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Spatial Diffusion Patterns of Cholera in Katsina State, Nigeria (2010–2023): A Geographical Analysis of the Outbreak Dynamics and Public Health Implications

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Abstract

This study examines the spatial diffusion patterns of cholera in Katsina State, Nigeria, from 2010 to 2023. The cholera record was collected from the the Department of State Epidemiology and the Incident Manager at EOC, where it contains the locations of patients as latitude (X) and longitude (Y) and the date of onset of the disease (Z), utilising Inverse Distance Weight (IDW) and Linear Trend Surface (LTS) analyses to map the spread of the disease. Findings reveal that cholera outbreaks often originate in specific regions before spreading to neighbouring areas. The study underscores the importance of timely interventions and targeted public health responses to contain cholera outbreaks. Spatial analysis tools such as IDW and LTS proved valuable in identifying high-risk areas and guiding resource allocation for effective disease control. The findings emphasize the need for improved reporting systems, continuous monitoring, and addressing geographical, social, and environmental factors to reduce the burden of cholera in the Katsina.

Keywords: ***cholera, diffusion, Katsina, pattern, spatial***

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Introduction

Cholera is an acute diarrheal disease caused by the ingestion of food or water contaminated with Vibrio cholerae (serogroups 01 or 0139). It remains a significant public health challenge, particularly in developing countries. The disease is characterized by high morbidity and mortality rates, cholera outbreaks are often indicative of poor sanitation, inadequate access to clean water, and weak healthcare systems (World Health Organisation (WHO), 2017). The disease's rapid spread and potential for widespread outbreaks make it a critical concern for global health, especially in regions with vulnerable populations living in unhygienic conditions. Recent studies have also highlighted the role of climate change, particularly global warming, in creating favorable conditions for the proliferation of Vibrio cholerae (Adagbada *et al.,* 2012).

In Nigeria, cholera has been endemic since its first recorded outbreak in 1970, with recurrent epidemics occurring in subsequent decades. Notably, the northern region of Nigeria, including Katsina State, has been disproportionately affected by cholera outbreaks. In 2021 alone, Nigeria reported 93,932 suspected cases and 3,293 deaths, with a Case Fatality Rate (CFR) of 3.5%. Northern states accounted for 89% of all suspected cases, with Katsina State reporting 9,209 cases (Nigeria Centre for Disease Control (NCDC), 2021). The persistence of cholera in this region underscores the need for a deeper understanding of its spatial diffusion patterns and the underlying factors driving its spread.

This study focuses on the spatial diffusion patterns of cholera in Katsina State, Nigeria, from 2010 to 2023, employing geographic information systems (GIS) to analyze the outbreak dynamics. By utilizing spatial interpolation techniques such as Inverse Distance Weighting (IDW) and Linear Trend Surface (LTS) analysis, this research aims to map the spread of cholera over time and space. These methods allow for the estimation of unknown values based on known data points, providing insights into how cholera moves outward from initial outbreak locations and how its spread is influenced by geographic and environmental factors. The findings from this geographic analysis will have significant implications for public health interventions, enabling more targeted and effective responses to future cholera outbreaks in Katsina State and beyond.

The same or similar methods were used by a number of diseases mapping studies thus; Richard (2013) uses cluster analysis in GIS of climate variables and Cerebrospinal Meningitis (CSM) cases where the result predicted that not all areas with same climatic condition have same CSM cases, while Lawal (2015) uses the Linear Trend Surface and Cubicle Analysis for the diffusion of cholera in Adamawa state Nigeria, and Umaru et al., (2015) use GIS ellipse model for Urban sprawl and CSM incidence, Zakari *et al.,*(2018) uses IDW and LTS for modeling the diffusion of CSM in Kano State. From the forgoing, GIS analysis for disease mapping is becoming easy and practicable to demonstrate.

Methodology

Study Area Description

Katsina State is in the northwestern part of Nigeria and lies between latitudes $11^0.08'$N and $13^0.22'$ N and from longitudes $6^0.25'$ E to $6^0.15'$ E (Figure 1). The State is bounded by the Niger Republic to the north, Jigawa and Kano State to the east, Kaduna State to the south, and Zamfara State to the west. It is worthy of note that there are 4 federal health institutions, 23 general hospitals and over 1700 primary healthcare centers across the state (Katsina State Investment Promotion Agency, 2023).

The climate of the study area is the 'Aw' type as determined by Koppen in which distinctive wet and dry seasons with total annual rainfall figures ranging from 1000mm around Funtua to over 800m around DutsimMa, the North of Katsina State (from around Kankia to the extreme northeast) has total rainfall figures ranging from 600 to 700mm annually. The maximum temperature range in Katsina is between 29^0C and 38^0C but Harmattan season (November to February) lowers the temperature to about 18^0C and 27^0C in the noon, the daily temperature range is greater in the north and decreases south region where daily ranges are almost the same as in parts of Katsina area. The temperature in the Katsina area is more extreme during the dry season reaching over 42^0C. (Dardau, 2021). The State is blessed with abundant underground water, dams, and streams, which are used for domestic purposes as well as dry season farming. Some of these dams include Zobe Dam in Dutsinma Local Government Area, Ajiwa Dam in Batagarawa Local Government Area, Sabke Dam in Mai'adua Local Government Area, Jibia Dam in Jibia Local Government Area and Mairuwa and Gwaigwaye Dams in Funtua (Ibrahim & Aliyu, 2018).

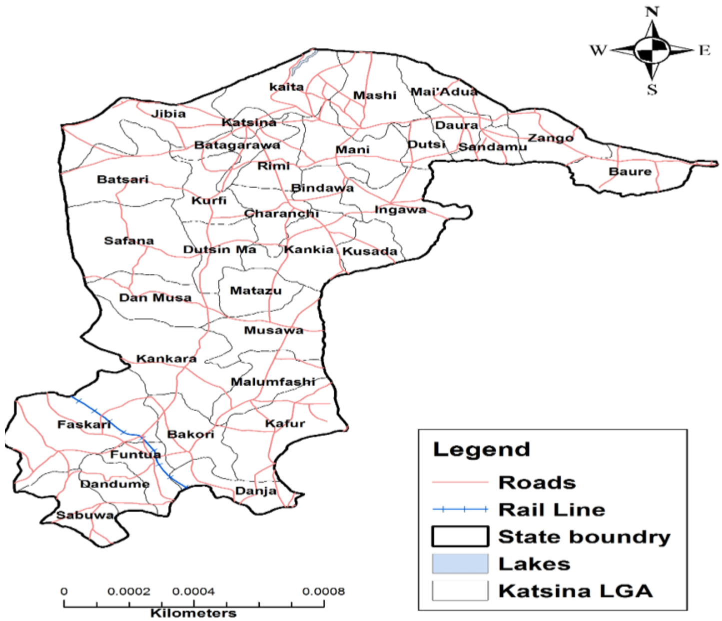

Fig. 1: Katsina State map showing the study area. Source: Department of Environmental Management, Federal University Dutse (FUD, 2023)

Method

The study utilizes the secondary data of the Katsina State cholera line-list (cholera data) from 2010-2023 which was collected from the Department of State Epidemiology and the Incident Manager at EOC, the data contains the locations of cholera patients as latitude (X) and longitude (Y) and the date of onset of the disease (Z) as variables from the excel sheet database.

The data was exported into ArcGIS for analyses were each case is treated as a point and the date of onset as the diffusion timeline (Z). The exported file was then converted to ArcGIS format shapefile, to allow use for GIS analysis, together with Katsina State shapefile (Katsina State Local Government and State Boundary map) with same georeference format was set to World_WCG_1987. To examine the spatial diffusion patterns of the cholera in the study area, two diffusion models were used, thus, Inverse Distance

Weight (IDW) and Linear Trend Surface Analysis (LTS) using GIS tool in ArcGIS 10.4.1 software environment. The Z value was use as power to generate the two diffusion models. The two analyses were run simultaneously to compare the power of predicting surface trend of the cholera diffusion pattern in the State.

1. Inverse distance weight (IDW): IDW is a spatial interpolation method used in Geographic Information Systems (GIS) to estimate values of unknown locations based on the values observed at nearby known locations. IDW moves a variable toward average, near exact, deterministic. It assumed that the near points are generally more related/have much influence on each other than the far away points. It is useful in displaying infectious diseases like Cholera diffusion in space because the disease normally spread or move outward from a point or beginning place (Meade & Emch 2010). On each of the locations, the date and specifically the month was used as the power value to determine the weight and to analyze the result in spatial and temporal trend map obtained from the IDW assumption.
2. Linear Trend Surface (LTS) Analysis: The Linear Trend Surface method is also a spatial interpolation technique used in (GIS) to estimate values across a continuous surface based on a linear trend observed in the input data points. LTS is a mathematical model of spatial variation, deterministic, inexact interpolation method that uses every known point to estimate the unknown values using polynomial regression. The LTS used here create a floating-point raster, useful for fitting a surface to the sample points when the surface varies gradually from region to region over the study area. Regionalization of diffusion is best analyzed using trend surface (Chang, 2008).

For all the years, four classes of analyses were adopted as different diffusion stages: that is first, the second, third and fourth waves, the waves were displayed using a colour scale or symbology in GIS. From the time it started in the State to the time it dissipated. All the results are displayed on a map to show the diffusion for each year and to show whether the cases are dispersed or otherwise, based on the magnitude and direction and the relationship between the index and the last case per year.

Result and Discussion

The study analyzed the spatial diffusion patterns of cholera in Katsina State, Nigeria, from 2010 to 2023, revealing varying patterns of disease spread over the years. The findings align with existing literature on disease diffusion, particularly the concepts of expansion, relocation, mixed, and hierarchical diffusion (Pyle, 1979; Hornsby, 2000; Cromley and McLafferty, 2002). The results demonstrate that cholera outbreaks in Katsina State often follow a wave-like pattern, intensifying in the origin region before spreading outward, consistent with the expansion diffusion model described by Hornsby (2000).

In the 2010 cholera outbreak in Katsina State, the index case was reported in Tashar Gamji Settlement of Kankia LGA on August 2, 2010. The disease initially remained in Kankia LGA for two weeks before spreading to Dutsinma LGA and subsequently to other parts of the state, particularly the southern region. The diffusion pattern was expansion diffusion, where the disease intensified in the origin region and spread outward. IDW analysis indicated a contagious diffusion pattern (Figure 2a), with the first wave in Kankia LGA and subsequent waves spreading to other LGAs. LTS analysis grouped cholera cases into regions based on geographical characteristics and onset dates, showing waves moving from east to west and south (Figure 2b). The 2010 outbreak exemplified expansion diffusion, where the disease intensified in Kankia LGA before spreading to neighboring areas such as Dutsinma, Batsari, and Funtua LGAs. This pattern is consistent with Pyle's (1979) description of disease diffusion, where the disease spreads outward from a central source.

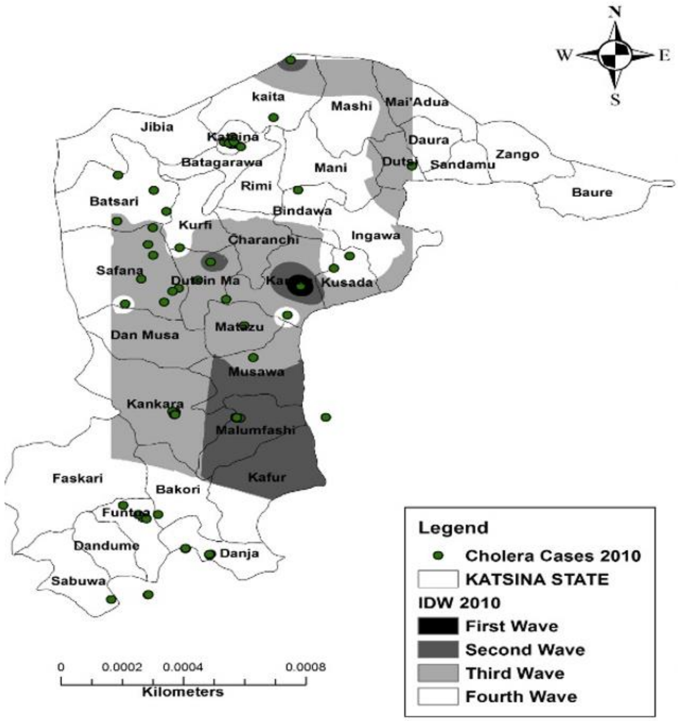

Fig. 2a: IDW for cholera outbreak in 2010.

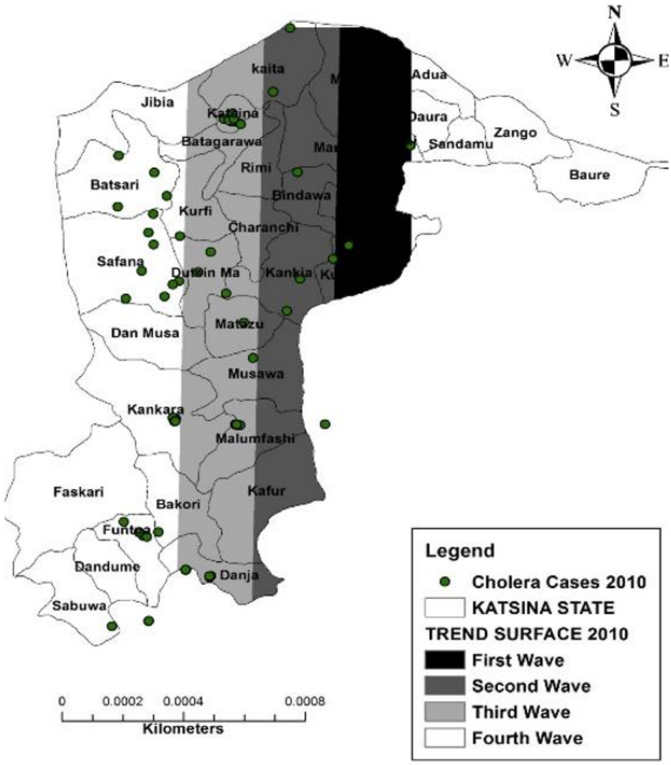

Fig. 2b: *LTS for cholera outbreak in 2010.*

The 2014 outbreak began with an index case reported in Katsina LGA at Kofar Sauri settlement in week 23. The disease moved to Batsari and Faskari LGAs, exhibiting a relocation diffusion pattern, where the disease moved from the central to the western and southern parts of the state. IDW analysis showed the first wave in Katsina LGA and subsequent waves in Batsari and Faskari LGAs (Figure 3a). LTS analysis indicated the outbreak started in the central and northeastern parts of the state (Figure 3b), with subsequent waves moving south and northwest.

The 2014 outbreak demonstrated relocation diffusion, where the disease moved from Katsina LGA to Batsari and Faskari LGAs, leaving the origin area as it spread to new regions (Hornsby, 2000). This type of diffusion highlights the importance of human mobility and contact patterns in disease transmission, as the disease did not remain confined to its origin but relocated to new areas.

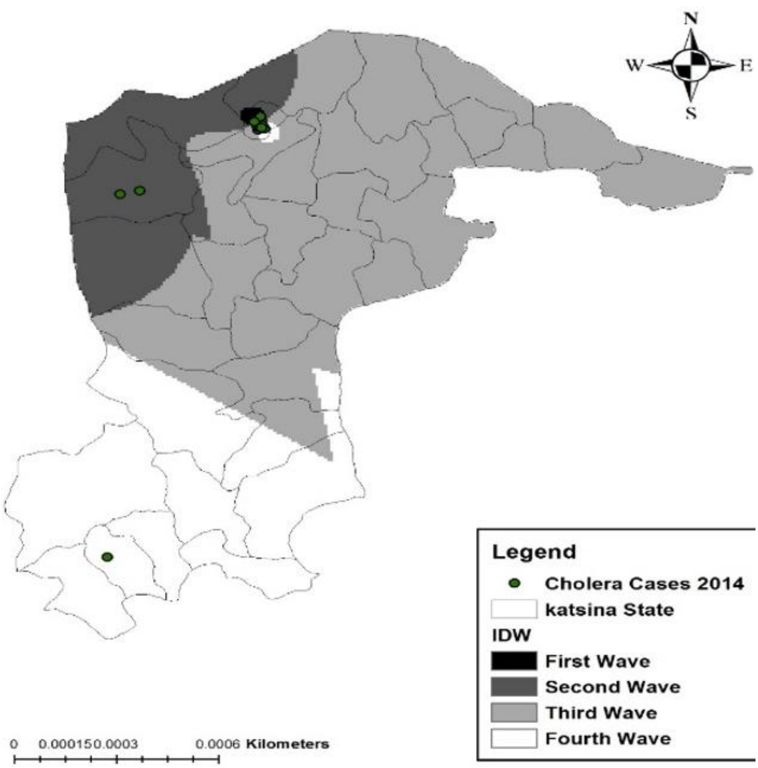

Fig. 3a: IDW for cholera outbreak in 2014.

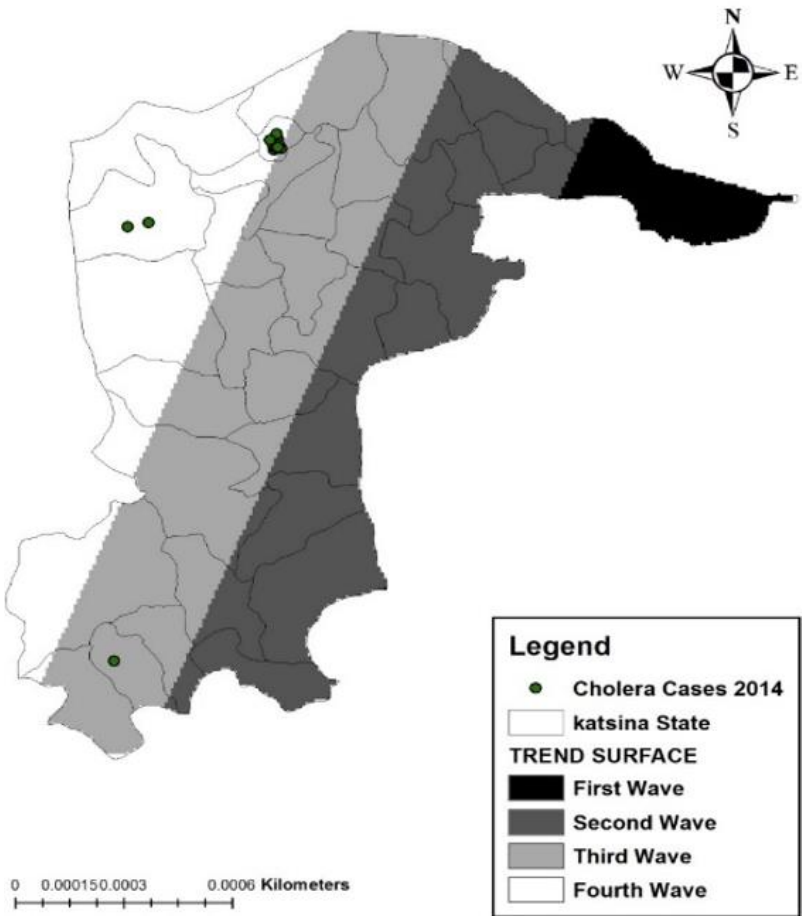

Fig. 3b: LTS for cholera outbreak in 2014.

In 2015, the index case was reported in Charanchi LGA during the 15th epidemic week. The disease initially clustered in the central zone before dispersing to the southwestern part of the state, showing a mixed diffusion pattern combining expansion and relocation diffusion. IDW analysis indicated the origin in the central zone, with waves moving southwest (Figure 4a). LTS analysis agreed with IDW, showing the first wave in the southwest and subsequent waves moving northeast (Figure 4b).

The 2015 outbreak exhibited a mixed diffusion pattern, combining elements of expansion and relocation diffusion. Initially clustered in the central zone, the disease later dispersed to the southwestern part of the state. This non-linear behavior, as described by Cromley and McLafferty (2002), complicates predictions and analyses, as the relationship between driving forces and disease spread is not straightforward.

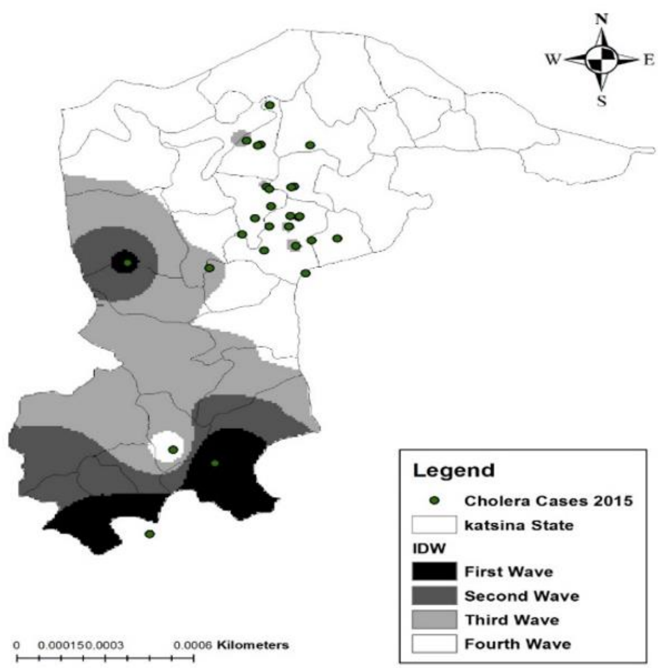

Fig. 4a: IDW for cholera outbreak in 2015

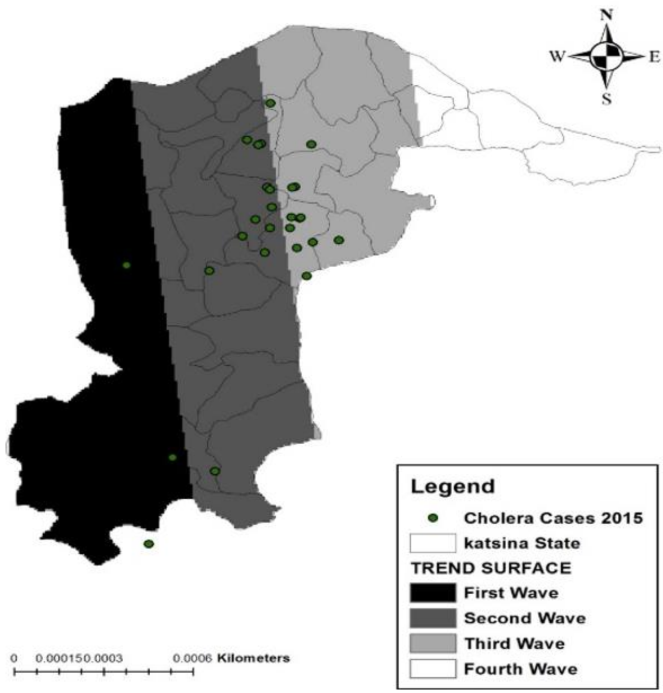

Fig. 4b: LTS for cholera outbreak in 2015

The 2019 outbreak began with an index case reported in Batsari LGA at Gawon Barda settlement in the 2nd week. The disease spread to Jibia, Katsina, and Kurfi LGAs, with Funtua LGA reporting the highest number of cases. The outbreak reached the epidemic threshold for Nigeria. IDW analysis indicated the origin in the northwest and southwest, with waves moving north and east (Figure5a). LTS analysis showed the first wave in the southwest, moving northeast (Figure 5b).

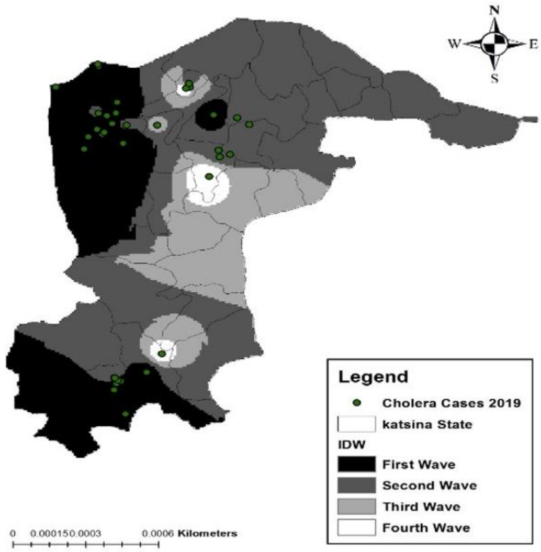

Fig. 5a: IDW for cholera outbreak in 2019

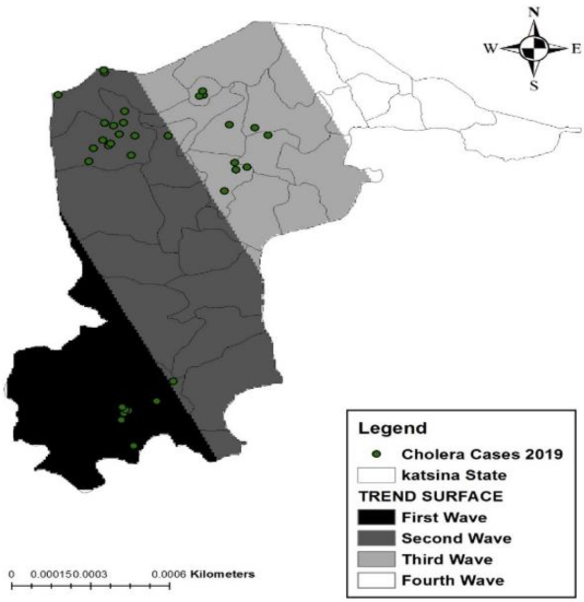

Fig. 5b: LTS for cholera outbreak in 2019

In 2020, the index case was reported in Katsina LGA at Kwado Community in March 2020. The outbreak lasted until November 2020, with Kankia LGA reporting the highest number of cases. The diffusion pattern was hierarchical (cascade) diffusion, moving from larger areas to smaller centers. IDW analysis showed the first wave in the northern part, with subsequent waves moving south (Figure 6a). LTS analysis agreed with IDW, showing waves moving from north to south (Figure 6b).

In contrast, the 2020 outbreak followed a hierarchical (cascade) diffusion pattern, moving from larger urban centers to smaller towns and peripheral villages (Hornsby, 2000). This top-down approach suggests that cholera can spread rapidly through key population centers before reaching rural areas, emphasizing the need for targeted interventions in urban hubs to prevent widespread dissemination.

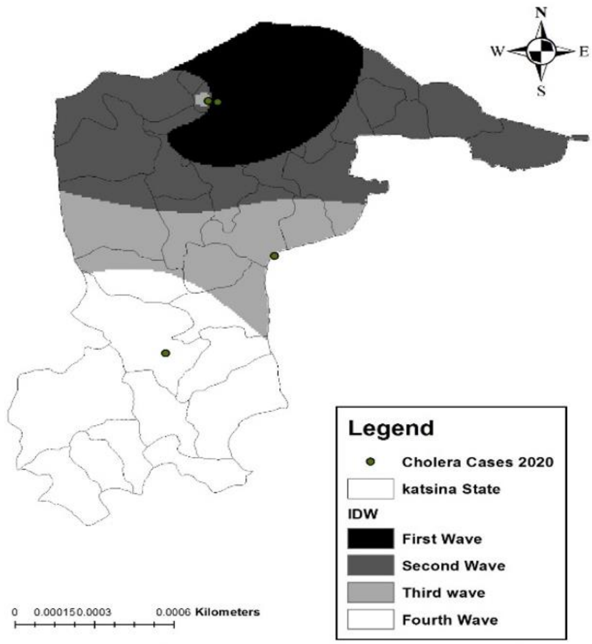

Fig. 6a: *IDW for cholera outbreak in 2020*

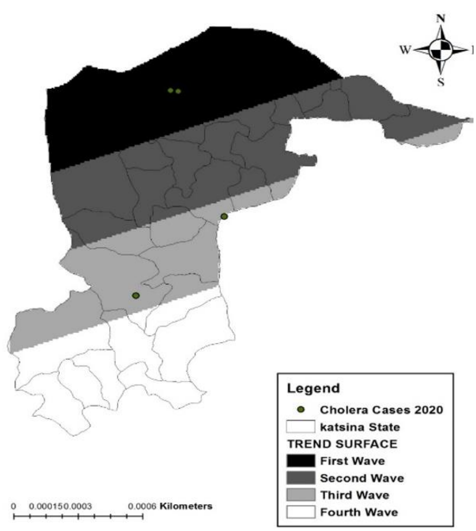

Fig. 6b: *LTS for cholera outbreak in 2020*

The 2022 outbreak began with an index case reported in Charanchi LGA at Walawa settlement in the 1st week. The outbreak lasted until September 2022, affecting 13 LGAs. The diffusion pattern was fixed diffusion, where the disease originated and ended in fixed locations. IDW analysis indicated the origin in the central part, with waves moving northeast (Figure 7a). LTS analysis showed waves covering the entire state, moving from northeast to south (Figure 7b).

The 2022 outbreak demonstrated fixed diffusion, where the disease originated and ended in specific locations (Schærstöm, 2009). This pattern suggests that certain areas may act as persistent hotspots for cholera, requiring sustained public health efforts to prevent recurrent outbreaks.

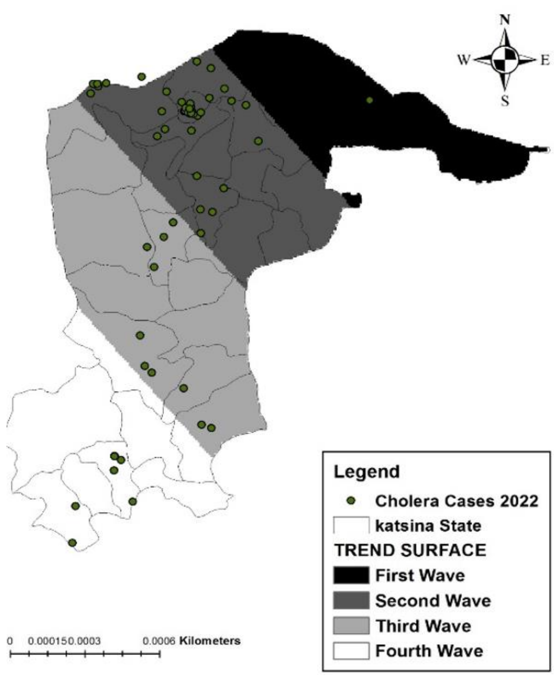

Fig. 7a: IDW for cholera outbreak in 2022

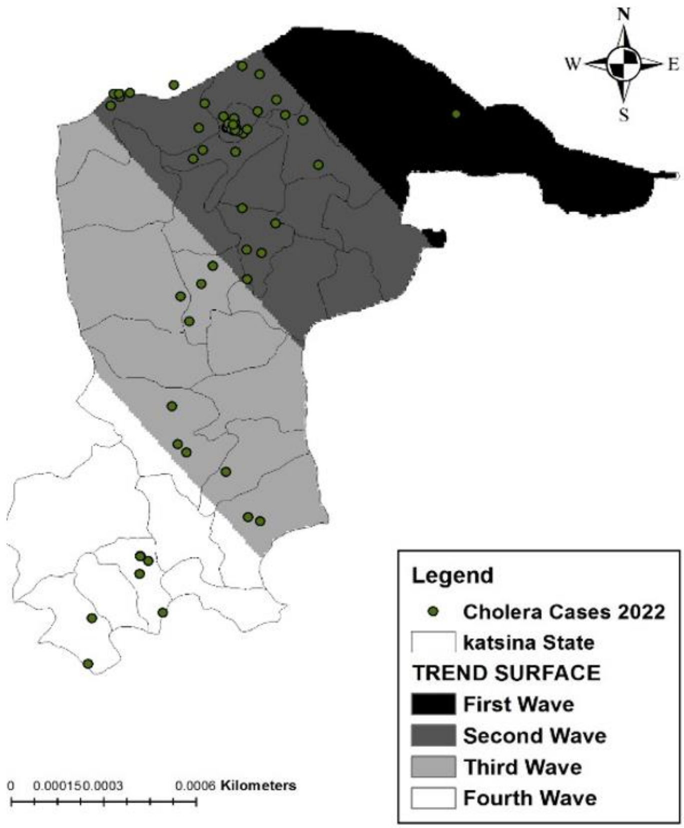

Fig. 7b: ***LTS for cholera outbreak in 2022***

In 2023, the index case was reported in Charanchi LGA at Garazawa settlement on January 8, 2023. The outbreak reached the epidemic threshold, affecting 19 LGAs, with Funtua LGA reporting the highest number of cases. The outbreak started virulently, with multiple origins across the state. IDW analysis indicated multiple nodes of origin, with waves moving from central to northern and southern parts (Figure 8a). LTS analysis showed waves moving from southeast to northwest (Figure 8b).

The 2019 and 2023 outbreaks reached the epidemic threshold as defined by the World Health Organization (WHO, 2020), highlighting the potential for cholera to escalate into large-scale epidemics if not promptly controlled. The 2023 outbreak, in particular, showed a virulent start with multiple origins across the state, indicating the possibility of unreported cases or pre-existing conditions that facilitated rapid spread.

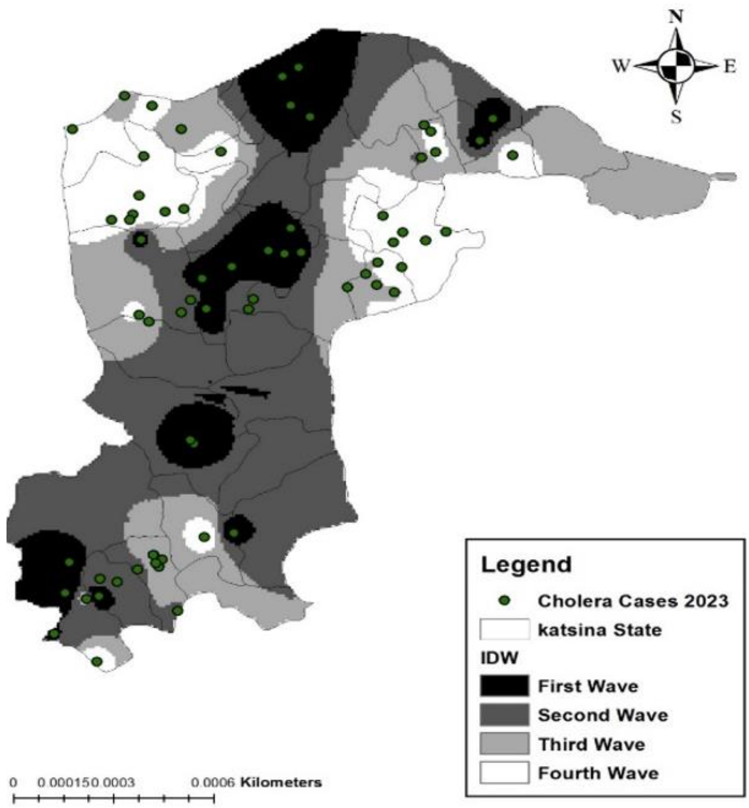

Fig.8a: IDW for cholera outbreak in 2023

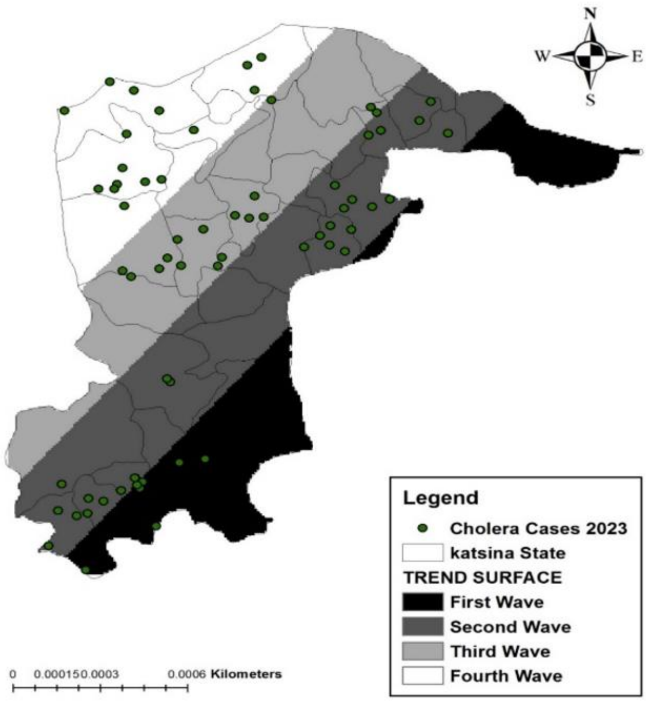

Fig. 8b: LTS for cholera outbreak in 2023

The findings underscore the importance of timely interventions and targeted public health responses to contain cholera outbreaks. The use of spatial analysis tools such as Inverse Distance Weight (IDW) and Linear Trend Surface (LTS) analyses provided valuable insights into the spatial and temporal spread of cholera, enabling the identification of high-risk areas and guiding resource allocation for effective disease control. These tools, as demonstrated in this study, can help public health officials predict disease spread and implement preventive measures in vulnerable regions.

Conclusion

In conclusion, the study provides valuable insights into the dynamics of cholera diffusion in Katsina State, contributing to the broader understanding of cholera disease spread in similar settings. The varying patterns of diffusion observed over the years emphasize the complexity of cholera transmission and the need for tailored public health strategies to mitigate its impact. By leveraging spatial analysis tools and understanding the underlying mechanisms of disease diffusion, public health officials can better prepare for and respond to future cholera outbreaks.

The study also highlights the need for improved reporting systems and continuous monitoring to better understand and predict the spread of cholera. The spatial diffusion patterns observed in Katsina State suggest that cholera outbreaks are influenced by a combination of geographical, social, and environmental factors. Addressing these factors through improved sanitation, access to clean water, and public health education is crucial for reducing the burden of cholera in Katsina State and similar region.

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