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Spatio-temporal epidemiology of intestinal infectious diseases in Blantyre District, Malawi

Richard Lizwe Steven Mvula,[1,2] Emmanuel Chinkaka,[3,4] Vincent Katonda,[5] Wilson Tchongwe,[4] Lemson Kachedwa,[5] John Njalam'mano,[6] Wilfred Kadewa,[1] Fasil Ejigu Eregno[2]

[1]Department of Energy, Ndata School of Climate and Earth Sciences, Malawi University of Science and Technology, Limbe, Malawi; [2]Faculty of Engineering Science and Technology, Department of Building, Energy and Material Technology, UiT The Arctic University of Norway, Narvik, Norway; [3]Department of Geography and Spatial Sciences, University of Delaware, Newark, USA; [4]Department of Earth Sciences, Malawi University of Science and Technology, Limbe, Malawi; [5]Department of Climate Sciences, Malawi University of Science and Technology, Limbe, Malawi; [6]Department of Water Resources, Ndata School of Climate and Earth Sciences, Malawi University of Science and Technology, Limbe, Malawi

Abstract

Intestinal infectious diseases remain among the leading causes of death, mainly in sub-Saharan Africa. In Malawi's commercial hub, Blantyre, the spatiotemporal dynamics of these diseases have not been extensively studied, despite their significant public health burden. We studied high-risk areas and analyze the spatial and temporal patterns of intestinal infectious diseases, including cholera, schistosomiasis, and Other Diarrheal Diseases (ODDs) in Blantyre district from 2018 to 2023. Descriptive statistics were used to evaluate the epidemic characteristics of the intestinal infectious diseases. Spatial autocorrelation with Local Moran's *I* was employed to detect spatial clusters, and the Kulldorf retrospective method for space-time analysis. ODDs had the highest incidence rates, ranging from 2714/100,000 to 3631/100,000, while cholera had the lowest, ranging from 0 to 320/100,000. Temporal characteristics showed that ODDs and cholera peaked during the rainy season (October-March), while schistosomiasis occurred from April to June. Spatial clustering of schistosomiasis declined from two High-High (HH) clusters in Blantyre's northern and western parts (2018-2020) to one (2021-2023). Cholera exhibited High-High (HH) clusters only in the northern part from 2021 to 2023. ODDs expanded from two to three HH clusters extending southward between 2018-2020 and 2021-2023. Space-time analysis identified nine most likely clusters for schistosomiasis and ODDs and two for cholera. Most likely, clusters were in the city, with secondary clusters in the northern and western parts. Given their high incidence, focused public health strategies for schistosomiasis and ODDs should be prioritized in future planning.

Key words: intestinal infectious diseases; spatiotemporal; space-time; Moran's I, Malawi.

Correspondence: Richard Lizwe Steven Mvula, Faculty of Engineering Science and Technology, Department of Building, Energy and Material Technology, UiT The Arctic University of Norway, Postboks 385, 8514 Narvik, Norway. E-mail: poh-004-22@must.ac.mw

Introduction

Intestinal (enteric) infectious diseases are among the top ten leading causes of mortality and disability-adjusted life years across all age groups (GBD 2016 Diarrhoeal Disease Collaborators, 2018; Chua *et al.*, 2021; Wang *et al.*, 2025). The burden is more prevalent in low and middle-income countries, particularly in sub-Saharan Africa and South Asia (Black *et al.*, 2024). This burden is attributed to rapid population growth, informal settlements, unsafe drinking water, poor access to health care, and limited sanitation infrastructure, such as waste disposal systems, waste treatment, limiting the capacity to handle the problem (GBD 2016 Diarrhoeal Disease Collaborators, 2018; Black *et al.,* 2024; Sharma *et al.*, 2024). Additionally, overpopulation subjects public health resources to extreme pressure, resulting in more morbidities and mortality.

Intestinal infectious diseases result from exposure to enteric pathogens, including bacteria, viruses, and parasites. The primary sources of these pathogens are human and animal faeces, and they commonly spread through the faecal-oral path in water, contaminated food, and contact with animal waste (Mertens *et al.*, 2023). The disease burden of intestinal infections is driven by complex interactions among environmental, climatic, and socioeconomic factors (Lan & Delmelle, 2023). These factors provide a favourable environment for the proliferation of insects and rodents that are carriers of various pathogens responsible for spreading enteric infectious diseases (Neiderud, 2015). These factors contribute to the outbreaks of various intestinal diseases. Given the adverse health impacts of intestinal infectious diseases and their cost implications, it is crucial to understand the transmission patterns in low-income regions such as Malawi.

Despite a decline in the burden of enteric infection over the past 30 years (Li *et al.*, 2024, they remain a serious public health challenge. Although there have been advances in public health interventions, including improved sanitation, water treatment, and vaccines, intestinal infections continue to pose a significant threat, particularly in low- and middle-income countries. These interventions have been aimed at minimising exposure to the faecal-oral route. However, the expected reduction in disease spread has not been achieved, suggesting that animal waste and faeces should also be incorporated into Water, Sanitation, and Hygiene (WASH) projects (Lowenstein *et al.*, 2020). This is crucial, especially in low- and middle-income countries, where humans and animals live together, heightening the risk of intestinal infectious diseases (Barnes *et al.*, 2018; Baker *et al.*, 2018). Recent advances in statistical methods, Geographic Information Systems (GIS), and access to high-resolution health and environmental data have improved the ability to study how diseases change across geographic areas. Spatial epidemiology combines spatial statistics and map-based visualization techniques to analyse and describe the geographic spread of diseases and health conditions, as well as their links with environmental factors (Elliott & Wartenberg, 2004; Wang & Chen, 2024). The development of spatial transmission models for infectious diseases has advanced from simple statistical representations to complex spatiotemporal forecasts (Hu *et al.*, 2025). Innovations in GIS and remote sensing technology have enabled spatial modelling tools to incorporate data from various sources, leading to more accurate simulations of disease transmission dynamics. Modern spatial transmission models not only include traditional point pattern analysis and areal data analysis but also integrate advanced techniques such as space–time scan statistics, Bayesian hierarchical models, and mechanistic transmission models, thereby enhancing the predictive accuracy of disease spread forecasts (Hundessa *et al*., 2016; Jia, 2019; Tatem, 2018; Hu *et al*., 2025; Huang *et al*., 2025). These models provide significant advantages for assessing the effectiveness of various prevention and control strategies, thereby establishing a strong scientific basis for public health decision-making.

Previously, studies have been conducted at the global and regional levels regarding the spatial distribution of diarrheal-related mortalities and soil-transmitted helminths (Dunn & Johnson, 2018 Sartorius *et al*., 2021; Almasi *et al*., 2022). Similar studies on the spatial distribution of cholera have been conducted nationally (Tobias *et al.*, 2023; Chinkaka *et al.*, 2024). However, mapping diseases at the regional or national level overlooks district-level differences and provides limited information for policy planning (Local Burden of Disease Diarrhoea Collaborators, 2020). Consequently, studies focusing on the spatial distribution of diseases at the district level that combine three intestinal infectious diseases are lacking. Studying multiple diseases with similar risk factors is essential, as it provides a comprehensive overview of their epidemiology at the population level and supports coordinated efforts to control them (Kazembe *et al*., 2009). This study contributes information for the Blantyre District for three diseases, cholera, schistosomiasis, and other diarrheal diseases pertinent for planning and developing crucial interventions at a district level. Additionally, studies that map multiple enteric diseases and compare them are rare.

This study aimed to determine the annual incidence rates of cholera, schistosomiasis, and other diarrheal diseases at the sub-district level in Blantyre District, Malawi from January 2018 to December 2023, and to identify specific geographic hotspots and high-risk communities for these enteric infectious diseases during this period. We used descriptive methods, spatial autocorrelation, and spatial-temporal scan statistics. By gaining a deeper understanding of the spatial distribution of these intestinal infectious diseases, targeted strategies can be developed to minimise risks and implement localised interventions.

Materials and Methods

Study setting

Blantyre District is situated in Malawi's southern region (Figure 1), with a population of approximately 1.3 million and a growth rate of 2%. The district covers an area of 2,012 km^2 and has nine administrative subdivisions (National Statistical Office, 2019). The district has a mean annual rainfall of 1,122 mm, and the annual temperature ranges between 13°C and 21°C. Socioeconomic challenges are widespread, with an estimated 65% of rural residents living below the poverty line (Government of Malawi, 2023). Despite 89% having access to improved water sources, only 37% benefit from improved sanitation (Mwapasa *et al*., 2023). Furthermore, the leakage and discharge of untreated sewage in rivers and streams, coupled with poor solid waste management with open dumping in rivers, roadsides, and drains, pose a serious risk to public health and contribute to the spread of intestinal infectious diseases in the district (World Bank, 2022; Ouattara *et al.*, 2023).

Data sources

The spatial unit of analysis for this study was the district level, where intestinal infectious disease cases were aggregated. The epidemiological health data were obtained from the District Health Information System (DHIS2) database (https://dhis2.health.gov.mw/) for health facilities in Blantyre District. The available case data did not involve any patient interaction; hence, there was no need for ethical clearance. The case data was necessary for the spatial and temporal analysis. Additionally, population data from the 2018 population and housing survey by the National Statistical Office were used and projected forward using a reported annual growth rate of 2%. Figure 2 displays the methodology followed in the study.

Spatial methods - cluster analysis

We utilised spatial autocorrelation and space-time scan analysis to study the distribution of intestinal diseases. Spatial autocorrelation indicates the spatial association of nearby geographic units at a specific point in time (Anselin, 1995). On the other hand, the space-time scan delineates the clusters using time and space data, although it is limited to identifying specific types of spatial clusters (Zhu *et al.*, 2018). Combining these two methods provides a com-

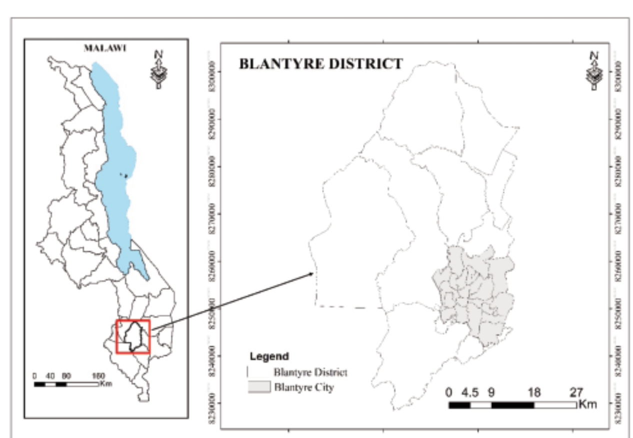

Figure 1. Study area, Blantyre District, Malawi.

prehensive understanding of disease dynamics and enhances effectiveness. These techniques are essential for identifying persistent high-risk areas and understanding seasonal or time-dependent trends (Lan & Delmelle, 2023).

Local Moran's I

Local Indicator of Spatial Association (LISA) demonstrates local geographical trends or clustering and shows different types of spatial linkages (Anselin *et al.*, 2006). The spatial classes of LISA include *high-high* (HH), which denotes high LISA values and high values in the surrounding area, thus a positive autocorrelation. Conversely, High-Low (HL) signifies higher LISA values than lower values in the surrounding area, thus a negative autocorrelation. Similarly, Low-High (LH) values indicate that LISA values are lower than those in the surroundings, signifying a negative autocorrelation. Further, Low-Low (LL) is attributed to low LISA values and low values in the surrounding area, indicating positive autocorrelation (Raza *et al.*, 2020; Indriyani & Widaningrum, 2021; Jesri *et al.*, 2021). Generally, local spatial autocorrelation indicates the spatial clustering of each feature. The following formula is for LISA:

$$I = \frac{\sum_i \sum_j W_{ij} Z_j Z_i}{\sum_i Z_i^2} \qquad \text{(Eq. 1)}$$

where Wij signifies the components of the spatial weight's matrix; Z the deviations from the mean: and $\sum_i \sum_j W_{ij}$ the sum of all the weights (Anselin *et al.*, 2006). We employed the Queens contiguity for the weight matrix, utilising neighbouring units based on shared boundaries and corners. Contiguity-based weights were chosen to represent geographically relevant adjacency relationships aligned with administrative boundaries and possible local interaction processes (Jaya *et al.*, 2023; Tesema *et al.*, 2023). The significance of Moran's I was tested using Monte Carlo randomisation with 999 permutations and a pseudo significance level of $p < 0.05\%$ (Anselin et al., 2006). LISA cluster maps for the three intestinal infectious diseases were obtained using the univariate Moran's I function to get the hotspot maps. The analysis was performed using two aggregated periods (2018-2020 and 2021-2023) to address the low number of recorded cases.

Spatio-temporal cluster analysis

The time-space scan statistics employed the Kulldorf retrospective method to identify clusters of infectious diseases using the Poisson model. The technique examines a broad area for potential disease clusters. It estimates the location of these clusters and conducts a significance test for each, adjusting for the multiple tests involved (Kulldorff *et al.*, 1997). A cylindrical window is used to identify potential clusters based on the time and geographical regions scanned (Kulldorff *et al.*, 1997). The circular geographic basis moves, with its height varying with the selected time interval, and its radius changing with the area's population range. The relative Risk Ratio (RR) is computed by dividing the observed case number by the expected case number within and outside the windows, and the Log-Likelihood Ratio (LLR) (Wu *et al.*, 2017).

$$\text{LLR} = \text{Log}\left(\frac{n}{E(n)}\right)^n \left(\frac{N-n}{N-E(n)}\right)^{N-n} \qquad \text{(Eq. 2)}$$

where N indicates the total number of cases; n the observed number within the scan window; $E(n)$ and $N-E(n)$ are the expected number of cases within and outside the scan window (Wu *et al.*, 2017). LLR was utilised to identify clusters based on LLR values, yielding the most likely cluster, secondary cluster, second secondary cluster, and third secondary cluster. In this study, we used a Monte Carlo simulation with 999 replicates and a significance of 0.05 to evaluate statistical significance and the assumption that 50% of the total population is at risk.

Data analysis and visualization

We utilised ArcGIS v., 10.8 (ESRI Redlands, CA, USA) and QGIS (v., 3.40.2-Bratislava) software for spatial analysis and map production. GeoDa (v., 1.22.0.10, GitHub, San Francisco, CA, USA) was used to obtain the LISA cluster maps. SatScan software (v., 10.2.5 64-bit, Kulldorff and Information Management Services, Inc., Boston, MA, USA) was utilised for space-time scans. Additionally, Microsoft Excel was used for data entry and cleaning.

Results

Descriptive disease analysis

This section describes the incidence rates per 100,000 persons of cholera, Other Diarrhoeal Diseases (ODDs), and schistosomiasis from 2018 to 2023. ODDs have the highest incidence, and cholera has the least. As for ODDs, the annual incidence was highest in 2019 (3631) and lowest in 2021 (2714). On one hand, schistosomiasis had the highest incidence in 2019 (388) and the lowest in 2020 (254). Cholera's incidence was highest (320) in 2023 and lowest in 2021 (0). The cholera trend is flat, with increases in 2022 and 2023. Meanwhile, ODDs remained fairly stable over the years, with spikes around 2022 and 2023. For schistosomiasis, the incidence peaked in 2019, dropped significantly in 2020, and then gradually recovered through 2023. The annual incidence of the disease per 100,000 persons is presented in Table 1.

Temporal characteristics of cases

Temporal data characteristics were categorized quarterly from 2018 to 2023. The trend for cholera shows that it was stable from 2018 through the first quarter of 2022, then increased in the second quarter of 2022, peaked in the last quarter of 2022, and remained

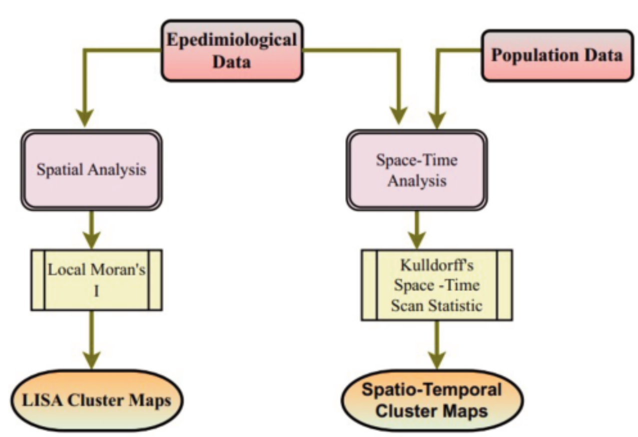

Figure 2. Methodology flow chart for the study.

elevated through the second quarter of 2023, reaching 3,783 cases (Figure 3). Schistosomiasis showed a consistent trend in cases from 2018, and all cases were below 2,000 from 2018 to 2023. The cases peaked in the 2021 second quarter at 1280. For ODDs, the cases have varied over the years. The cases peaked in the first quarter of 2019, reaching 13,860 and were at their lowest in the third quarter of 2020, at 5,999 (Figure 3).

Spatial disease clusters

Spatial clusters revealed variation in the spatial clustering among the diseases. Schistosomiasis exhibited clustering over the years, with notable changes in the distribution of the HH cluster. During the 2018 to 2020 period, clustering was observed in two district zones: northern (TA Chigaru) and western (TA Kunthembwe). In the same period, coldspots were detected in two areas of Blantyre City, South Lunzu ward and Mzedi ward (Figure 4a). However, from 2021 to 2023, clustering was limited to a single area extending from the North to the central part (TA Kuntaja), with LH clustering in the western and northern parts (Figure 4b). As for cholera, there was no clustering between 2018 and 2020; thus, Local Moran's I statistic was weak (Figure 5a) and showed only outliers for LH and HL. From 2021 to 2023, HH clustering emerged in the district's northern part (TA Chigaru) (Figure 5b). Conversely, ODDs exhibited two areas with HH clustering: the northern part of the district (TA Chigaru) and the central area of Blantyre City (Chilomoni ward). Notably, the coldspot in the same period (2018-2020) was on the eastern side of the district, which is also part of the city (Mzedi ward) (Figure 6a). From 2021 to 2023, three HH clusters were identified, extending from the original northern region to one in the central area and another in the city (TA Chigaru, TA Kuntaja, and Michiru Ward). There were no coldspots, but an outlier in LH (Figure 6b).

Spatio-temporal scan analysis

The study identified several space-time clusters for the three diseases in the Blantyre District. These clusters were most likely, secondary, second secondary and third secondary clusters. A cluster was qualified when it had no geographical overlap and consisted of more than one unit; single-unit clusters were not considered. There were nine most likely schistosomiasis clusters (Figure 7a), located in Blantyre City from 2021 to 2023, similar to the secondary and second secondary clusters, which spanned from 2019 to 2019 (Table 2). An adjusted-for-time trend for schistosomiasis generally displayed an annual decrease of 1.2%. On the other hand, the third secondary cluster in the eastern part of the district covered two locations. There were two categories of cholera clusters: most likely and secondary. There were two most likely clusters of cholera from 2022 to 2023 in Blantyre City (Figure 7b), while there were five secondary clusters spread across different locations in the district from 2021 to 2023 (Table 2). The adjusted-for-time trend showed an annual increase of 3956% in cholera, as there were no reported cases in previous years. This dramatic percentage rise reflects the recent emergence and surge in cases since 2021. ODDs were recorded at 9 locations, with the most likely clusters in

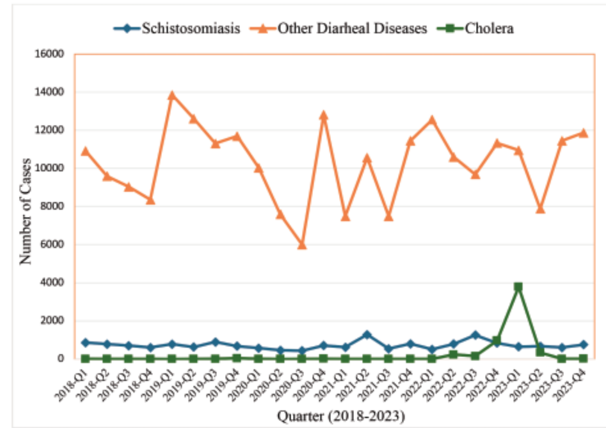

Figure 3. Quarterly temporal characteristics of schistosomiasis, cholera, and ODDs for Blantyre District from 2018 to 2023.

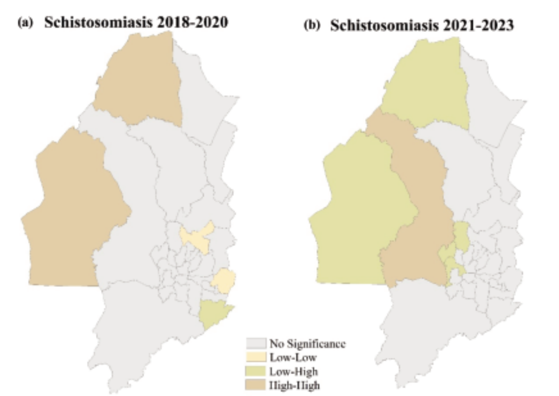

Figure 4. Univariate LISA maps of incidence of Schistosomiasis in Blantyre District, Malawi.

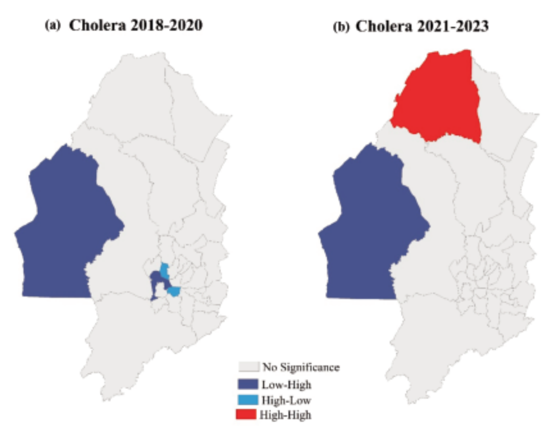

Figure 5. Univariate LISA maps of incidence of cholera in Blantyre District, Malawi.

Table 1. Annual incidence of intestinal diseases from 2018 to 2023.

Annual Incidence[a]	2018	2019	2020	2021	2022	2023
Cholera	0	2	1	0	55	320
Other diarrhoeal diseases	3,395	3,631	2,752	2,714	3,371	3,371
Schistosomiasis	334	388	254	281	316	316

[a] *1 per 100,000 population.*

Blantyre City; they spanned from 2018 to 2020. Conversely, the secondary clusters were in the northern and eastern parts of the district, for 6 locations from 2018 to 2020 (Figure 7c). The second secondary cluster comprised 7 locations in 2022, whereas the third secondary cluster comprised 5 locations spread across the district in 2022 (Table 2). The adjusted-for-time trend displayed an annual decrease of 1.8%.

Discussion

This study analysed the spatial and temporal characteristics of three intestinal infectious diseases: schistosomiasis, cholera, and ODDs from 2018 to 2023 in Blantyre District, Malawi. Understanding the spatial and temporal characteristics is essential in preventing and mitigating intestinal infectious diseases.

Table 2. Spatial-temporal analysis with 50% population at risk for the target diseases 2018-2023.

Disease	Cluste (type)	Cluster area (ward)	Coordinates	Radius (km)	Time (year)	Case (number)	Annual 1/100,000	RR	LLR	p
Schistosomiasis	Most likely	Namalimwe, Soche East, Ndirande Matope, Mbayani, Limbe Central, Nkolokoti, Soche West, Chilomoni, Bangwe Mthandizi	15.789850 S, 35.027536 E	5.91	2021to 2023	292,781	528.9	2.14	874.5738	0.001
Schistosomiasis	Secondary	Bangwe Mthandizi, Limbe Central, Misesa	15.821228 S, 35.072150 E	3.49	2019 to 2019	873	863.5	3.09	383.861	0.001
Schistosomiasis	2nd secondary	Ndirande Matope, Nkolokoti	15.778508 S, 35.048337 E	2.06	2019 to 2019	27	28.4	0.097	187.5384	0.001
Schistosomiasis	3rd secondary	TA Kuntaja, TA Kunthembwe	15.669665 S, 34.922335 E	11.37	2018 to 2020	1715	418.9	1.5	112.7832	0.001
Diarrhoea	Most likely	Namalimwe, Soche East Ward, Ndirande Matope, Mbayani, Limbe Central, Nkolokoti, Soche West, Chilomoni, BangweMthandizi	15.789850 S, 35.027536 E	2018 to 2020	78416	8993.2	2.67	22361.5	0.001	
Diarrhoea	Secondary	TA Chigaru, TA Lundu, TA Kapeni, TA Kuntaja, TA Kunthembwe, Michiru	15.447134 S, 34.948207 E	32.15	2018 to 2020	27666	2173.1	0.46	9207.359	0.001
Diarrhoea	2nd secondary	Namalimwe, Soche East, Ndirande Matope, Mbayani, Limbe Central, Nkolokoti, Soche West, Chilomoni, Bangwe Mthandizi	15.789850 S, 35.027536 E	5.91	2022 to 2022	26208	8881.4	2.25	6229.58	0.001
Diarrhoea	3rd secondary	TA Chigaru, TA Lundu, TA Kapeni, TA Kuntaja, TA Kunthembwe	15.447134 S, 34.948207 E	29.93	2022 to 2022	8935	2620.6	0.61	1230.569	0.001
Cholera	Most likely	Bangwe Mthandizi, Limbe Central	15.821228 S, 35.072150 E	1.97	2022 to 2023	1681	1002.7	13.67	2586.155	0.001
Cholera	Secondary	TA Chigaru, TA Lundu, TA Kapeni, TA Kuntaja, TA Kunthembwe, Michiru	15.447134 S, 34.948207 E	32.15	2021 to 2023	975	38.3	0.26	949.1986	0.001

RR, relative risk; LLR, log likelihood ration.

Targeted interventions in high-risk areas can be prioritised, enabling policymakers and public health personnel to optimally allocate resources. The study complements the knowledge of intestinal diseases that has been conducted in the past at the national level and in other districts. The temporal characteristics of the three diseases showed a similar pattern of peaking in the rainy season. Cholera peaked in the first and second periods of the rainy season in Malawi (Nicholson *et al.*, 2014). Diarrhoea and cholera are more prevalent in this season due to poor sanitation, eating contaminated food, and drinking contaminated water. In 2021, the worst cholera outbreak was reported in Malawi since 1998, with an overall case fatality rate of 3.3 %, and it was declared a public health emergency by the government of Malawi (World Health Organisation, 2023). The transmission pathway for cholera is a faecal-oral route through the pathogen *Vibrio cholerae*. The Cholera epidemic is attributed to civil unrest and natural disasters, and is escalated by inadequate sanitation (Zuckerman *et al.*, 2007). Therefore, in this study, we hypothesise that the cholera outbreak was compounded by the two cyclones Ana and Gombe that occurred between January 2022 and March 2022, respectively, and contributed to the displacement of people, lack of proper sanitation, and clean and portable water (Chabuka *et al.*, 2023;Valerio *et al.*, 2024). The heightened cases of schistosomiasis towards the end of the rainy season in our study align with a study that found similar findings from January to May and from May to June (Kayuni *et al.*, 2020; Arsuaga *et al.,* 2023 cf list). Schistosomiasis ranks among Malawi's top 20 causes of hospital visits (Mtethiwa *et al.*, 2015), underlining its considerable public health burden. Similarly, ODDs were more prevalent in the rainy season. This pattern is consistent with results from a study in Guinea-Bissau, where diarrhoeal diseases due to bacterial pathogens peaked during the hot summer and rainy season (Mero *et al.*, 2023). One possible explanation for this increase during the rainy season is poor sanitation, drinking contaminated water, and the introduction of faecal pathogens into agricultural fields, food markets, and households through heavy rains. Despite improvements in the Water, Sanitation and Hygiene (WASH) infrastructure, such as increased water kiosks and protected water sources, Blantyre District has seen limited progress in household water treatment and sanitation over the past decade (Gauld *et al.*, 2020).

Schistosomiasis displayed clusters in the northern and western parts of the district. These areas include rural areas and parts of Blantyre City, which, although administratively separate, lie geographically within the district. We hypothesise that the clustering in such regions is due to limited sanitation, hygiene, and untreated water use since there is more access to piped water in the city than in the rural areas. There is a drop in one HH cluster from 2021 to 2023 compared to 2018 to 2020. The decrease in the spatial distribution of the disease is similar to a study in Senegal that found a decline in the disease from 2022 to 2024 (Kane *et al.*, 2025). Another study by Gal *et al.* (2022) found a declining trend in the spatial distribution of schistosomiasis in Ethiopia from 2009 to 2022. The decline in the disease is attributed to improved sanitation services and Mass Drug Administration (MDAs), which helped minimise the risk of schistosomiasis. Mass Drug Administration (MDA) programmes have been implemented in the district; however, detailed spatial data on their coverage, timing, and intensity within the specific study areas are scarce or unavailable, limiting our ability to evaluate their role in the observed decline in cases. Importantly, our results do not agree with the results found by Kayuni *et al.*, (2020), which saw an increasing disease pattern along the Shoreline of Lake Malawi. A possible explanation is the presence of risk and climatic factors, such as warm temperatures, consistent rainfall and high humidity along the shoreline, which are favourable for the spread of the disease.

For ODDs, clusters increased in the northern and central parts of the district, specifically in Blantyre city from 2018 to 2020. This increase can be attributed to disasters such as Tropical Storm Ana in the district from 2021 to 2022, as well as poor waste management and sanitation services in the city. A study by Mvula *et al.* (2025) found numerous dumpsites along rivers and streams, located within 10 meters of the nearest house. These households use the water for washing, cooking, and bathing. Additionally, the increased threat of zoonotic enteric diseases is attributed to interactions between poultry and other livestock. These risks are also linked to markers of environmental enteric dysfunction (Beyene *et al.*, 2018; Lowenstein *et al.*, 2020). Our findings align with the increasing trend of diarrheal diseases in Ethiopia, which has been attributed to new facilities reporting cases and the recruitment of health workers to diagnose the disease (Beyene *et al.*, 2018). The spatial trend for cholera from 2018 to 2020 showed a negative Moran's *I*, indicating no significant clustering or dispersed pattern, with only LH and HL outliers (Figure 5a). Conversely, the spatial trend from 2021 to 2023 showed a single area of HH clustering in the northern part of the district. The possible spatial change is well explained by the cholera outbreaks in 2021, 2022, and 2023. The clustering were focused on the rural areas, where limited access to health services, inadequate sanitation, and potable water are significant challenges compared to the city.

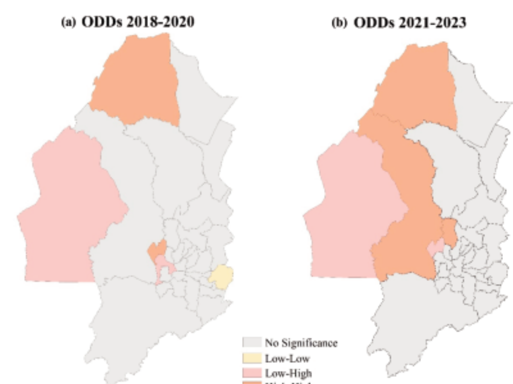

Figure 6. Univariate LISA maps of incidence of other diarrhoeal diseases in Blantyre District, Malawi.

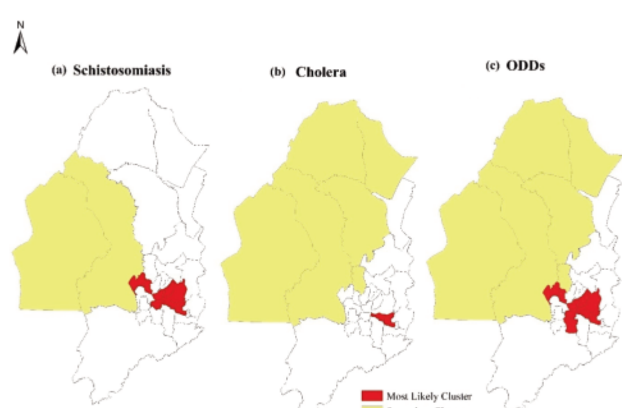

Figure 7. Space-time analysis for schistosomiasis, cholera and ODDS in Blantyre District, Malawi 2018 to 2023

The spatio-temporal cluster analysis of all three diseases showed clustering in the city. We hypothesise that the most likely clusters are concentrated in the city since over 70 % of the urban population lives in unplanned areas, occupying 23% of the city's land, with the poverty level estimated at 24% (U.N. Habitat, 2011). Additionally, only 28% of Blantyre City's waste is collected for disposal (UN-Habitat, 2023). This highlights the importance of improving the district's waste management and sanitation infrastructure, especially in informal settlements and rural areas.

The annual trend increase in cholera cases in our study is in line with a surge in cholera cases following floods in Mozambique that previously contributed to more than 17,000 cases of cholera (Naidoo & Patric, 2002). Similarly, the tropical cyclones Ana and Gombe impacted the Blantyre District, which heightened the cholera cases (World Health Organization, 2023). As for schistosomiasis, the decreasing annual trend is consistent with the studies in sub-Saharan African countries of South Africa and Ethopia (Gal *et al.*, 2022; Makhubele *et al.*, 2022). We attribute this decreasing trend to improved sanitation and the provision of MDA, which is common in primary schools and sometimes covers the entire community.

Regarding ODDs, the decrease in the adjusted-for-time trend displayed an annual reduction that is consistent with studies elsewhere (Jaya *et al.*, 2023; Fakhrizal *et al.*, 2025). Despite this reduction, proper measures should be taken to minimise the spread of the disease in the district, especially during the rainy season. The differences observed between the LISA and space–time cluster results stem from the different analytical approaches used; some areas identified as hotspots in the LISA analysis might not appear as significant space–time clusters if the increased risk is not confined to a specific time period.

Strengths and limitations

A key strength of our study is its contribution to valuable insights into the spatial and temporal distribution of three critical intestinal diseases. The map visualisations provide added value to policymakers and health managers by helping them prioritise interventions in high-risk areas while remaining vigilant in low-risk zones to minimise the likelihood of outbreaks. Our study analysed six years of data, providing a sufficient timeframe to offer a comprehensive overview of the disease trends. Furthermore, we employed hotspot and spatiotemporal analysis techniques, powerful tools in spatial epidemiology, to detect disease hotspots and clusters in space and time. Despite the strengths, the study has some limitations. First, the data utilised were obtained from the DHIS2 platform, which does not provide real-time updates on various disease cases, resulting in underreporting. Secondly, most data were from government hospitals; only one was from a private clinic, because the cases were not reported in the system.Thirdly, the results should be interpreted with some caution. As wards vary in size and shape, this might introduce bias related to the Modifiable Areal Unit Problem (MAUP). Additionally, some wards have more adjacent units than others, and this could influence local autocorrelation estimates and the identification of spatial clusters. Furthermore, the reported cases may not accurately reflect the true spatial distribution of disease hotspots or coldspots, as case locations are assigned to the reporting health facility rather than the patients' place of residence. Since individuals may seek care at more convenient facilities, such as those near workplaces or along commuting routes, this can introduce spatial misclassification and bias the identification of high- and low-risk areas. Lan and Delmelle (2023) highlighted that disease reporting is often influenced by factors such as proximity to workplaces and the availability of treatment services. This can be overcome by collecting the individuals' specific locations. Lastly, adding other variables to the study, such as rainfall, temperature, living conditions, socioeconomic status, gender, age groups, WASH indicators, settlement data, and other spatial models could have enriched the analysis by explaining the relationships between these factors and disease prevalence.

Conclusion and future insights

Our study utilised geospatial-temporal techniques to identify hotspots, coldspots, and clusters of three intestinal diseases: Cholera, schistosomiasis, and ODDs from 2018 to 2023 in Blantyre, Malawi. The high incidence of cholera and ODDs occurred during the hot and rainy seasons, specifically between October and March. On the other hand, schistosomiasis showed a high incidence in May towards the end of the rainy season. Regarding the high-risk areas, cholera and ODDs displayed an increase, as compared to schistosomiasis. Our study identifies the risk areas where the government and stakeholders should focus their interventions to minimise the spread of intestinal diseases. Based on the findings of our study, we therefore recommend the following: i) targeted interventions: implement area-specific interventions aiming at identifying high-risk zones, specifically in Blantyre's northern (TA Chigaru), western (TA Kunthembwe) for schistosomiasis, while cholera (TA Chigaru) and the risk areas for ODDs (TA Chigaru, TA Kunthembwe, TA Kuntaja, Chilomoni ward and Michiru ward), in addition to Blantyre City are at risk for clustering of the three diseases; ii) improve case reporting: all diagnosed cases should be reported to the DHIS2 on time to ensure accurate disease modelling and appropriate interventions; iii) improve water, sanitation, and hygiene: much effort should be put into improving the situation in high-risk areas and controlling and protecting safe zones; iv) incorporate broader datasets: further studies should include other factors like climate and socioeconomic status, gender, age groups, etc. that can provide a good understanding of the intestinal diseases in the study area; v) one health approach: combined public health, environmental health, and animal experts' efforts to design surveillance systems. The approach addresses intestinal infectious diseases transmitted from animals to humans (zoonotic) or from humans to humans (anthroponotic), with the environment as the host.

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