal was to map diarrheal disease risks and identify priority sub-districts for prevention efforts through multi-indicator spatial analysis. The geospatial approach was used to identify spatial distribution patterns of diarrhea cases, combining environmental indicators and public health behaviors.

Population and Sample/Informants

The study population comprised all 12 administrative sub-districts in Manggarai Regency. Because this study used aggregate secondary data, no sampling technique was applied; all sub-districts were included as units of analysis using a total population approach.

Research Location

The study was conducted in Manggarai Regency, East Nusa Tenggara Province, Indonesia. Manggarai was chosen as the study location due to its rural characteristics, complex environmental health challenges, limited healthcare infrastructure, and high incidence of diarrhoeal diseases as recorded in routine health reports

Instrumentation or Tools

The research instrument consisted of secondary data obtained from the Manggarai District Health Office and the 2023 Manggarai District Health Profile. The data used included four main indicators: 1) Number of diarrhea cases per sub-district; 2) Percentage of households with access to and use of improved sanitation (healthy latrines); 3) Percentage of households with access to clean water; and 4) Percentage of households practicing handwashing with clean water. Spatial data processing in this study used Quantum Geographic Information System (QGIS) software. This software facilitates the creation of thematic maps, spatial visualization, and classification of priority areas.

Data Collection Procedures

Data collection involved several sequential steps. First, secondary data was collected from the Manggarai District Health Office in 2023 and the District Health Profile in 2023. Secondary data included diarrhea cases, access to improved sanitation, access to clean water, and handwashing practices at the sub-district level. These secondary data from the health office were collected through routine health monitoring and administrative records. Second, data validation was conducted to ensure completeness, internal consistency, and comparability across sub-districts. Because the dataset was aggregated at the sub-district level and exceeded 95% completeness across all indicators, no statistical imputation procedures were applied. Instead, records with incomplete entries were verified through administrative reconciliation to minimize information bias. Third, the validated data were aggregated at the sub-district level and prepared for spatial analysis. An equal-interval classification method was applied to categorize indicator values into low, medium, and high levels. This approach was chosen to ensure interpretability and transparency for policy-oriented analysis, particularly given the limited number of spatial units (n = 12) and the study's objective of supporting program decision-making at the district level. Unlike quantile classification, which imposes an equal number of units per category, or Jenks natural breaks, which can overestimate local variance, the equal interval method allows consistent comparison of indicator ranges across administrative units and facilitates communication with non-technical stakeholders.

Data Analysis

Data analysis was conducted using descriptive and spatial techniques. Descriptive analysis was conducted to calculate the incidence rate of diarrhoea and the percentage achievement of sanitation and hygiene indicators per sub-district. Spatial analysis employed a gradation technique using the *equal interval classification* method. Each indicator was scored based on low, medium, and high classifications. The scores from the four indicators were summed to determine priority levels, categorized as follows:

Table 1. Classification of Diarrhoeal Cases, Improved Sanitation, Clean Water Access, and Handwashing with Clean Water

No	Classification	Incidence Rate (%)	Diarrhoae Score	Improved Sanitation (%)	Clean Water (%)	Handwashing with Clean Water (%)	%
1	Low	1.29 – 2.80	1	27.85 – 48.79	29.693 – 50.791	29.48 – 48.38	3
2	Medium	2.80 – 4.12	2	48.79 – 60.82	50.791 – 60.753	48.38 – 58.33	2
3	High	4.12 – 5.44	3	60.82 – 68.42	60.753 – 70.108	58,33 – 68.33	1

Ethical Approval

This study used aggregated secondary data without individual identifiers, ensuring minimal risk to confidentiality. Formal authorization to access and use the data was obtained from the Manggarai District Health Office, and all data handling procedures adhered to national data governance and ethical guidelines. As no individual-level or identifiable information was involved, formal ethical clearance was not required.

RESULTS

The mapping results in figure 1 show that the sub-districts with a high category of diarrhoea incidence rate are West Cibal, Cibal, Lebak, and Satar Mese. The sub-districts in the moderate category are West Reok, North Rahong, Ruteng, and West Satar Mese. The sub-districts classified in the low incidence rate category are Reok, Wae Ri, Langke Rembong, and North Satar Mese.

Based on the distribution map of the percentage of healthy latrines usage (Figure 2), it can be concluded that the sub-districts with high category for healthy latrines usage are Langke Rembong, Ruteng, Lelak, Wae Ri'i, Reok, and North Satar Mese. Sub-districts with moderate category include West Satar Mese, Satar Mese, and Cibal. Meanwhile, West Reok, West Cibal, and North Rahong have low category in the use of improved sanitation.

According to the distribution map of clean water usage in 2023 (Figure 3), the high category of clean water usage was found in Langke Rembong, Ruteng, Lelak, Wae Ri'i, North Satar Mese, and Reok Sub-Districts. Sub-districts with a moderate category of clean water usage include Satar Mese, West Satar Mese, and Cibal. Meanwhile, sub-districts with a low category of clean water usage are North Rahong, West Reok, and West Cibal.

The distribution map of handwashing with clean water (Figure 4) shows that the sub-districts with a high category of handwashing practices using clean water—one of the household-level indicators of Clean and Healthy Lifestyle Behavior (PHBS)—include Langke Rembong, Ruteng, Lelak, Wae Ri'i, Satar Mese, and North Satar Mese. Sub-districts classified in the moderate category are West Satar Mese, Cibal, and Reok. Meanwhile, sub-districts with a low percentage of handwashing with clean water are North Rahong, West Reok, and West Cibal.

Table 2 shows a consistent pattern between the incidence rate of diarrhoea and the conditions of access to sanitation, clean water, and handwashing behavior at the sub-district level in Manggarai District. Sub-districts with a high incidence rate of diarrhoea generally exhibit suboptimal WASH conditions. For instance, West Cibal and Cibal sub-districts are both categorized as high-incidence rate areas for diarrhoea, yet their levels of access to sanitation, clean water, and handwashing behavior fall into the low to moderate categories. A similar pattern was also found in North Rahong District. Despite being classified as having moderate diarrhea incidence, this area demonstrated low achievement across all WASH indicators. This finding strengthens the link between limited access to sanitation and clean water and high diarrhea incidence. Conversely, several districts exhibited anomalous patterns. Lelak District, for example, had a high diarrhea incidence despite all WASH indicators being in the good category. This situation indicates the possibility of other risk factors not yet accommodated in the indicators used, such as household environmental hygiene, food security, or access to health services. On the other hand, Reok District demonstrated a low diarrhea incidence in line with good sanitation and clean water coverage, although handwashing behavior remained at a moderate level. This suggests that the interventions implemented may be effective in reducing diarrhea incidence, although challenges in behavior change remain. West Reok District also requires special attention because, despite its moderate diarrhea incidence, sanitation indicators and handwashing behavior remain low, indicating a potential for future risk increases if intervention is not implemented. Based on this combination of indicators, intervention priorities are focused on areas with a double burden, namely high diarrhea incidence coupled with poor WASH conditions. The districts of West Cibal, North Rahong, and Cibal have been designated as top priority areas for diarrhea prevention interventions, with an emphasis on improving sanitation access, providing clean water, and strengthening education on clean and healthy lifestyles.

Lelak and Satar Mese Sub-Districts also require attention as medium-priority areas because the high incidence rate of diarrhoea indicates the existence of other risk factors that need to be further investigated. Meanwhile, sub-districts such as Langke Rembong, North Satar Mese, and Wae Ri'i, which show low diarrhoea incidence rate with good WASH indicators, can serve as models or good practice references for other areas. Additionally, West Reok Sub-District needs to be closely monitored as a hidden risk area, where improving WASH indicators could prevent a potential increase in diarrhoea cases in the future.

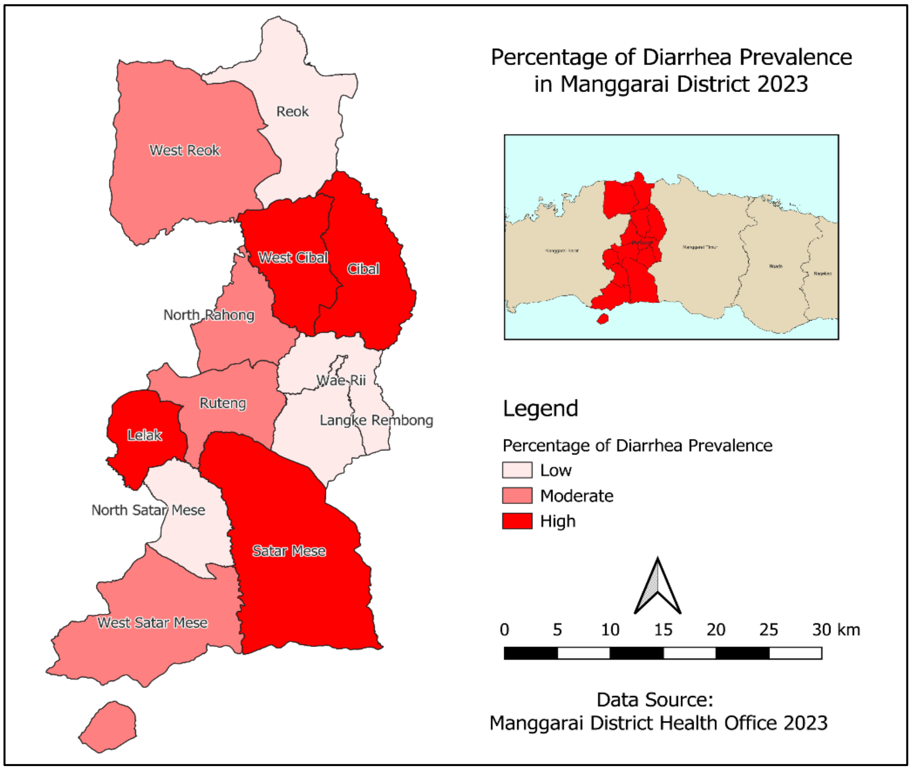

Figure 1. The Distribution Map of Diarrhea Incidence Rate in Manggarai District 2023

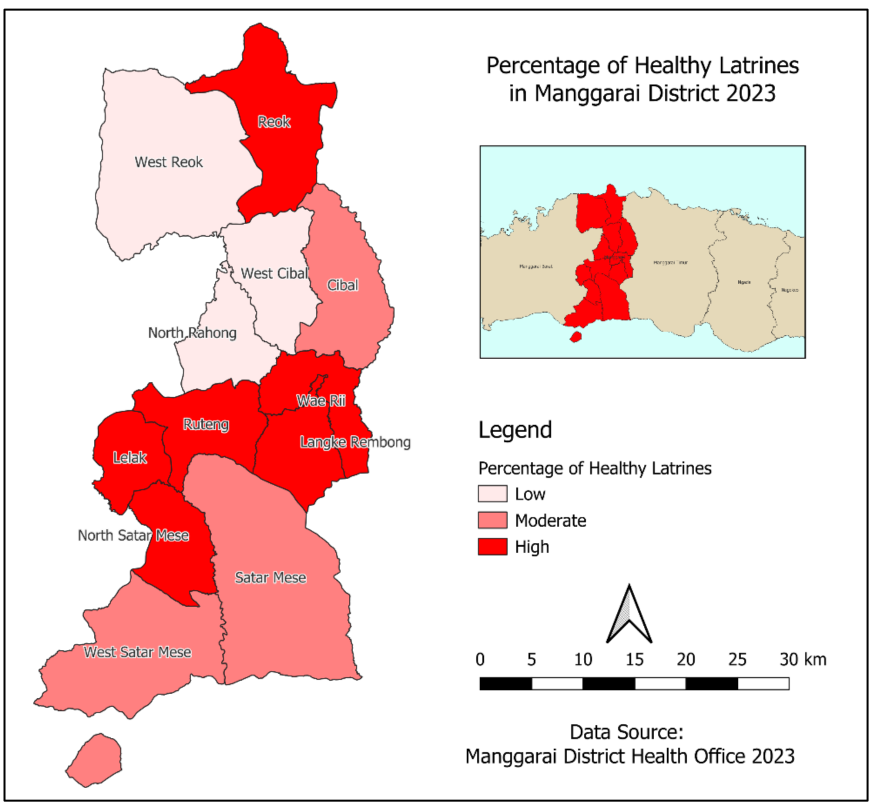

Figure 2. The Distribution Map of Healthy Latrine Usage in Manggarai District 2023

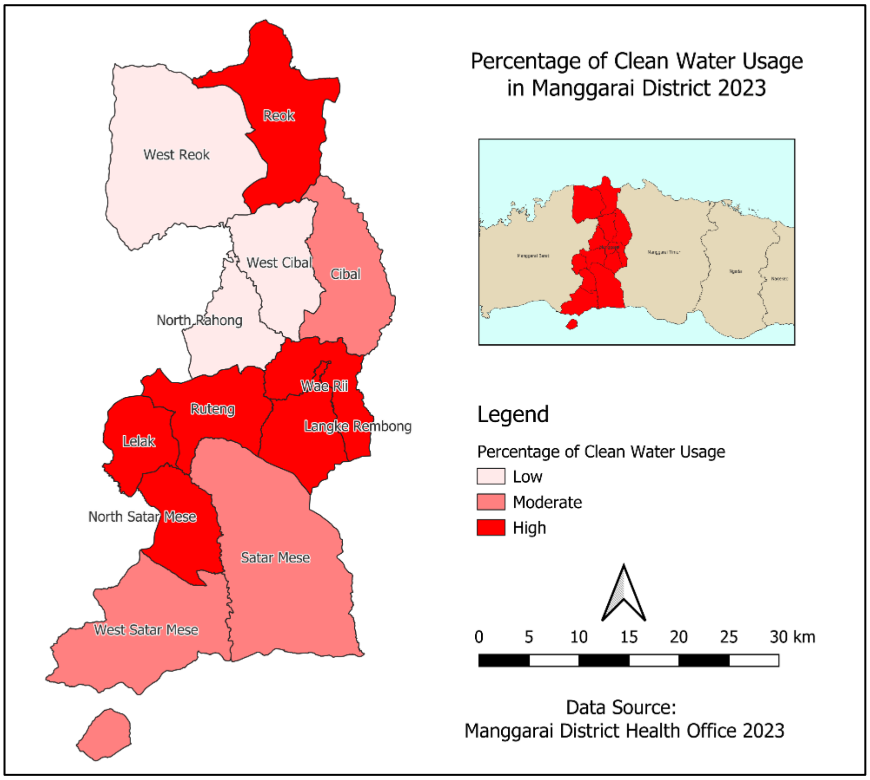

Figure 3. The Distribution Map of Clean Water Usage in Manggarai District 2023

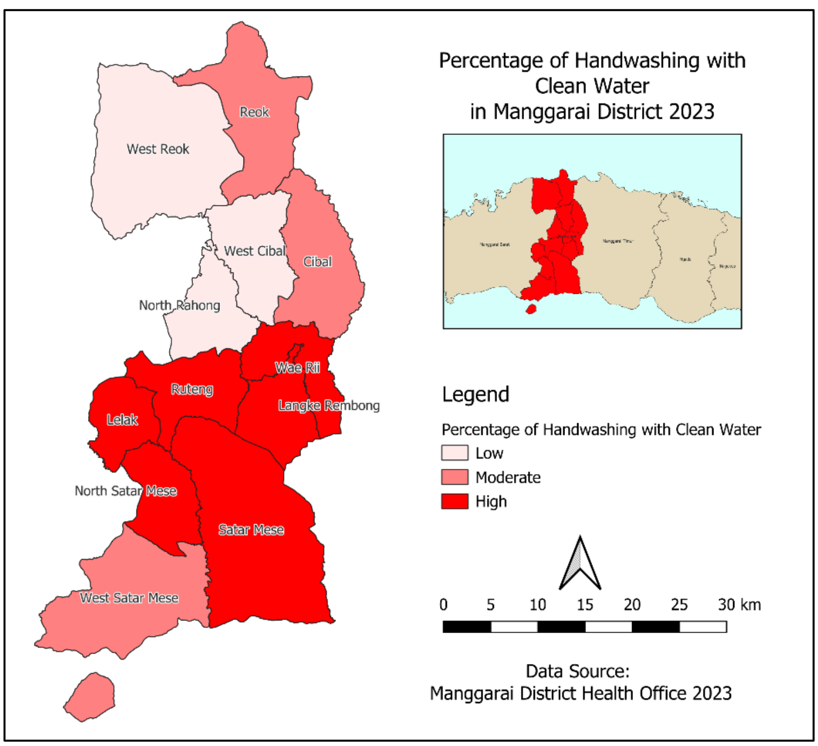

Figure 4. The Distribution Map of Handwashing with Clean Water in Manggarai District 2023

Table 2. The Priority Sub-districts for Prevention of Increased Cases of Diarrhea

No	Sub-districts	Diarrhea Incidence Rate		Improved Sanitation (%)		Clean Water (%)		Handwashing with Clean Water (%)		Total Score	Level of Priority
		Category	Score	Categoru	Score	Category	Score	Category	Score		
1	Cibal	High	3	Moderate	2	Moderate	2	Moderate	2	9	High
2	West Cibal	High	3	Low	3	Low	3	Low	3	12	High
3	Langke Rembong	Low	1	High	1	High	1	High	1	4	Low
4	Lelak	High	3	High	1	High	1	High	1	6	Moderate
5	North Rahong	Moderate	2	Low	3	Low	3	Low	3	11	High
6	Reok	Low	1	High	1	Low	3	Moderate	2	7	Moderate
7	West Reok	Moderate	2	Low	3	High	1	Low	3	8	Moderate
8	Ruteng	Moderate	2	High	1	High	1	High	1	5	Moderate
9	Satar Mese	High	3	Moderate	2	Moderate	2	High	1	8	Moderate
10	West Satar Mese	Moderate	2	Moderate	2	Moderate	2	Moderate	2	8	Moderate
11	North Satar Mese	Low	1	High	1	High	1	High	1	4	Low
12	Wae Ri	Low	1	High	1	High	1	High	1	4	Low

Table 3. Observation of Socio-Economic, Environmental Exposure (Water & Sanitation), and Health Services Conditions in Manggarai Disctrict

No	Subdistrict	Socioeconomic Characteristics	Environmental Exposure (Water & Sanitation)	Health Services
1	**Cibal**	Rural, agriculture-based livelihoods	Uneven access to safe drinking water and improved sanitation	Primary health center available; no hospital
2	**West Cibal**	Remote rural area, subsistence economy	Limited sanitation coverage and low STBM implementation	Primary health center with limited human resources
3	**Langke Rembong**	Urban–semi-urban, economic and administrative hub	Generally good access to safe water and sanitation	Hospital and multiple primary health centers
4	**Lelak**	Rural agrarian community	Incomplete access to improved water and sanitation	Primary health center available
5	**North Rahong (Rahong Utara)**	Rural, dispersed settlements	Suboptimal sanitation and safe water access	Primary health center available
6	**Reok**	Coastal, semi-urban economy	Relatively better water access; sanitation varies by village	Primary health center; limited referral access
7	**West Reok**	Coastal–rural area	Sanitation coverage remains uneven	Primary health center with geographic access challenges
8	**Ruteng**	Urban center, highest socioeconomic status	Best access to safe water and improved sanitation	Hospital, well-distributed health workforce
9	**Satar Mese**	Rural highland area	Limited access to safe water and sanitation	Primary health center available
10	**West Satar Mese**	Remote rural area	Low coverage of safe water and STBM implementation	Primary health center with limited resources
11	**North Satar Mese**	Rural, difficult topography	Persistent sanitation and water access challenges	Primary health center available
12	**Wae Ri**	Rural agrarian subdistrict	Incomplete access to safe water and sanitation	Primary health center; no hospital

Table 3 shows that the risk of diarrhea in Manggarai Regency is shaped by layered and interacting factors, where socioeconomic conditions, environmental exposure, and health service capacity jointly influence disease outcomes. The sub-districts classified as high-priority intervention areas—West Cibal, North Rahong, and Cibal—demonstrate an overlap between structural socioeconomic vulnerability and high environmental exposure. These areas are predominantly rural, with livelihoods based on subsistence agriculture and limited economic diversification, which limits households' capacity to invest in adequate sanitation facilities and clean water infrastructure. At the same time, uneven implementation of community-based sanitation programs and reliance on unsafe water sources increase exposure to fecal contamination, creating a highly conducive environment for diarrhea transmission. Limited health services—which are generally only available at the primary care level with limited human resources—also reduce the effectiveness of prevention and early detection efforts. This convergence of socioeconomic vulnerability, poor WASH conditions, and limited-service capacity provides a strong explanation for the persistence of high diarrhea incidence despite various public health interventions.

In contrast, Lelak and Satar Mese sub-districts, categorized as medium-priority areas, exhibit more complex epidemiological patterns. Although these two regions do not consistently have the worst WASH indicators, they still report relatively high diarrhea incidence. This suggests the presence of additional contextual risk factors not fully reflected in water and sanitation access indicators, such as household hygiene practices, seasonal fluctuations in water availability that impact water quality, food handling behaviors, and geographic barriers that limit access to timely health services. These findings suggest that infrastructure improvements alone are likely insufficient, and further exploration of behavioral and environmental micro-determinants is needed.

Subdistricts such as Langke Rembong, North Satar Mese, and Wae Ri'i, which are characterized by low diarrhea incidence and relatively good WASH indicators, reflect the protective effects of more favorable socioeconomic conditions and service systems. Langke Rembong, as a semi-urban area, benefits from higher household income levels, more stable access to protected or piped water sources, and the availability of more adequate health facilities and personnel. Meanwhile, in North Satar Mese and Wae Ri'i, the presence of well-functioning primary health care facilities and more consistent implementation of preventive measures appear to have contributed to a reduced risk of diarrhea, despite their rural context. Thus, these areas can be seen as examples of good contextual practice, where coordinated improvements in infrastructure, health services, and community engagement are associated with a lower disease burden.

DISCUSSION

Interpretation of Key Findings

The study's findings underscore the critical role of water, sanitation, and hygiene (WASH) indicators in influencing diarrhea incidence rates at the sub-district level in Manggarai Regency. Spatial analysis shows that areas with poor WASH access tend to report higher diarrhea incidence rates (11). Districts such as West Cibal, Cibal, and North Rahong consistently show high or moderate diarrheal incidence rates, combined with poor WASH conditions. Deficiencies in sanitation infrastructure, limited access to clean water, and poor hygiene practices remain significant contributors to the diarrheal burden in these areas. These findings align with previous studies from LMIC, where improvements in WASH infrastructure are associated with substantial reductions in diarrheal risk (12).

The existence of anomalies such as those in Lelak and Reok Districts demonstrates that WASH indicators alone do not fully reflect the complexity of diarrheal risk. The high incidence of diarrhea in Lelak, despite relatively good WASH indicator performance, suggests the role of other determinants not yet accommodated in standard WASH metrics, such as environmental sanitation conditions around homes, food handling practices, or limited access to health services. This finding aligns with literature confirming the multifactorial nature of diarrheal disease, where other factors, including nutritional status and health service utilization, also contribute to the risk of occurrence (13,14).

In contrast, Reok District presents a more positive picture, with relatively good WASH coverage associated with low diarrheal disease incidence, even though behavioral indicators such as handwashing practices are not yet fully optimal. This pattern is consistent with findings from large-scale WASH interventions showing that improved infrastructure—particularly access to clean water and sanitation—contributes significantly to reducing the risk of diarrheal disease, particularly in low- and middle-income countries (15). However, the results of the WASH Benefits trial in Bangladesh show that while the provision of WASH infrastructure can reduce the burden of disease, optimal health benefits can be hampered by low adoption of key behaviors, such as adherence to handwashing practices and safe drinking water treatment (16).

In contrast, Reok Barat District reflects an early warning situation, where moderate diarrheal incidence coincides with low sanitation and hygiene practices, exacerbated by limited infrastructure. This pattern aligns with previous research findings describing high-risk environments, where the lack of basic sanitation combined with inadequate hygiene practices has a synergistic effect on disease transmission (11). These conditions emphasize the importance of integrated interventions that combine infrastructure improvements with behavior change strategies based on established theoretical frameworks, such as the Integrated Behavioral Model for WASH (17).

From a programmatic perspective, the research findings can support multilevel intervention strategies. For example, in high-priority areas such as West Cibal, North Rahong, and Cibal, where disease burdens remain high and WASH indicators are poor, comprehensive interventions that combine infrastructure improvements and intensive health promotion activities are crucial. This approach is supported by previous studies that emphasize that the most sustainable WASH outcomes are achieved when the “hardware” (physical infrastructure) and “software” (behavior change components) are integrated within a community-led framework, particularly in areas with a high disease burden (18). In medium-priority areas like Lelak and Satar Mese, context-specific approaches are needed. For example, investigating alternative risk pathways, such as contamination through the food chain or environmental vectors, and strengthening multi-sectoral coordination in the health, education, and infrastructure sectors. Such context-based interventions are essential for tailoring WASH interventions based on local transmission dynamics and advocate for multi-sectoral engagement to address indirect disease pathways (19).

Furthermore, areas with low incidence rates and high WASH coverage, including Langke Rembong, North Satar Mese, and Wae Ri’i, show that these areas have the potential to be used as pilot areas, which can then be replicated by other areas (20). Finally, hidden-risk areas like West Reok, characterized by moderate disease incidence but poor sanitation practices, need to proactively strengthen WASH interventions to prevent escalation. Investments in improving basic sanitation are highly cost-effective in preventing infectious diseases and antibiotic resistance, especially in settings with latent risk (21).

Comparison with Previous Studies

The study findings show significant spatial disparities in diarrhea incidence rates, access to sanitation, clean water, and hygiene practices across sub-districts in Manggarai District. This spatial heterogeneity indicates a complex interaction between environmental and behavioral health determinants. Similar patterns have been observed in other rural contexts, such as Peru and Rwanda. Spatial analysis conducted in Peru revealed that diarrhea incidence rates are significantly clustered in specific geographic areas. The main hotspots are located in areas with poor access to clean water, inadequate sanitation, and suboptimal hygiene practices (22).

Studies in Rwanda show that the risk of diarrhea is not evenly distributed across districts. Statistically significant clustering of cases occurs in areas with low sanitation coverage and limited access to clean water (23). Recent spatio-temporal analysis conducted in Ethiopia shows that diarrhea cases are significantly concentrated in certain geographic zones, with high-risk groups closely associated with lack of access to clean water and sanitation services (24). Similarly, a geospatial study in rural Karnataka, India, identified significant hotspots for diarrhea cases in children under five, particularly in villages where improved sanitation coverage and access to clean water are very limited (25). Further supporting this observation, a multi-country spatial analysis study revealed that in some low-income contexts, diarrhea incidence rates are highly concentrated in rural areas with poor WASH indicators, and limited access to improved drinking water and toilet facilities is the most significant predictor of diarrhea hotspots (26).

In Indonesia, several studies have analyzed the factors influencing diarrhea in children under five years of age and have shown that the lack of adequate sanitation facilities and limited access to safe drinking water significantly increase the likelihood of diarrheal disease, especially in provinces located in Eastern Indonesia, such as East Nusa Tenggara (NTT) (27). For example, a study found that children living in households with inadequate sanitation had a 1.56 times higher risk of diarrhea, while unsafe drinking water also contributed to an increased risk of diarrhea in young children (27). Similarly, other studies confirm that inadequate sanitation and unpiped drinking water sources are significant predictors of diarrhea in Indonesian children under two years of age (28). These findings align with current research in Manggarai District, where sub-districts such as West Cibal, North Rahong, and Cibal, characterized by inadequate sanitation coverage, limited access to clean water, and poor hygiene practices, were identified as priority areas for intervention. This consistency between national-level evidence and local spatial analysis highlights the critical need to prioritize WASH interventions in these high-risk areas to effectively reduce the burden of diarrheal disease among children.

Several studies have highlighted the utility of GIS-based mapping in prioritizing diarrhea interventions, particularly in rural areas where health disparities are closely linked to environmental and infrastructure factors. A study in India used a spatial epidemiology approach to map childhood diarrhea in 707 districts and demonstrated that incorporating multi-indicator mapping, particularly WASH variables, provided a more comprehensive understanding of local health inequalities (29). Similarly, studies in Bangladesh and India have used GIS-based methods such as Moran's I and Local Indicators of Spatial Association (LISA) to identify diarrhea hotspots, revealing that poor access to clean water and sanitation is a key driver of these spatial clusters (30,31). In addition, other studies also strengthen the value of multi-indicator mapping by showing that diarrheal disease hotspots can be predicted more accurately when WASH variables are combined with socio-economic and environmental indicators (32). These studies support our methodological approach to research in Manggarai District, where the integration of epidemiological data with environmental and behavioral indicators, particularly variables related to WASH (Water, Sanitation, and Hygiene), creates a practical and context-sensitive tool for identifying high-risk areas. This approach enhances the capacity of the local health system to deliver targeted and equitable interventions, addressing infrastructure gaps and behavioral determinants of diarrheal disease in rural populations.

Limitations and Cautions

This study has several limitations that should be considered when interpreting its findings. First, the spatial analysis was conducted using a single year of cross-sectoral data (2023), which limits the ability to observe causal relationships and only reflects associations between diarrheal disease incidence rates and WASH indicators. Because the analysis only captures a moment in time, it does not account for temporal fluctuations or seasonal variations in diarrheal incidence, which are known to vary significantly between the dry and rainy seasons, particularly in rural areas. Second, the analysis relies on aggregated sub-district-level data, which introduces the potential for ecological fallacy, where conclusions about individual-level risk are drawn from group-level data. Consequently, caution is needed when applying these findings to individual risk profiles. Third, the study did not account for the impact of ongoing health programs or interventions that may influence the distribution of diarrheal disease in a given area. Without incorporating program data, there is a risk of overlooking areas where improvements are underway or where previous interventions have reduced risk. Fourth, the study used the same interval classification method to categorize spatial risk levels. While this approach aligns with the applied public health orientation of this study by enhancing interpretation and comparison across administrative units, it may not fully capture spatial heterogeneity. Alternative classification methods, such as quantiles or natural breaks (Jenks), may reveal different spatial patterns and should be explored in future studies with larger and more detailed datasets.

While inferential statistical techniques such as Spearman correlation or multivariate regression can provide quantitative estimates of associations, their application was not prioritized in this study due to the limited number of spatial units ($n = 12$) and the aggregated nature of the data. Instead, a descriptive spatial approach was adopted to emphasize interpretation and policy relevance. Future studies with larger sample sizes and finer spatial resolutions are encouraged to apply inferential and spatial statistical methods, including bivariate correlation analysis and spatial autocorrelation techniques (e.g., Moran's I or Local Indicators of Spatial Association [LISA]), to more robustly quantify the relationship between diarrhea burden and WASH indicators.

This analysis does not account for the potential influence of ongoing health programs or interventions that may have modified local disease patterns. The absence of programmatic and temporal data may obscure the effects of recent improvements or targeted interventions. Collectively, these limitations highlight the need for cautious interpretation and underscore the importance of future research incorporating longitudinal data, finer spatial resolution, and integrated program information to strengthen evidence-based diarrheal disease prevention strategies.

These findings should also be interpreted with caution due to the risk of ecological fallacy, as the analysis relies on aggregated sub-district-level indicators that may obscure substantial heterogeneity within areas. Associations observed at the sub-district level may not necessarily reflect exposures and outcomes at the individual or household level, and high diarrhea incidence may coexist with adequate WASH conditions for certain population groups, while disproportionately affecting more vulnerable households. Furthermore, potential data bias may arise from underreporting of diarrhea cases, differences in health service utilization, and variability in surveillance sensitivity across sub-districts, particularly in remote or hard-to-reach areas. WASH indicators derived from administrative records may also overestimate functional access, as they do not fully capture consistency in water quality, sanitation facility maintenance, or actual hygiene practices. To strengthen the validity of these findings, triangulation through field-based validation, including household surveys, water quality testing, and qualitative assessments of hygiene behaviors and health-seeking patterns, is recommended. Integrating these spatial findings with a mixed-methods approach will enable a deeper understanding of local transmission pathways and support the development of context-sensitive diarrhea prevention strategies.

Recommendations for Future Research

Future research should prioritize the use of multi-year, seasonally disaggregated datasets to better capture the temporal dynamics and seasonal variability in diarrheal disease transmission. Given that diarrheal incidence in rural areas is strongly influenced by climatic conditions (particularly rainfall patterns and water scarcity during the dry season), longitudinal data will allow for a more robust assessment of temporal trends, risk cycles, and intervention effectiveness over time. Furthermore, future studies should incorporate a broader range of socioeconomic, demographic, and environmental determinants, including household income, maternal education, population density, food hygiene practices, and geographic accessibility to health services. Integrating these variables will reduce residual bias and provide a more comprehensive understanding of the multifactorial nature of diarrheal risk in rural contexts. To improve spatial precision, future studies should employ finer spatial units, such as village- or neighborhood-level data, and adopt advanced spatial analysis techniques, including spatial autocorrelation (e.g., Moran's I, LISA) and spatial regression models. Such an approach would allow for more accurate identification of disease clustering and underlying spatial dependencies that cannot be captured through aggregated sub-district analyses. Future studies should also incorporate information on ongoing health and WASH interventions, including program coverage, intensity, and duration. Accounting for program exposure is crucial for distinguishing between structural vulnerability and the effects of recent interventions, thereby improving causal interpretation and policy relevance. Combining routine surveillance data with primary data collection (such as household surveys, environmental sampling, or community-based assessments) would help reduce underreporting and improve data validity, particularly in remote or hard-to-reach areas. Mixed-methods and multi-source approaches would strengthen evidence generation and support more targeted, equitable, and context-sensitive diarrhea prevention strategies in rural and resource-limited areas.

CONCLUSION

This study identified West Cibal, North Rahong, and Cibal sub-districts as priority areas for diarrhea prevention in Manggarai Regency, based on a multi-indicator spatial analysis combining diarrhea incidence rates, access to clean water, healthy sanitation, and handwashing practices. The findings highlight that limited access to clean water and sanitation, combined with low adoption of healthy hygiene behaviors, significantly contribute to the higher burden of diarrheal disease in these rural areas. These results are consistent with previous studies linking poor water, sanitation, and hygiene (WASH) conditions to an increased risk of diarrhea, particularly in resource-limited rural settings. However, this study offers additional value by applying integrated spatial mapping to a remote district in Eastern Indonesia, an area with limited evidence.

Despite its contributions, this study has several limitations. Reliance on single-year cross-sectoral data collected at the sub-district level limits the ability to capture temporal dynamics and may obscure intra-regional variability, particularly in settings where diarrhea risk fluctuates seasonally. Furthermore, the absence of socioeconomic, climate, and accessibility variables limits a more comprehensive understanding of the structural drivers shaping diarrheal vulnerability. Consequently, these findings should be interpreted with caution.

Future research should incorporate multi-year and seasonal datasets to better capture temporal variability and disease dynamics. Integrating socioeconomic indicators (e.g., household income, education), climate factors (e.g., rainfall and temperature variability), and measures of physical accessibility to health services would enable more robust diarrheal risk modeling. Methodologically, developing a composite index or weighted scoring system (potentially supported by multivariate or spatial regression techniques) could improve the precision of risk stratification and better reflect the multifactorial nature of diarrheal transmission.

From a translational perspective, the findings of this study underscore the value of spatially integrated health information to guide decision-making at the sub-district level. Strengthening the use of locally generated data in routine health planning could support more targeted, equitable, and context-sensitive interventions, particularly in resource-constrained rural areas. Such an approach could help bridge the gap between epidemiological evidence and actionable public health policies for diarrhea prevention.

AUTHOR CONTRIBUTION STATEMENT

GMK: conceptualization, data analysis, writing original draft, editing. MM: conceptualization, writing original draft, supervision, editing. YPSM: data collection, writing original draft. All authors read and approved the final manuscript.

CONFLICTS OF INTEREST

All The authors declare no conflict of interest.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

The authors hereby declare the utilization of generative AI technology, specifically ChatGPT developed by OpenAI, as a supportive tool in the preparation of this manuscript. The use of this technology was strictly limited to non-substantive tasks, namely improving the clarity of language, enhancing grammatical quality, and assisting in the synthesis of scientific references that were thoroughly examined and selected by the authors prior to inclusion. Throughout the manuscript development process, the use of AI remained under the direct oversight and intellectual control of the authors. All critical components of this study (including the conceptualization of the research design, data analysis, interpretation of results, and development of scholarly arguments) were entirely developed and finalized by the authors without AI influence. The authors accept full responsibility for the scientific integrity of the manuscript. Additionally, all AI-generated content was meticulously reviewed, edited, and verified to ensure accuracy, appropriateness, and alignment with academic ethical standards prior to submission.

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