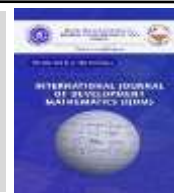




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Spatio-Temporal Analysis of Tuberculosis Case Notifications in Gombe State

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ABSTRACT

Tuberculosis (TB) still constitutes a critical public health issue in Nigeria, especially in the Northeastern part of the country due to persistent socio-economic, environmental and healthcare factors. Spatio-temporal distribution of TB is vital to improve the quality of surveillance and intervention strategies. In this study, the spatio-temporal distribution of TB was evaluated by analyzing annual number of cases notified in Gombe State, Nigeria for five years (from 2020 to 2024). Choropleth mapping in R was used to create visual maps while global spatial autocorrelation of annual TB data was assessed using Global Moran's I with a distance-based Gaussian kernel weight function. The findings of this study revealed an increasing trend in the number of cases reported during the period under review. Yamaltu/Deba and Akko LGAs had higher figures than other local government areas. Global Moran's I did not identify any statistical significance in spatial autocorrelation in the years 2020, 2021, 2022 and 2023. However, in the year 2024, there was a significant positive spatial autocorrelation with Moran's I = 0.0923 and p-value = 0.024. Thus, there is the likelihood that TB case notifications have become geographically clustered in the local government area as at 2024. The implication these findings demand the need to incorporate spatial intelligence in active case finding strategy.

1 Introduction

Tuberculosis (TB) continues to impose a heavy burden on global public health, especially in low- and middle-income countries (World Health Organization, 2024). Nigeria is one of the high-burden TB countries according to the World Health Organization classification and contributes substantially to the global tuberculosis burden despite ongoing national TB control programs (World Health Organization, 2024).

The distribution pattern of TB cases in Nigeria demonstrates pronounced spatial heterogeneity due to differences in population, socioeconomic status, environment, and access to medical services. The control of TB in the northeast part of Nigeria, such as Gombe state, is complicated due to poor economic development, climate variability, and a lack of healthcare facilities.

In Niger State, Balogun *et al.* (2022) conducted a spatial analysis of TB case notifications from 2016 to 2020 through Global Moran's I and Kriging interpolation. Contrary to other areas, there was no statistically significant spatial

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clustering in the area of study, but there were specific local government areas (LGAs) such as Chinchaga and Bosso, which had to be addressed because of being hotspots for TB.

On the other hand, Adam *et al.* (2019) carried out a spatio-temporal analysis of TB case notifications in Madobi local government area of Kano State, where the study showed that TB was not equally distributed both spatially and temporally in the region. From the study, TB cases increased from 2012 to 2015, with wards such as Madobi and Kwankwaso being key hotspots for TB infection.

A spatio-temporal study done in Oyo State, Nigeria, by Ayandeyi Teibo *et al.* (2025), which evaluated the disease in over 28,000 individuals between 2015 and 2019 using the space-time scanning and the Getis-Ord G_i^* methods found out that the riskiest municipality is Ibadan South West, contributing more than 10% of cases at the state level. This research proved that TB prevalence can vary temporally and thus emphasizes the importance of consistent surveillance as a way of evaluating the effectiveness of interventions in controlling the disease.

Research conducted by Ebonyi *et al.* (2026) on the spatiotemporal patterns of TB cases reported between 2019 and 2022 in Jos Metropolis through use of SaTScan and Moran's Index revealed three major spatiotemporal clusters, with one cluster emerging during the period 2021–2022 (Ebonyi *et al.*, 2026). This implies that there are local clusters in the metropolis where the disease is concentrated and that there is the potential for spreading the infection to other parts of the metropolis, thus the adoption of the ACF strategy in the geographic regions of the metropolis (Ebonyi *et al.*, 2026).

A previous GIS-based study done by Makadi and Ahmed (2021) examined the spatial distribution of tuberculosis in Gombe State between 2010 and 2015 using Moran's I and Inverse Distance Weighting (IDW) interpolation. Their findings revealed that spatial variations in TB hotspots, with high-burden areas shifting from northern LGAs such as Dukku and Nafada in 2010 to central and southern LGAs including Akko and Shongom by 2014. This study provides an important baseline for understanding the evolution of tuberculosis hotspots in Gombe State over time.

Spatio-temporal analysis offers powerful approaches to studying the geographical variations in disease risk and spatial clustering. Metrics such as Global Moran's I provide quantitative data indicating whether there exists any spatial clustering, dispersal, or random distribution of disease case notifications (Anselin, 1995; Lawson, 2018). While several studies have explored the case notifications patterns of TB in Nigeria or its regions, spatiotemporal research at the local government area level is relatively rare.

The current research seeks to investigate the spatial and temporal patterns of TB case notifications among local government areas in Gombe State between 2020 and 2024. The research objectives include (i) the visualization of the annual pattern of TB case notifications through R-based choropleth mapping and (ii) the assessment of spatial clustering using Global Moran's I metrics. The results offer valuable baselines to inform TB control.

2 Materials and Methods

2.1 Study Area

Gombe State is located in northeastern Nigeria, between latitudes 9°30'N and 12°30'N and longitudes 8°45'E and 11°45'E. The State comprises eleven (11) Local Government Areas and has an approximate population of 3.6 million people. The climate is generally defined by a pronounced rainy season and a dry Harmattan season.

2.2 Data Sources and Quality Considerations

Data on TB cases reported annually (2020-2024) was extracted from NTBLCP and Gombe State Ministry of Health and analyzed at the level of LGA. Shapefiles containing administrative boundaries were used to determine geocoding coordinates of TB cases reported. Data was prepared by ensuring validity and uniformity before analysis. Nevertheless, several considerations regarding limitations need to be highlighted including underreporting of cases based on the lack of symptoms or difficulty accessing health care services, variations in diagnostic capabilities (for example implementation of GeneXpert), and impact of the COVID 19 pandemic (2020-2021). It is important to note that no completeness assessment was conducted during this research.

2.3 Spatial Visualization

Spatial visualization was performed using the R statistical computing platform. Shapefiles of LGA boundaries were processed through the use of the *sf* package, and choropleth maps were created via the *tmap* and *ggplot2* packages (Pebesma, 2018; Bivand *et al.*, 2013). Annual TB case notification data were merged with LGA boundary shapefiles and visualized using choropleth maps.

2.4 Spatial Autocorrelation Analysis

Spatial autocorrelation among TB case notification rates was measured through the use of the Global Moran's I statistic (Bivand *et al.*, 2009). Distance-based weights were generated using the centroid coordinates for the eleven LGAs. Spatial dependency among LGAs were captured through the use of a Gaussian kernel function, whereby LGAs that were closer to each other had more weight than those that were further apart. The spatial weights were calculated as

$$w_{ij} = \exp \left[-\frac{1}{2} \left(\frac{d_{ij}}{b} \right)^2 \right] \quad (1)$$

where

d_{ij} denotes the Euclidean distance between LGAs i and j , and b is the bandwidth parameter selected through cross-validation (Jiang *et al.*, 2020). This approach allows spatial influence to decrease smoothly with distance while avoiding abrupt neighborhood boundaries.

Global Moran's I was then computed annually (2020–2024) using the **spdep** package in R (Anselin, 1995; Bivand *et al.*, 2013). Statistical significance was assessed using 999 permutations. The calculations were done individually per year from 2020 to 2024.

The value of Moran's I indicates the extent to which observations with similar TB case notifications values cluster spatially, disperse spatially, or distribute randomly throughout the study region.

The Global Moran's I statistic is defined as:

$$I = \frac{N}{W} \frac{\sum_i \sum_j w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\sum_i (x_i - \bar{x})^2} \quad (2)$$

where,

N is the number of spatial units (LGAs), w_{ij} is the spatial weight between LGAs i and j (e.g., 1 if adjacent, 0 otherwise, or based on distance), W is the sum of all spatial weights w_{ij} , x_i and x_j are the TB case notifications rates at LGAs i and j , and $\bar{x}$ is the mean TB case notifications rate across all LGAs.

2.4.1 Hypothesis Testing for Global Moran's I

To evaluate whether tuberculosis (TB) case notifications exhibit significant spatial autocorrelation across the Local Government Areas (LGAs) of Gombe State, the following hypotheses were tested:

Null Hypothesis (H_0):

There is no spatial autocorrelation in TB case notifications among LGAs; the spatial distribution of TB cases is random.

$$H_0: I = 0$$

Alternative Hypothesis (H_1):

There is significant spatial autocorrelation in TB case notifications among LGAs; the spatial distribution is not random.

$$H_1: I \neq 0$$

where I denotes the Global Moran's I statistic.

The significance of Moran's I was assessed using a permutation test based on 999 random permutations. A significance level of $\alpha = 0.05$ was adopted. The null hypothesis was rejected when the associated p-value was less than 0.05, indicating significant spatial clustering or dispersion. Otherwise, the null hypothesis was not rejected, suggesting a random spatial pattern of TB case notifications.

3 Results

Table 1. Annual TB case notifications by LGA, Gombe State (2020–2024)

3.1 Spatial Distribution of TB Case Notifications

The choropleth maps showed a rising trend in the cases of tuberculosis in Gombe state from 2020 to 2024. There was also a steady rise in the case notifications of TB in Yamaltu/Deba and Akko LGAs during this period. There was an increase in TB cases in central LGAs like Gombe by 2023. In 2024, there was clustering of high TB case notifications.

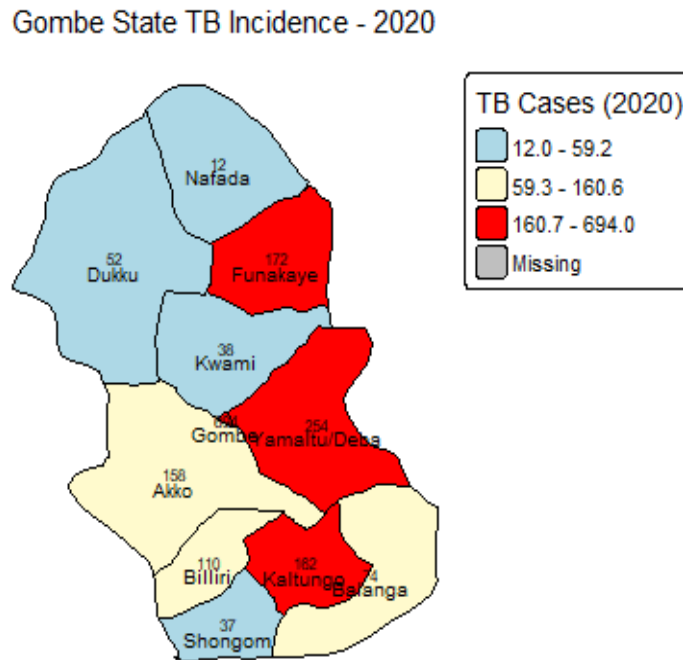


Figure 1: Spatial distribution of tuberculosis (TB) case notifications across Local Government Areas (LGAs) in Gombe State, Nigeria, 2020.

Gombe State TB Incidence - 2021

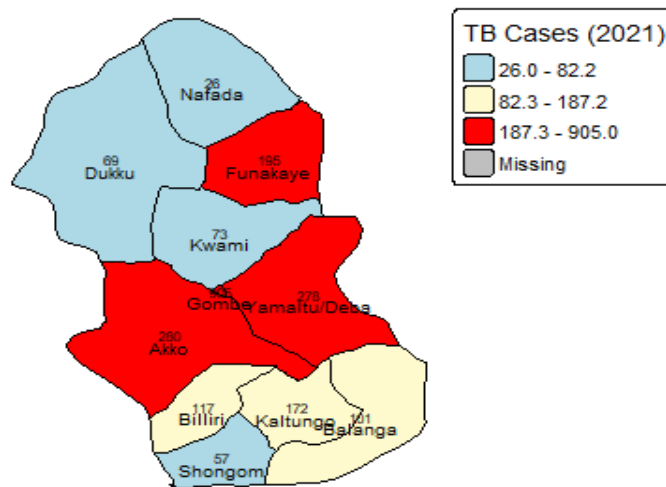


Figure 2: Spatial distribution of tuberculosis (TB) case notifications across Local Government Areas (LGAs) in Gombe State, Nigeria, 2021.

Gombe State TB Incidence - 2022

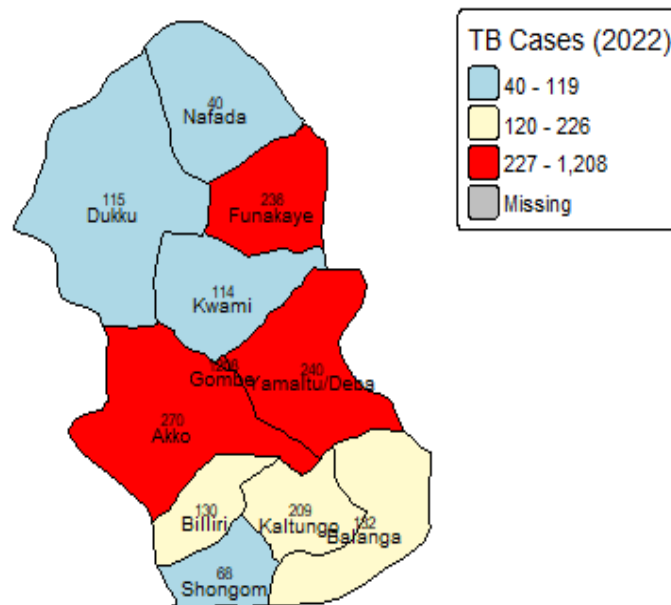


Figure 3; Spatial distribution of tuberculosis (TB) case notifications across Local Government Areas (LGAs) in Gombe State, Nigeria, 2022.

Gombe State TB Incidence - 2023

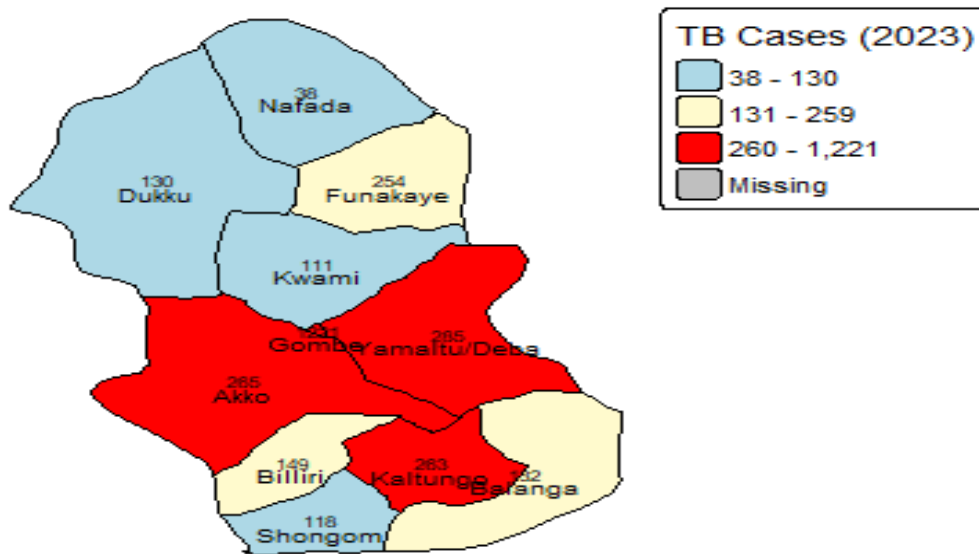


Figure 4; Spatial distribution of tuberculosis (TB) case notifications across Local Government Areas (LGAs) in Gombe State, Nigeria, 2023.

Gombe State TB Incidence - 2024

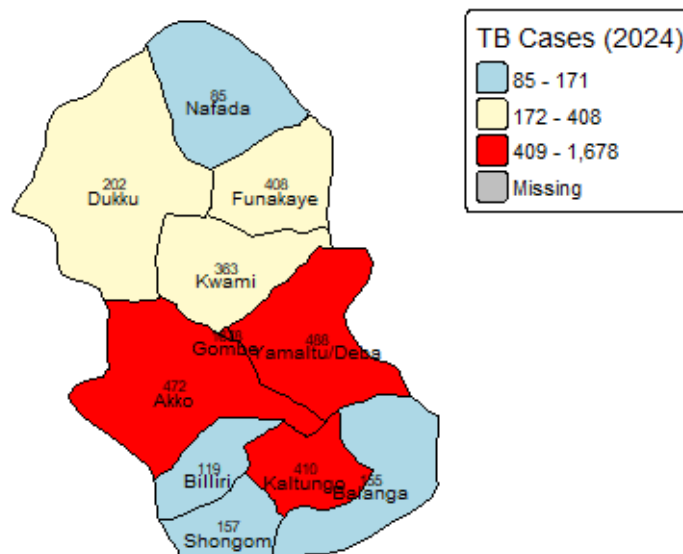


Figure 5: Spatial distribution of tuberculosis (TB) case notifications across Local Government Areas (LGAs) in Gombe State, Nigeria, 2024.

A review of Figures 1–5, covering the years 2020–2024, indicates the following trends:

Increase in Number: The trend indicates an increase in reported TB cases. Approximately 700 cases were recorded in 2020, while the number exceeded 1,500 cases in 2024, indicating a substantial rise in TB case notifications over the study period.

Consistent Hotspots: Yamaltu/Deba and Akko LGAs consistently emerged as high-notification areas throughout the study period. Their persistent high burden of TB highlights the need for targeted public health interventions and enhanced disease control measures in these areas.

Emerging Hotspot Areas: Funakaye emerged as a hotspot LGA beginning in 2022, showing increasing TB notifications and progressing to higher case notifications in subsequent years.

Low-Burden Areas: In contrast to the hotspot LGAs, Nafada and Shongom LGAs remained low-burden areas throughout the study period, as indicated by their relatively low TB case notifications.

3.2 Spatial Autocorrelation

Table 1. Global Moran's I for TB case notifications (2020–2024)

Year	Moran's I	Expected	p-value	Interpretation
2020	0.0235	-0.100	0.130	Random Distribution
2021	0.0652	-0.100	0.052	Random Distribution
2022	0.0048	-0.100	0.071	Random Distribution
2023	-0.0083	-0.100	0.114	Random Distribution
2024	0.0923	-0.100	0.024	Significant Clustering ($p < 0.05$)

From Table 1, the degree of spatial dependence in tuberculosis (TB) case notifications across the Local Government Areas (LGAs) of Gombe State was assessed annually using the Global Moran's I statistic. The results indicate that there was no statistically significant spatial autocorrelation in TB case notifications from 2020 to 2023, as all associated p-values exceeded the 0.05 significance level. Although positive Moran's I values were observed in 2020, 2021, and 2022, the corresponding p-values were not sufficiently small to reject the null hypothesis of spatial randomness. Similarly, the slightly negative Moran's I value recorded in 2023 was not statistically significant. Therefore, the spatial distribution of TB case notifications during the period 2020–2023 can be regarded as random, with no evidence of significant clustering or dispersion among the LGAs.

On the other hand, the 2024 results confirmed the presence of a statistically significant spatial clustering pattern based on Moran's I test (Moran's I = 0.0923, $p = 0.024$), implying that spatial clustering has begun to form for TB case notifications. The findings demonstrate that the LGAs that had TB cases notifications tended to be close to each other, whereas LGAs with few cases tended to be surrounded by other LGAs with a fewer number of TB cases.

Hence, the results of this study demonstrate that there is an evident change in the spatiotemporal trend regarding TB incidence in Gombe State, from a non-significant cluster pattern during the year 2020-2023 to a significant clustering pattern in the year 2024.

4 Conclusion

Results from this study indicate that an increasing trend in TB case notifications in Gombe state between 2020 to 2024, with high burden LGAs being Yamaltu/Deba and Akko. Although the annual spatial auto-correlation between 2020 to 2023 is insignificant, there was a statistically significant global clustering observed in 2024 (Moran's I = 0.0923, p -value = 0.024).

Limitations

The results presented are based only on the number of cases reported and are subject to issues such as underreporting, impacts of the disruption in surveillance due to the outbreak of COVID 19 (2020 to 2021), and improved diagnostics (introduction of GeneXpert). No standardized rate analysis or local clusters (LISA) was done.

Recommendations

Focus efforts towards active case finding (ACF) and resource mobilization in Yamaltu/Deba and Akko LGAs. Increase efforts to improve routine TB data completeness and undertake capture-recapture studies to determine underreporting. Finally, undertaking further analysis with Local Moran's I (LISA) technique to identify wards within these LGAs and incorporate spatial intelligence into the TB surveillance dashboard for real-time clustering detection in Gombe state

References

- Adam, A. I., & Yakudima, I. I. (2019). Spatio-temporal trends of tuberculosis in Madobi Local Government Area, Kano State. *Bayero Journal of Pure and Applied Sciences*, 12(1), 166–175.
- Anselin, L. (1995). Local indicators of spatial association—LISA. *Geographical Analysis*, 27(2), 93–115.
- Ayandeyi Teibo, T. K., Berra, T. Z., Alves, Y. M., Tavares, R. B. V., Olayemi, O. A., & Arcêncio, R. A. (2025). Surveillance of tuberculosis incidence and mortality through spatio-temporal analysis in Oyo State, Nigeria. *PLOS ONE*, 20(7), e0311739. <https://doi.org/10.1371/journal.pone.0311739>
- Balogun, S. O., Oguntade, E. S., & Oladimeji, D. M. (2022). Statistical analysis of spatial distribution of tuberculosis

- in Niger State from 2016–2020. *Journal of Sciences, Islamic Republic of Iran*, 33(2), 149–156.
- Bivand, R. S., Pebesma, E., & Gómez-Rubio, V. (2013). *Applied Spatial Data Analysis with R* (2nd ed.). New York, NY: Springer.
- Ebonyi, A. O., Ebonyi, M. E., Tinuola, F. R., & Gwitira, I. (2026). Spatial pattern of tuberculosis cases in Jos Metropolis, Nigeria during the period 2019–2022. *Geospatial Health*, 21(1).
- Lawson, A. B. (2018). *Bayesian Disease Mapping: Hierarchical Modeling in Spatial Epidemiology* (3rd ed.). Boca Raton, FL: CRC Press.
- Makadi, Y. C., & Ahmed, B. Y. (2021). Spatial distribution of tuberculosis in Gombe State using geographical information systems approach. *Bima Journal of Science and Technology*, 5(2), 92–101.
- National Tuberculosis and Leprosy Control Programme (NTBLCP). (2023). *2023 Annual Tuberculosis Report*. Abuja, Nigeria: Federal Ministry of Health.
- Pebesma, E. (2018). Simple features for R: Standardized support for spatial vector data. *The R Journal*, 10(1), 439–446. <https://doi.org/10.32614/RJ-2018-009>
- World Health Organization. (2024). *Global Tuberculosis Report 2024*. Geneva, Switzerland: World Health Organization.