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Spatiotemporal Analysis of the Distribution of Waterborne Diseases in Children Under 5 Years of Age From 2018 to 2022 in the Lemba Health Zone in Kinshasa, DR Congo: A Retrospective and Observational Analysis

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ABSTRACT

Background and Aim: The city of Kinshasa faces the problem of access to drinking water and sanitation; its municipalities and health zones are exposed to a proliferation of waterborne diseases, a problem for the public health of the population. This study aims to carry out a spatial and temporary analysis of the distribution of waterborne diseases.

Methods: We carried out an environmental investigation followed by the collection of data that were processed by tools of the geographic and statistical information system using Pearson correlation to see the link between these diseases in space and time.

Results: The distribution of malaria affects more intermediate zones, including Mbanza-Lemba with 9044 cases and an average of 1809 cases per year in the period studied; the same case is true for typhoid fever and diarrhea which affect the flood zone including Gombele with 12,420 cases with an average of 2484 cases per year of typhoid fever and 4931 cases for diarrhea. The Salongo health area has the most recorded cases of amoeba, including 2192, with an average of 438 per year. Malaria has a strong correlation with diarrhea, which is 0.99, these two diseases have a strong to medium correlation with amoeba. A negative correlation is observed with typhoid fever.

Conclusion: The distribution of waterborne diseases in space and time in the region studied is linked to physical factors such as altitude and slope, creating flood zones likely to increase the spread of these diseases. The problem of access to drinking water and the problem of sanitation are other factors facilitating the spread of these diseases.

1 | Introduction

The Democratic Republic of Congo (DRC), a developing country, faces several challenges to achieve the Sustainable Development Goals (SDGs), including waterborne diseases that are threats to the health and well-being of the population that are directly related to goals 1, 3, and 6, which are respectively the eradication of poverty, access to health, and access to safe

Summary

- The public health of tropical countries is seriously threatened by waterborne diseases due to the combination of high temperatures, limited water supplies, and poor sanitation infrastructure, which allows sickness to spread throughout these regions.
- The spatial and temporal analysis shows malaria together with typhoid fever, diarrhea, and amoebiasis spread based on environmental factors that link to altitude and flood risks in the Lemba health zone.
- Safe drinking water shortages and bad sanitation programs act as principal drivers that expand diseases, therefore requiring precise public health intervention strategies.

water and sanitation [1–3]. The city of Kinshasa faces sanitation problems that have consequences on the health of its urban population [4, 5]. These challenges continue to worsen as the population continues to grow. The city of Kinshasa had more than 17 million inhabitants in 2023, with a growth of 716,800 in 2023 equivalent to 4.39%, and an estimate of 22 million by 2030 [6].

Microbiological contamination of drinking water can cause and transmit diseases such as diarrhea, cholera, dysentery, typhoid fever, and polio, resulting in 505,000 consecutive deaths each year [7]. In the DRC, one in five children dies before reaching the age of 5 due to these diseases [8]. The DRC has more than 50% of the water reserves of the African continent, but despite this fabulous potential, 33 million people in rural areas do not have access to quality water [9]. Despite ongoing efforts, only 52% of the population has access to an improved water point and 29% to improved sanitation facilities [10, 11].

Several studies have highlighted the exposure of the population of cities in the DRC to contamination by polluted water while proposing solutions and recommendations. Various types of contaminants have been noted in not only surface and groundwater, exposing the population to diarrhea, amoeba, and typhoid fever but also areas conducive to the reproduction of malaria vector insects [12–16].

The municipality of Lemba, one of the 24 municipalities of the city of Kinshasa, is divided into 14 districts, which make up the area of interest for this work, which supports the study in space and time of the distribution of waterborne diseases by associating malaria, a disease developing in humid conditions. This work aims to make this assessment to provide a scientific database that can help in the fight against these diseases and the deaths linked to them to achieve some of the SDGs, specifically those that fit with good health and well-being (SDG3), clean water and sanitation (SDG6) [17], in the DRC through its urbanized cities.

2 | Description of the Study Area

The study was conducted in the municipality of Lemba, a health zone located in the city of Kinshasa (Figure 1), between 4°25′26″ South latitude and 15°20′04″ East longitude. The ordinance law of February 12, 1913, was one of the most important texts that required Africans residing in urban districts to form themselves into four districts. It was under the legal status of an annexed territory of the city of Léopoldville that Lemba was placed from 1950 to 1955, without any autonomy, and was managed by the administrator of the territory assisted by a village chief. The commune of Lemba is one of the 24 municipalities of the city of Kinshasa. It was initially occupied by the Humbu people, owners of the land south of the Pool Malebo. The territorial organization of the province of Leopoldville was based on the general provisions relating to the administration of all the provinces concerned in the royal decrees of 1 July 1897. In the city of Kinshasa, the commune of Lemba is bordered to the north by the commune of Limete; to the south by the commune of Mont-Ngafula; to the east by the communes of Matete and Kisenso; and to the west by the communes of Ngaba and Makala. The commune of Lemba has 14 districts serving as health areas: Commercial, Echangeur, Ecole, Foire, Gombele, Kemi, Kipmwanza, Livulu, Madradele, Masano, Mbanza-Lemba, Molo, Plateau, and Salongo. It is an important residential and commercial center, attracting people from various parts of the city and the country. The commune has experienced rapid urban growth in recent decades (Figure 2), with significant development in terms of infrastructure and construction. This urbanization has brought challenges in water, waste, and public service management.

The climate of the study area generally refers to that of the city of Kinshasa, which benefits from a tropical climate, characterized by two main seasons: a wet season and a dry season. The above-indicated rainy period is characterized by extensive rainfall and relatively moderate temperatures. However, the period between June and September in the dry season has dry trade winds, receiving few amounts of rainfall, and slightly lower temperatures at night [18, 19]. This climate together with high humidity does favor the growth of vegetation and influences the health state and the propagation of some diseases. The study area is cut by two watersheds, the first of which is the N'djili River watershed (Figure 3) which supplies the largest water treatment plant for human consumption in the DRC. Precipitation and relative humidity data show that April and December are the wettest months with 17 g/kg for December and 16.5 for April, November has the highest rainfall up to 10.02 mm/day. On the other hand, July is the driest and least humid month with an average humidity of 13.74 g/kg and average rainfall of 0.01 mm/day from 1984 to 2022.

3 | Methodology

3.1 | Geoenvironmental Investigation

We conducted a geoenvironmental investigation where we took into account geological and environmental factors which include not only the nature of the soil which is generally sand facilitating rapid infiltration and the recharge of aquifers but also the transport of contaminants resulting from the interaction between anthropogenic activities and

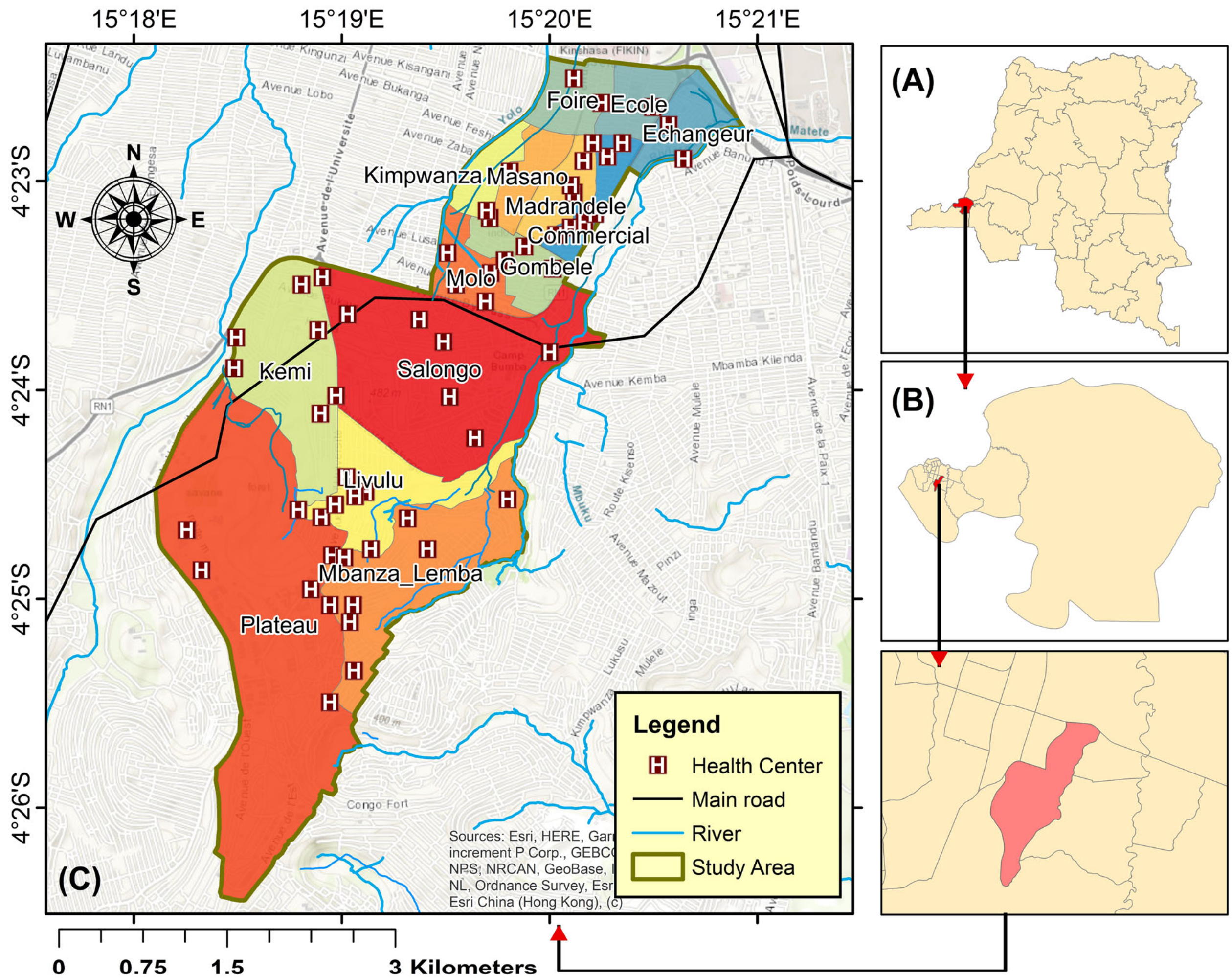

FIGURE 1 | Location map of the study area: Democratic Republic of Congo (A); the city-province of Kinshasa (B); the commune of Lemba serving as the health zone studied in this work with the health centers (C).

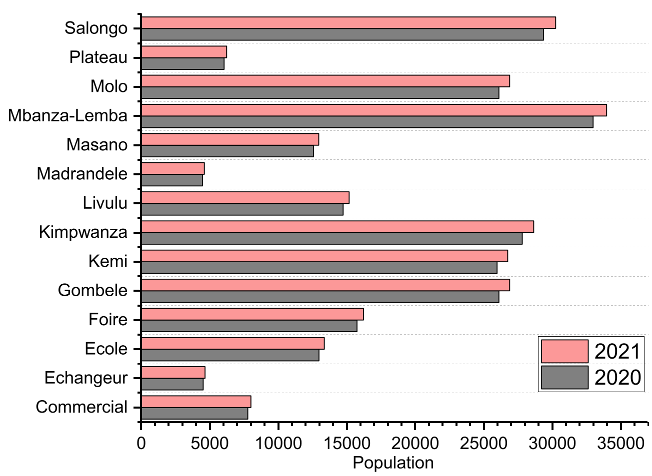

FIGURE 2 | Population of the Lemba health zone distributed according to districts (health areas) in 2020 and 2021.

the environment, then we established their link with the public health of the population. This phase of the work allowed us to list some of the causes of the diseases that are the subject of this study.

3.2 | Data Collection and Processing

3.2.1 | Data Collection

Health data on recorded cases of patients under 5 years of age suffering from waterborne diseases were collected at the Lemba urban health zone. The data cover the years 2018–2022 with an interest in waterborne diseases including typhoid fever, diarrhea, and amoebiasis, adding malaria since it proliferates in a water environment. Data from patients aged between 0 and 5 years were included, whereas data from patients aged over 5 years were excluded. Data from patients within the age range studied but not affected by the diseases studied were also excluded.

3.2.2 | Statistical Analysis of Data

Understanding the correlation between variables is essential for statistical modeling, as highlighted by various researchers such as Gong et al. [20], Chambers and Hastie [21], and Yan et al. [22]. According to Zaki et al. [23], Chatterjee and Rangarajan [24], and Steger et al. [25], correlation analysis is a frequently used and beneficial

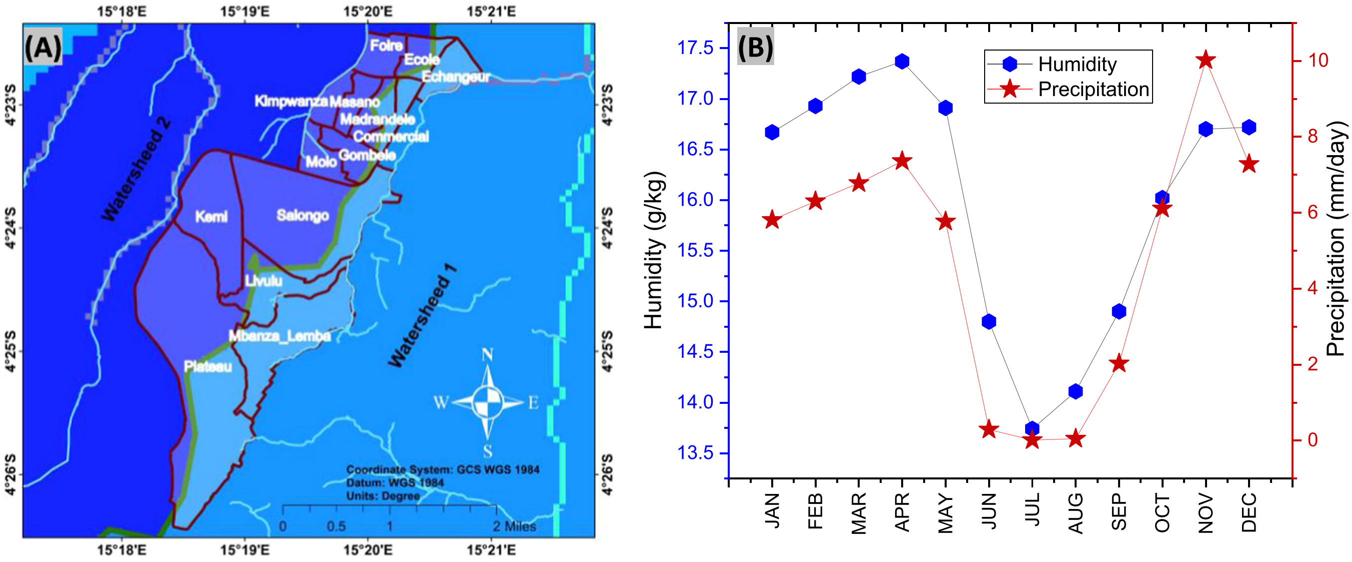

FIGURE 3 | Map of surface water resources of the study area (A). The area is contained in two watersheds that feed several rivers and groundwater reserves; the graph shows average relative humidity (g/kg) and average rainfall (mm/day) from 1984 to 2022 (B).

descriptive tool in this context for studies of this type. The Karl Pearson correlation coefficient, which is generally accepted for its reliability in capturing linear correlations, was used to assess the interdependence of variables in our survey.

The correlation coefficient between these diseases was calculated according to Pearson's law, which is expressed according to the following equation:

$$r = \frac{\sum_i^n (X_i - \bar{X}) - (Y_i - \bar{Y})}{\sqrt{\sum_i^n (X_i - \bar{X})^2} \cdot \sqrt{\sum_i^n (Y_i - \bar{Y})^2}} \quad (1)$$

X and Y are the sample means of the two variables, while X_i and Y_i stand for the ith occurrence of variables X and Y in a sample n. R can have a value between −1 and +1. There is no link between the variables of interest when $r = 0$. However, $r = 0$ indicates a negative connection between the variables, showing that a rise in one causes the value of another to fall. Conversely, a scenario where $r > 0$ indicates a positive correlation, which is the relationship between an increase in one variable and an increase in the value of another. Conditions where r approaches 1 imply that there is a strong association between the variables of interest.

The process requires linear regression correlation analysis (Figure 3) must be used for consideration of the spatial and temporal distribution of waterborne diseases in children below 5 years in Lemba health zone in Kinshasa, DR Congo, within the calendar years 2018–2022. With this method of statistics, it becomes easier to effectively examine different diseases for instance malaria, typhoid fever, diarrhea, and amoebiasis since it would allow us to search for some correlation or even dependency between a number of diseases. Moreover, in linear regression, there is the opportunity to introduce other covariates for example rainfall, population, or health facilities density into the model to see how these diseases are likely to progress spatially and temporally. Such an approach enhances the analysis by providing insight into other related mediating factors on the epidemiological characteristics which will enhance the use of differential prevention and efficient health intervention measures.

3.2.3 | Geospatial Data Analysis

Geospatial data of the study area, including health area polygons, were collected at the Department of Spatial Geodesy, Astronomy and Geophysics of the Geographic Institute of Congo. Statistical processing of the data was performed using Microsoft Excel 360 software and Origin Pro 2024b for graphics. Spatial distribution maps were produced using Geographic Information System (GIS) tools including ArcGIS (ArcMap 10.8), Global Mapper 22.0, and Surfer 18.

A humidity distribution map in the study area was made. For this, we downloaded the Digital Elevation Model (DEM) data type ALOS PALSAR L1 [26, 27] available at: https://asf.alaska.edu. These data were processed to calculate the Topographic Wetness Index (TWI) [28, 29] following the formula:

$$\text{TWI} = \ln \frac{a}{\tan b} \quad (2)$$

With a, upslope continuous area (m^2) and b, slope in radians.

The TWI was computed using a DEM raster layer with cell size = 12.5 m^2 in a GIS software program. The slope, flow direction, accumulation, tan of slope, and TWI were then determined using a number of tools in the program (Figure 4).

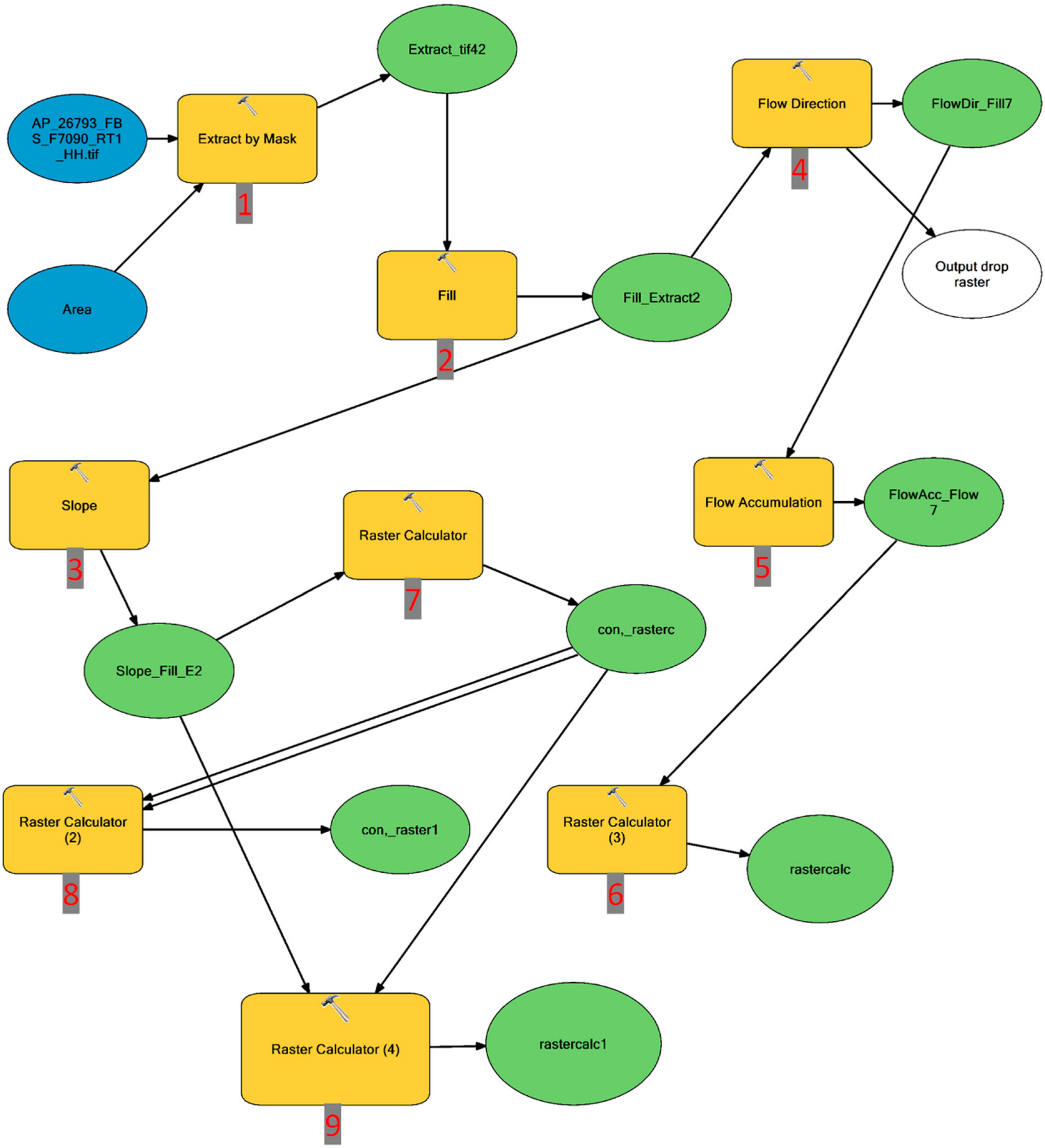

FIGURE 4 | Model builder of the Topographic Wetness Index map in ArcGIS 10.8. The steps are defined as follows: extraction of the Digital Elevation Model following the shapefile of the study area (1); filling of the voids by the GIS tools (2); calculation of the slopes (3); calculation of the flow direction (4); calculation of the flow accumulation (5); and use of the raster calculator for the TWI (6–9).

3.3 | Ethics Approval and Consent to Participiple

The study protocol was reviewed and approved by the Ethics Review Board of the Department of Research of the Medical Research Circle (MedReC) in DR Congo following the relevant approval letters respectively: Ref/00025/01/LO.DR-MedReC/2024 and the approval letter: MedReC/DR/0013/2024. The study design incorporated the separation of patient identification data by confidentiality codes to maintain anonymity and protect the privacy of the participants. Informed consent was obtained from all participants involved in the study. This study was performed in accordance with the ethics standards as laid in the 1964 Declaration of Helsinki and its later amendments or comparable ethics standards.

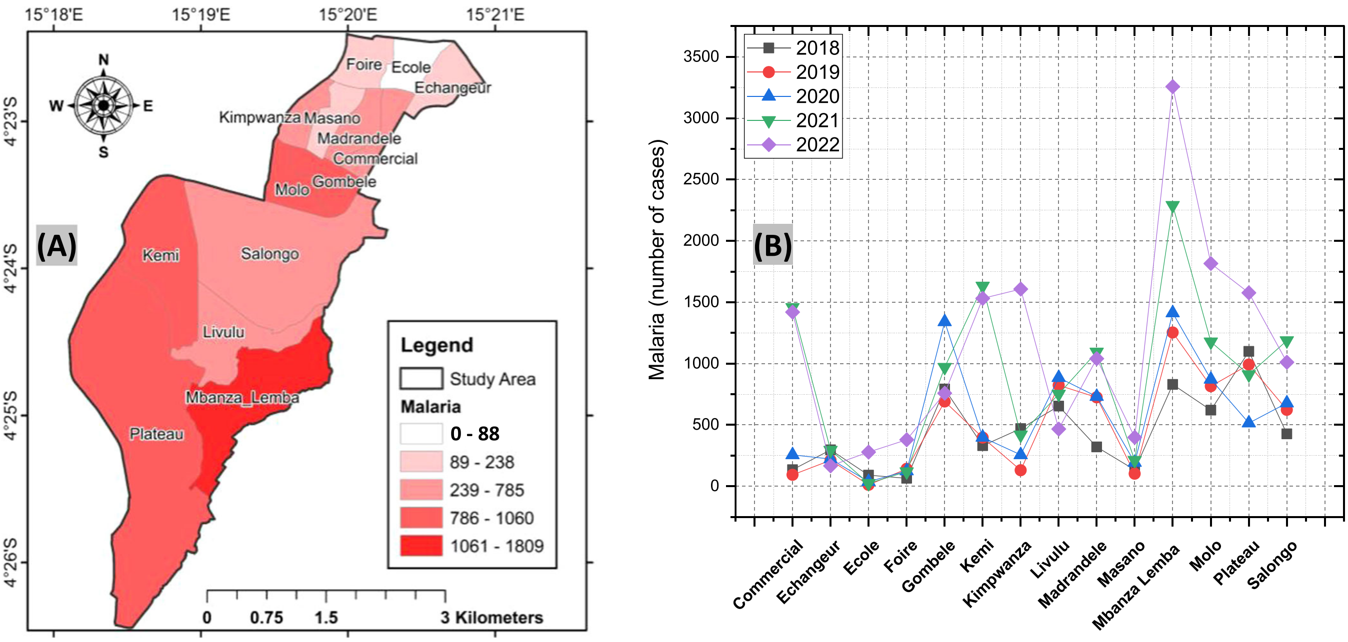

FIGURE 5 | Spatial distribution of malaria in the Lemba health zone with annual mean values from 2018 to 2022 (A) and temporary variations from 2018 to 2022 (B).

4 | Results

4.1 | Case of Malaria

In the Lemba health zone, 49,443 cases of malaria were recorded from 2018 to 2022. The maximum value was recorded in 2022, that is, 15,708 against 6265 in 2018. The Mbanza-Lemba health area has the highest value of cases in the period studied, which is 9044 corresponding to 18.29% with an average of 1809 cases per year. The Ecole health area has the lowest value of cases, which is 442 with an annual average of 88.4 cases. Figure 5 shows the spatial distribution of malaria with average values presented in classes (A) and the variations in the number of cases in the study area from 2018 to 2022.

4.2 | Case of Typhoid Fever

In the period from 2018 to 2022, 47,983 cases of typhoid fever were recorded in the Lemba health zone mainly for the years 2018 and 2019 with the most cases recorded for the year 2018, that is, 25,951. The Gombele health area recorded the highest number of cases, which is 12,420 corresponding to 25.88% of the total cases with an average of 2484 cases per year. The Salongo health area recorded the lowest number of cases of typhoid fever with a sum of 356 cases corresponding to 0.74%, and an average of 71.2 cases per year. Figure 6 shows the spatial distribution of typhoid fever with mean values presented in classes (A) and the variations in the number of cases in the study area from 2018 to 2022.

4.3 | Case of the Amoeba

A total of 11,044 cases of amoeba were recorded with the most cases in 2022 at 2918 compared to the fewest cases in 2021 at 1857. The Salongo health area has the highest number which is 2192 and is equivalent to almost 20% with an average of 438 cases per year. The Kimpwanza health area recorded only one case of amoeba during the study period. These results are presented in Figure 7 where we have the spatial distribution of the amoeba with average values presented in classes (A), and the variations in the number of cases in the study area from 2018 to 2022.

4.4 | Case of Diarrhea

During the study period, 19,198 cases of diarrhea were recorded with a maximum value in 2022 which was 5732. The Gombele health area has high values of up to 4931, or 25.68% of cases with an average of 986.2 cases per year. The Echangeur health area recorded the least number of cases, 108 which corresponds to 0.56% with an average of 21.6 cases per year. The results of diarrhea cases in the Lemba health zone are presented in Figure 8 where we have the spatial distribution with average values presented in classes (A), and the variations in the number of cases in the study area from 2018 to 2022.

5 | Conclusion

This study aimed to analyze the distribution of waterborne diseases in space and time in the Lemba health zone among children under 5 years old from 2018 to 2022. The findings suggest that waterborne diseases (amoebiasis, diarrhea, and typhoid fever) are correlated through shared environmental and health determinants. Malaria, of which water contamination does not facilitate, does not have statistically significant correlations with other diseases. These observations suggest that all the groups of disease require specific dynamics in the health intervention strategies. After a correlation analysis, it was noted that these diseases vary in time and space according to physical factors including topography because the area includes high

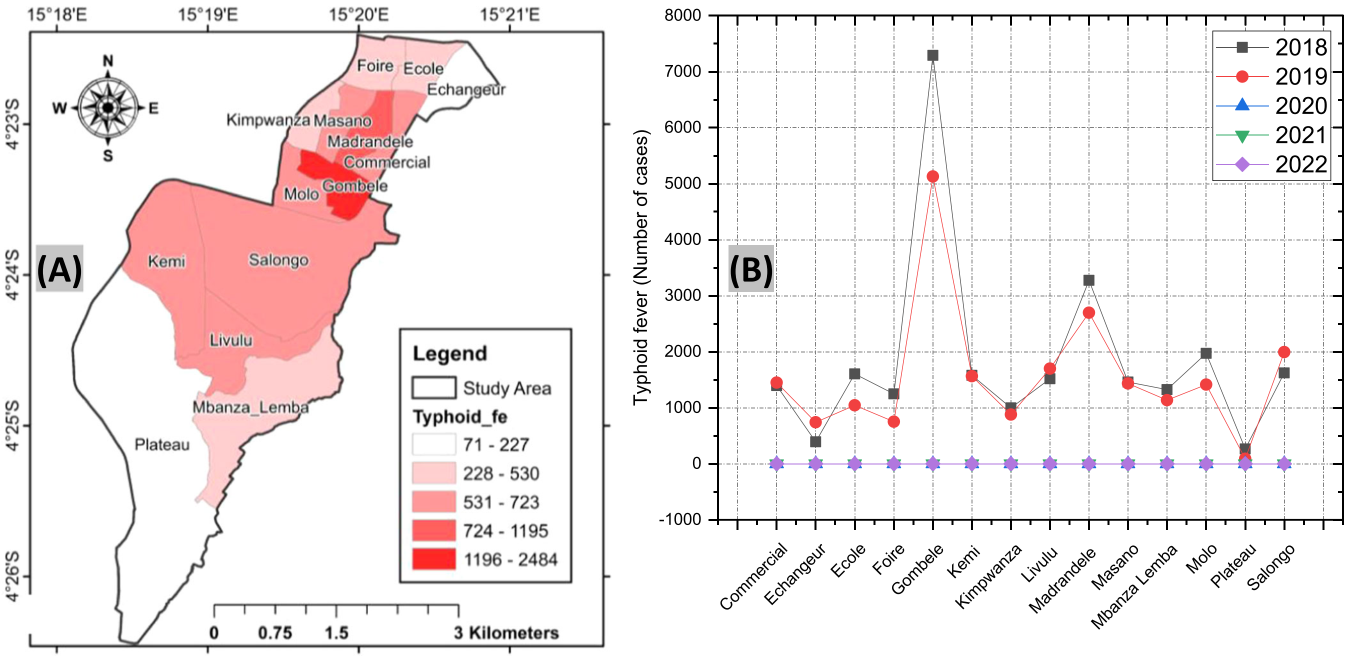

FIGURE 6 | Spatial distribution of typhoid fever in the Lemba health zone with annual mean values from 2018 to 2022 (A) and temporary variations from 2018 to 2022 (B).

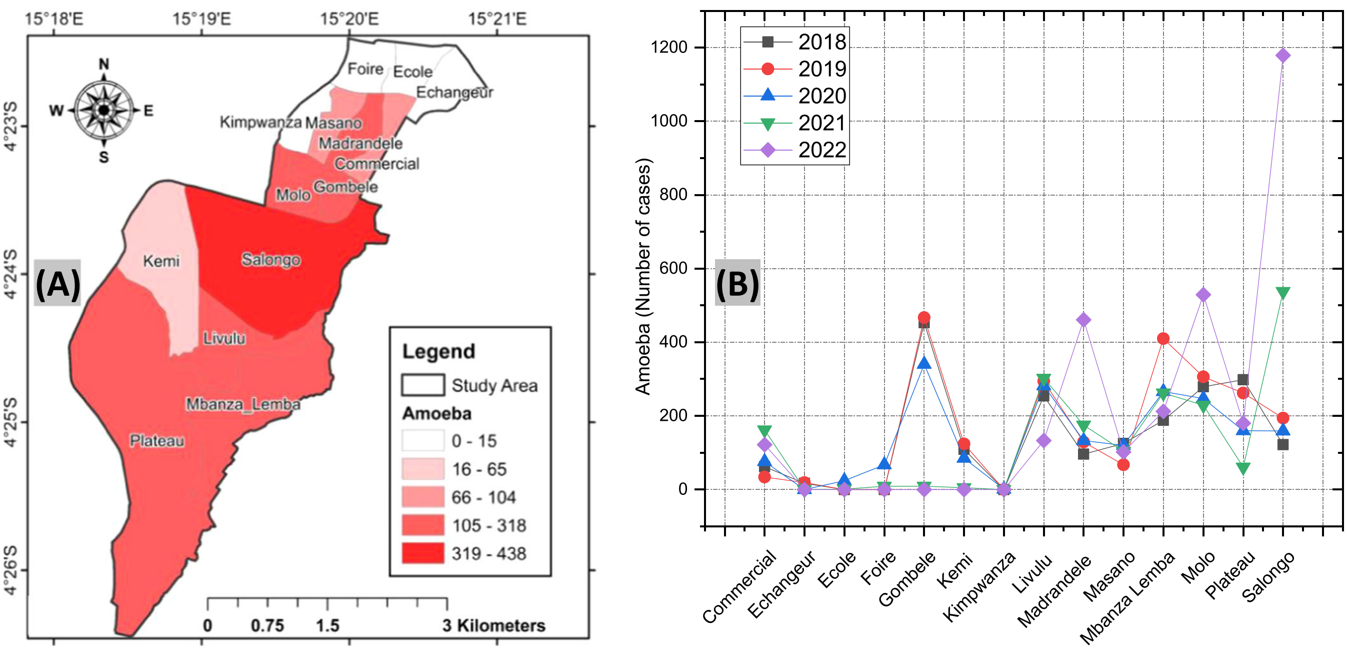

FIGURE 7 | Spatial distribution of the amoeba in the Lemba health zone with annual mean values from 2018 to 2022 (A) and temporary variations from 2018 to 2022 (B).

and low parts exposed to flooding creating an environment conducive to the spread of diseases. The causes of this spread include among others the problem of access to drinking water and poor sanitation which had to be addressed to hope for changes in the health zone.

6 | Discussion

The results of recorded waterborne diseases presented above show a distribution in space and time of malaria, amoeba, diarrhea, and typhoid fever. Malaria was the most present disease, occupying 38.73% of the total of 127,668 cases of waterborne diseases, followed by typhoid fever, which occupies 37.58 cases, then diarrhea with 15%, and finally amoeba with 8.65%. These proportions vary in the health areas where we observe the same pace of malaria followed by typhoid fever reaching sometimes more than 60%, particularly in the case of the health area of Mbanza-Lemba, where most cases of malaria were recorded. Figure 9A presents the proportion of waterborne diseases studied in the health areas, whereas Figure 9B presents the values of recorded cases of these diseases distributed according to the health areas.

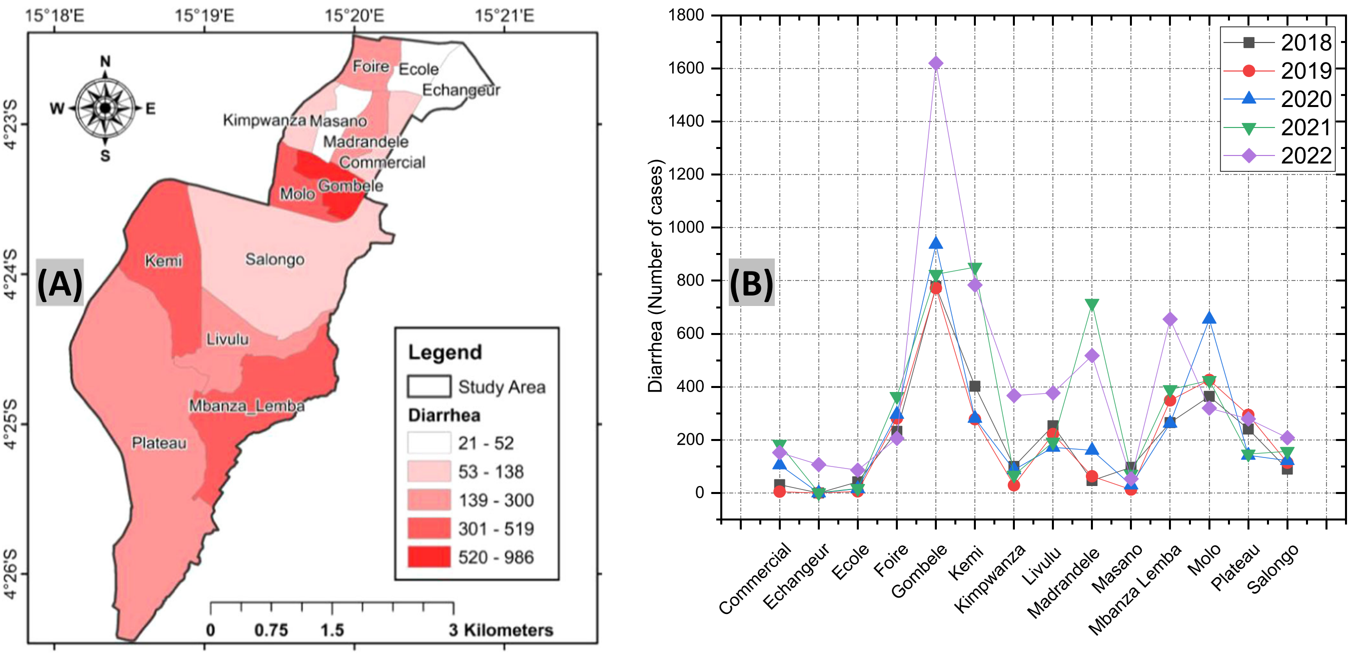

FIGURE 8 | Spatial distribution of diarrhea in the Lemba health zone with annual mean values from 2018 to 2022 (A) and temporary variations from 2018 to 2022 (B).

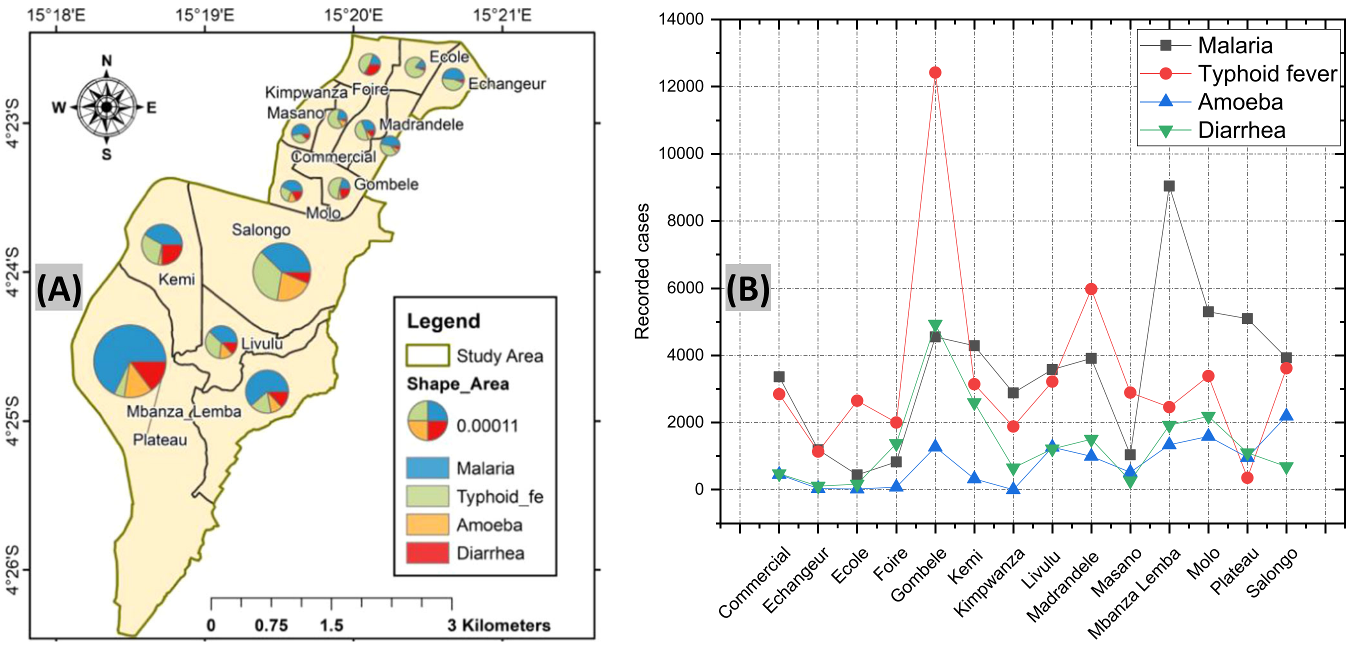

FIGURE 9 | Spatial distribution of waterborne diseases in the Lemba health zone with annual mean values from 2018 to 2022 (A) and temporary variations from 2018 to 2022 (B).

The waterborne diseases studied in the area show a correlation presented in Figure 10 according to the health areas, the hierarchical cluster for the relationship between the data (A) and the general correlation matrix of diseases in the health area studied (B) from 2018 to 2022. Malaria has a strong correlation with diarrhea up to 0.99, these two diseases have a strong to medium correlation with amoeba. A negative correlation is observed with typhoid fever. These observations vary slightly in health areas, but the general appearance remains the same. The correlation between malaria, diarrhea, and amoeba in children has been studied by several authors. Vecchio et al. studied in 2020 [30] the prevalence and risk factors for gastrointestinal symptoms in children with malaria aged 1 month to 5 years. They recorded 451 cases of children with malaria where 46.1% had gastro-intestinal symptoms. In a study conducted in 2015 on the coexistence of risk factors between malaria and diarrhea, Masangwi et al. [31] noticed a close association between malaria-like diseases and diarrheal diseases, especially at the household and individual levels. Several research studies

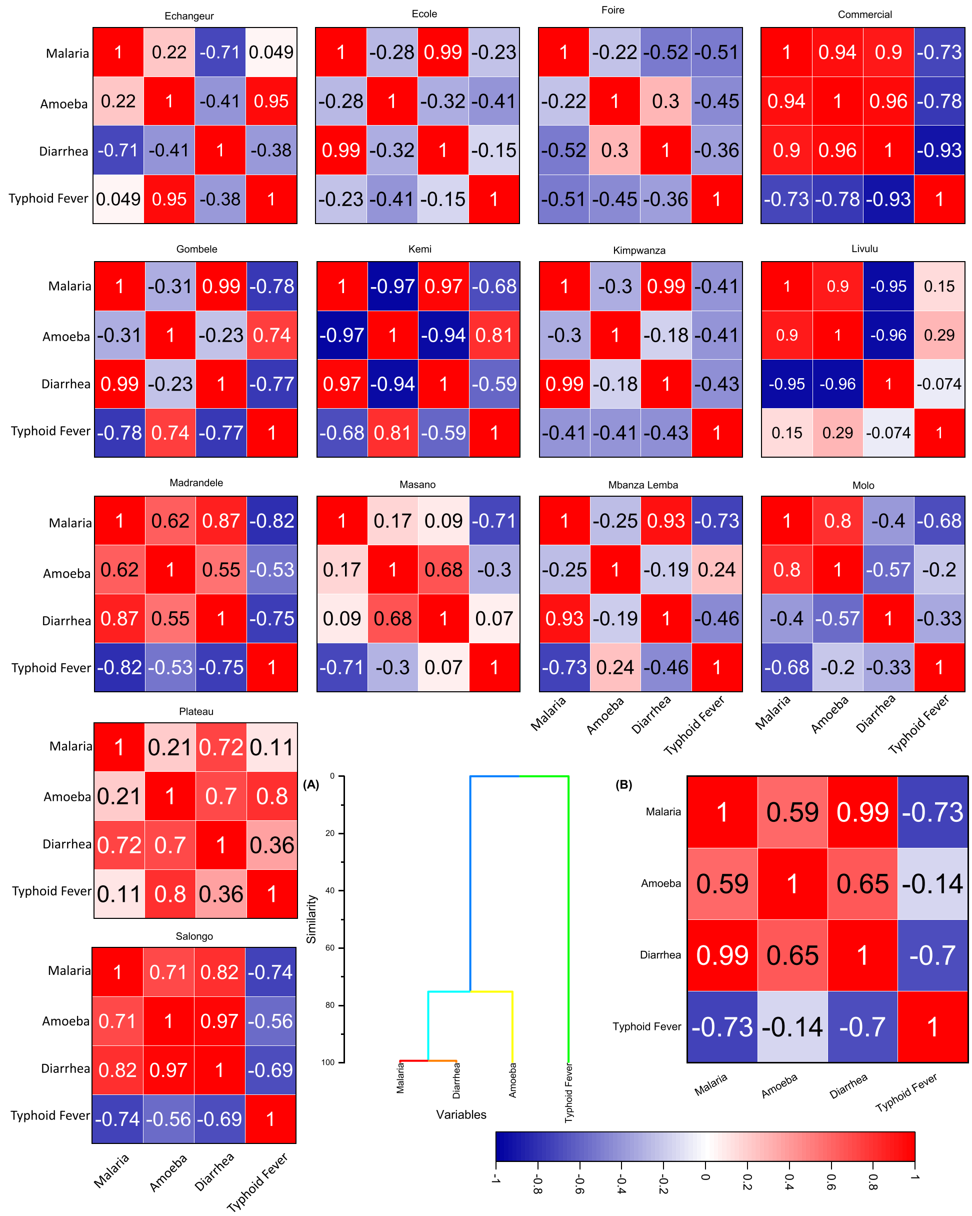

FIGURE 10 | Correlation matrix of waterborne diseases studied according to health areas and hierarchical cluster (A) for the relationship between data, the general correlation matrix of the health zone (B).

have shown the existing correlation between amoeba and diarrhea [32–34].

The coinfection between malaria and typhoid fever was noticed in this study. A study by Eze et al. in 2011 investigated the association between malaria and typhoid infections in Nigeria. The results indicated that there was no relationship between malaria and *Salmonella* infection, although both are present in the same areas [35]. The authors confirmed this study by proving the prevalence of malaria and typhoid fever that was found to be high in a study conducted in northwestern Ethiopia [36].

Malaria has several causes, here are those observed in the study area: the presence of vector mosquitoes; this mosquito (*Anopheles* mosquito, vector of malaria) is omnipresent in the area and takes advantage of urban conditions to reproduce in stagnant water found in ditches, ponds, abandoned swimming pools, waste, and water reservoirs; favorable climatic conditions: the city of Kinshasa is located in a region with high and humid temperatures favoring the rapid development of larvae and the survival of adult mosquitoes; the lack of preventive measures: in some areas, the resources and infrastructure to combat the proliferation and bites of mosquitoes are insufficient; socioeconomic conditions: poverty and poor health infrastructure underlie lack of access to malaria control resources and appropriate medical care, which can limit people's ability to protect themselves from mosquitoes and obtain rapid and effective malaria treatment.

The statistical analysis of the relationship between the data through linear regression [37–39] (Figure 11) reveals the following findings:

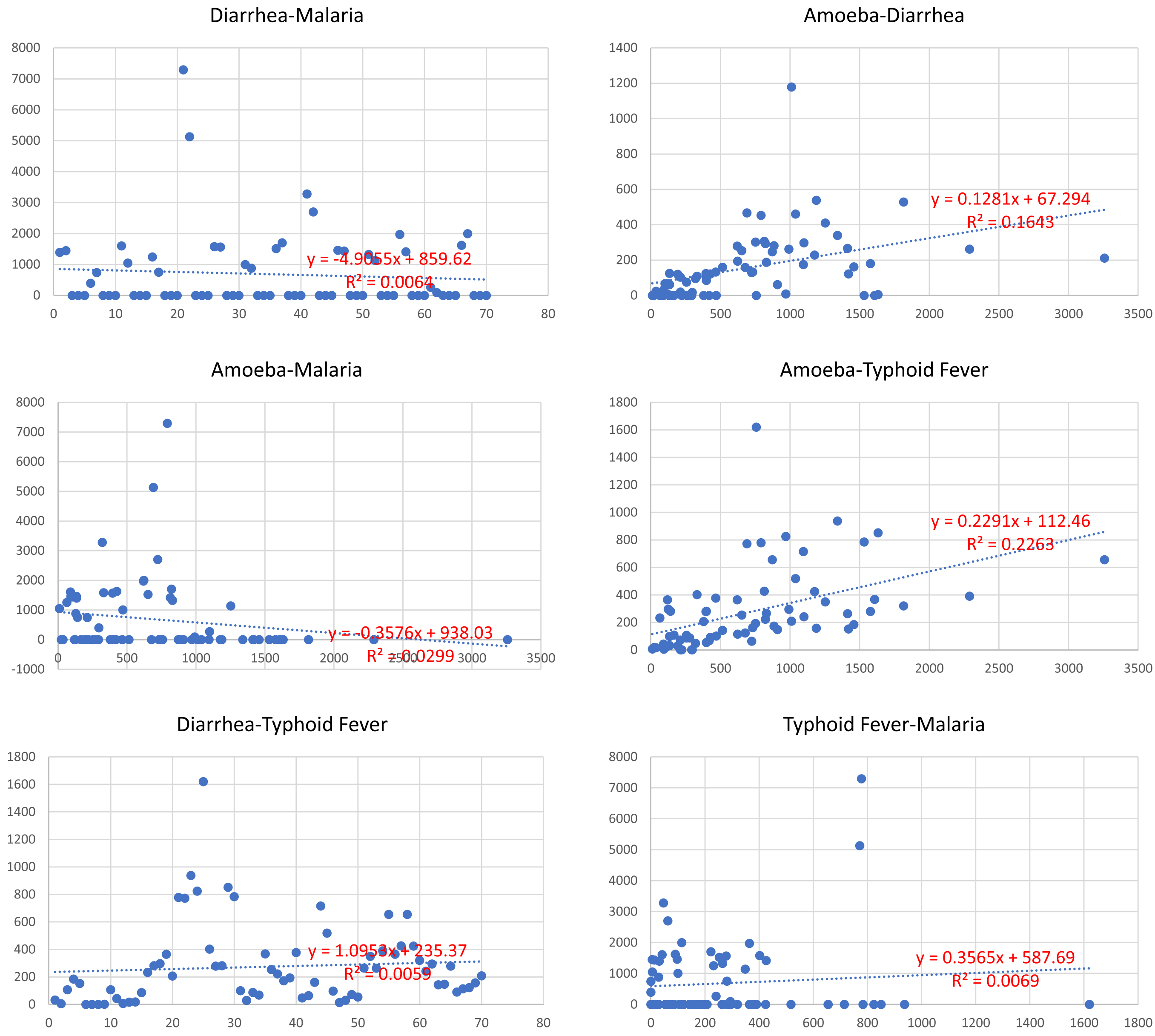

FIGURE 11 | Scatter chart to compare variables two by two to understand the relationship between the variables studied.

i. Amoeba and diarrhea ($p = 0.000499$): The p-value is less than 0.05; therefore, the observation of amoebiasis with diarrhea is statistically significant. This has led to speculation that the two diseases may have the same root causes, like waterborne diseases or bad hygiene, and that the two diseases are quite likely to be interrelated.

ii. Amoeba and typhoid fever ($p = 0.000032$): The p-value is also very low and close to zero, less than 0.05, proving the significance of the relationship between amoebiasis and typhoid fever. It can also mean that the two diseases are caused by the same factors, like pollution of water or foodstuffs.

iii. Amoeba and malaria ($p = 0.152$): The p-value is greater than 0.05, meaning that there is no calculated significant level of correlation between amoebiasis and malaria in this study. This may be due to the fact that the cause of malaria is the mosquito and not water, and other waterborne diseases can be prevented easily.

iv. Diarrhea and typhoid fever ($p = 0.134$): This model that has given a p-value greater than 0.05 also shows that there is not enough evidence to prove the fact that diarrhea has any relationship with typhoid fever. However, the correlation between the two diseases with respect to the environment may not be dire, and even if it exists, it is not very strong.

v. Diarrhea and malaria ($p = 0.147$): The p-value has now been calculated to be greater than 0.05; hence this implies there is no statistical significance between diarrhea and malaria. This affirms the fact that although malaria may be affected by environmental features, it is not influenced in the same way as waterborne diseases.

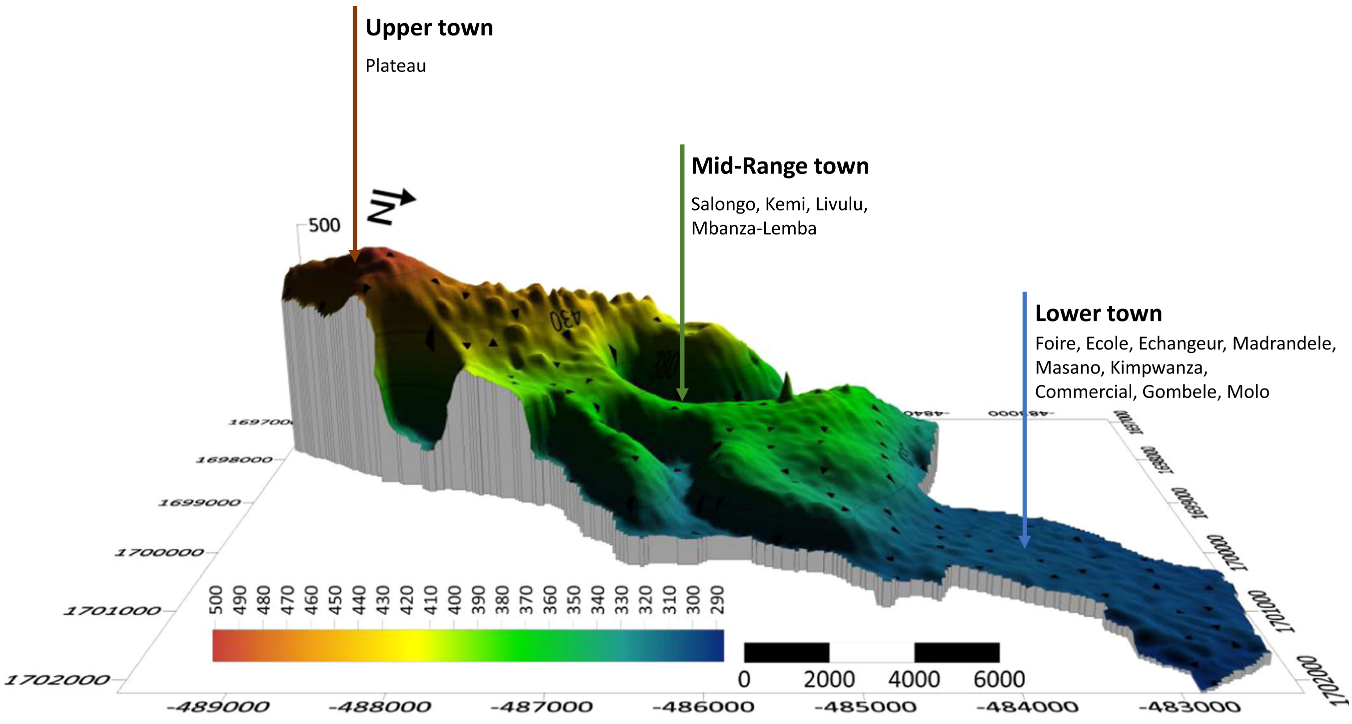

FIGURE 12 | 3D topographic model of the Lemba health zone showing the upper town, the medium upper town, and the lower town.

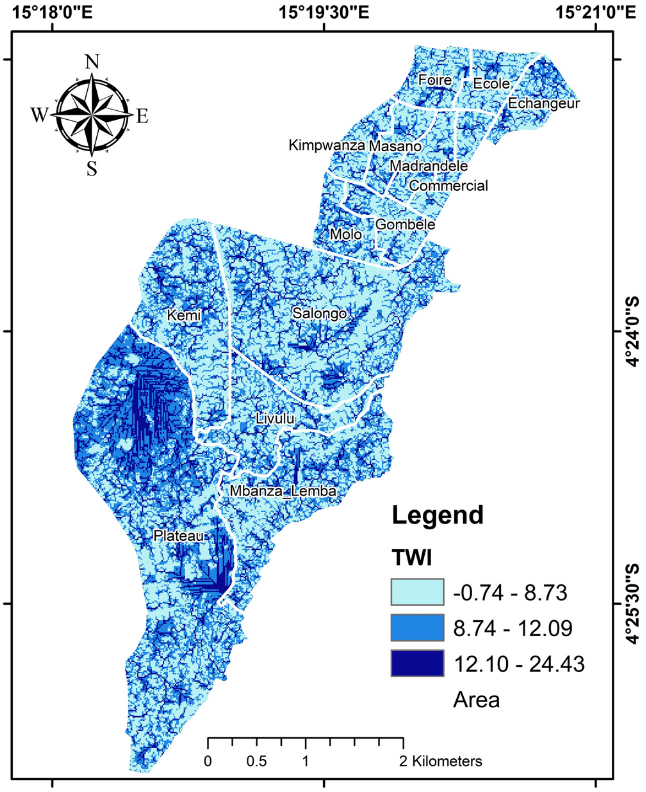

FIGURE 13 | Topographic Wetness Index map of the study area.

The distribution of waterborne diseases in the study area is influenced by the topography (Figure 12). During the rains, water flows from high-altitude areas to low-altitude areas causing flooding in these areas. This regular presence of water influences the proliferation of diseases such as malaria through the proliferation of vector insects in stagnant water [40–42]. Areas such as Plateau and Mbanza-Lemba have a high rate of malaria while they are in the upper and middle-high towns. This is explained by uncontrolled private and public boreholes with leaking pipes. This is the basis of stagnant water in the avenues favoring the proliferation of malaria vector insects. Yina showed a link between malaria and physical factors such as altitude, slope, and temperature in a study conducted in the city of Kinshasa in 2016 [43]. In the lower city, typhoid fever is more prevalent, this observation is explained by the lack of sanitation. Liquid and solid waste from the upper areas is transported to the lower city during heavy rainfall, this waste contains contaminants that are released into the water. Amoeba and diarrhea are evident in the upper city, an area that is not served with treated water intended for human consumption. The water available is that of boreholes which is consumed without any basic treatment.

These observations are also noted in Figure 13 showing the TWI map of the study area. Regions that seem sky blue on this map indicate that they will not accumulate water, regions that are blue indicate that they are neutral, and places that are dark blue indicate that they will accumulate water to varied degrees.

vi. Typhoid fever and malaria ($p = 0.496$): In the present case, $p < 0.05$ is more than 0.05, meaning that there is no correlation between typhoid fever and malaria. This means that these diseases may have different causes or etiologies.

In 2000, Rose et al. investigated the connection between waterborne illnesses and climate change. They discovered that high precipitation was linked to breakouts in 20%–40% of cases. Although it was more noticeable for outbreaks involving surface water, this association with high precipitation was statistically significant for both groundwater and surface water [42, 44]. The same was true for the study conducted by Lynch and Shaman in 2024. The study discovered a variety of correlations between hospitalization rates and geography, drinking water sources, and climatic factors. Precipitation, runoff, and rural areas were shown to have a beneficial impact on enteric bacterial and parasite diseases [45].

Typhoid fever, amoeba, and diarrhea have the same causes including contaminated water: a large part of the population does not have access to drinking water, which leads the population to consume untreated groundwater from boreholes and can lead to gastrointestinal infections; poor hygiene: there is a lack of sanitary infrastructure for the sanitation of liquid and solid waste in the area contributing to water contamination; inadequate dietary practices: ready-to-eat foods are sold in the streets, these foods are poorly preserved and sometimes prepared in poor hygienic conditions; insufficient health education: health education on good hygiene practices is lacking and above all a large part of the population believes that untreated groundwater is not drinkable since it is clear; climate and environmental changes: the city of Kinshasa is subject to floods and heavy rains affecting the quality of water and food; urban living conditions: in Kinshasa, overcrowding and poor conditions in the urban area can facilitate the spread of infections; insufficient waste management systems: improper waste management, including human waste, can lead to soil and water contamination. Amoeba cysts can end up in the environment and contaminate water sources or food. Sy et al. in 2017 [46] made the same observation during a study of diarrheal diseases in the urban commune of Nouakchott, they made the same observation on the origin and transmission of these diseases which is the lack of drinking water and poor sanitation. In a study conducted in Delhi in 2018, Bidhuri and Jain identified waterborne disease-prone areas (WBDP) and found a geospatial relationship based on the GIS using an analytical hierarchy process that relies on automated techniques [47]. The results of this study revealed that explanatory variables such as water purification, hand washing before drinking and eating, and surface water quality index (SWQI) are the most influential and positively associated, whereas dipping the hand into the container is negatively associated with WBD. The triangular fuzzy number study and range analysis conducted by Ajmal et al. in 2021 [48] show that the major factors responsible for controlling the distribution of waterborne diseases in the city are water quality index, irregular water supply, and inadequate sanitation with values of 0.247, 0.204, and 0.194, respectively. Similarly, it was found that most of the area of high vulnerability zones is located near the city center in the congested central part of the city. To effectively combat malaria, it is crucial to improve prevention strategies, such as the use of treated mosquito nets, management of mosquito breeding sites, and access to medical care. Awareness campaigns and community interventions also play a key role in reducing disease transmission. Improving access to safe drinking water and adequate sanitation, promoting hygiene education, and ensuring safe feeding practices are essential to reduce the prevalence of typhoid fever, diarrhea, and amoeba. Community awareness efforts, vaccination campaigns (especially against rotavirus), and improving socioeconomic conditions also play a crucial role in preventing diarrheal diseases.

This study has some limitations that have limited the scope of the analysis. First, the lack of means to carry out water sampling and their physicochemical and bacteriological analysis has limited the possibility of establishing a direct correlation between water quality and the incidence of waterborne diseases. The relationship could have been refined by adopting water and food analysis techniques such as gas chromatography to detect chemical contaminants [49, 50] and quantitative PCR to detect bacterial pathogens [51, 52]. The study failed to investigate mosquito breeding areas, and researchers should explore the potential of remote sensing and satellite imagery, as shown by Govindaraju et al. [53], Bravo et al. [54], and Adeola et al. [55]. The insufficient analysis of amoebiasis and typhoid fever distribution reduces our understanding of these diseases through both serological testing and bacteriological culturing methods [56, 57]. For future studies, it would be helpful to use interdisciplinary methods that include studying the environment, insects that spread disease, and advanced geospatialization techniques for health data, as well as looking into diseases that are not looked into as much [58]. The use of GIS coupled with predictive models could help identify high-risk areas and guide prevention strategies. In addition, longitudinal studies taking into account seasonal variations and climate change would provide a more precise vision of the spatio-temporal dynamics of waterborne diseases in the Lemba health zone.

Author Contributions

Jojo Mazama Sukami: data curation, supervision, writing – review and editing, writing – original draft. **Innocent Mufungizi:** conceptualization, data curation, formal analysis, visualization, writing – original draft, writing – review and editing, project administration, supervision, investigation, methodology, software, validation, funding acquisition, resources. **Julien Bompeta Lombo:** writing – original draft, writing – review and editing. **Alfred Ulama Kadima:** writing – original draft, writing – review and editing. **Didier Yina Ngunga:** writing – original draft, writing – review and editing, validation. **Aymar Akilimali:** writing – original draft, writing – review and editing, project administration, validation.

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The authors have nothing to report.

Conflicts of Interest

All authors have completed the ICMJE uniform disclosure form. The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Transparency Statement

The lead author Innocent Mufungizi affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

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