An application of spatial analysis and GIS in Tuberculosis (TB) cases in Central Luzon, Philippines

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Abstract. According to WHO (2022), tuberculosis (TB) is the primary cause of ill health and the leading cause of death globally. It is estimated that approximately a quarter of the world’s population has been infected. With 372,367 cases of tuberculosis in 2022, the Philippines is among the top eight countries that accounted for more than 66% of all TB cases worldwide. Region III, along with NCR and Region IV-A, is one of the regions in the Philippines with the highest incidence of TB. This paper utilized the geographical information system (GIS) for easier visualization, and Getis-Ord Analysis, a type of spatial analysis tool for quick interpretations to provide an evidence-based framework for TB response. The spatial analysis was conducted to (1) determine if there are clusters of TB cases in the region across various periods and (2) determine if there are hot spots of TB cases in the most recent TB data covering 2019, 2020, and 2021. The results indicate that only the 2019 TB cases exhibit significant non-random clusters. It is recommended that further investigation be conducted to determine if the spatial clustering in 2019 is associated directly or indirectly with the El Niño event that occurred that year. On the other hand, the non-significance of the results for the years 2020 and 2021 may be attributed to the underreporting due to the implemented health protocols implemented to minimize the spread of COVID-19 which affected the accuracy of the reported cases. The results of the paper may be used for optimal resource allocation in addressing the spread of the disease.

1 Introduction

1.1 A Brief Background on TB

The study of [1] states that the primary mode of transmission for Mycobacterium tuberculosis (M. tuberculosis), the bacterium that causes tuberculosis (TB) infection, is through the inhalation of droplet aerosols produced by an individual with active TBs while sharing the same air space. The overwhelming majority of individuals who have contracted the infection originate from economically disadvantaged groups in developing nations [2], [3]. Efforts to prevent the transmission of tuberculosis are essential for achieving the eradication of the disease. The current strategies for controlling tuberculosis primarily involve passive case-finding of individuals with the disease. These approaches are reducing the global incidence rates of tuberculosis by roughly 1% annually [4], [5].

Despite intensified efforts and greater resources, the actual decrease in new cases of tuberculosis is lower than expected [4], [5]. The little enhancement has prompted requests for more epidemiological data to aid in the creation of programmatic interventions that can complement existing tuberculosis control efforts [6–10]. Identifying areas with a high potential for tuberculosis transmission can provide opportunities to disrupt the spread of the disease (6, 10). However, there is a need for additional research to determine the specific locations where transmission of tuberculosis is more probable. This information is crucial for effectively allocating resources and implementing targeted prevention strategies in the future [6,11,12]. It has been widely theorized that the transmission of M. tuberculosis is more frequent within households than in the broader population [13]. Nevertheless, molecular epidemiological investigations conducted from the late 1990s to the early 2000s have not consistently demonstrated this correlation [12,14,15].

1.2 TB Situation in the Philippines

In the Philippine setting, tuberculosis incidence is ranked fourth globally [16]. Approximately one million individuals in the Philippines, according to the Department of Health (DOH), are currently afflicted with tuberculosis, and nearly 70 Filipinos succumb to this treatable ailment daily [17]. [18] demonstrated the impact of health difficulties, such as Human Immunodeficiency Virus (HIV) and illicit drug use, as well as socioeconomic factors like homelessness and low educational attainment, on tuberculosis outcomes in Brazil [18]. The Philippines is a country with a significant urban slum population of approximately 10 million people, social variables play a crucial role in driving the prevalence of tuberculosis. The recent 2019 TB Program Review revealed that vulnerable populations, such as the urban poor, individuals living with HIV, and those deprived of liberty, are more prone to infection and experience poorer treatment outcomes.

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The majority of the projected rise in tuberculosis fatalities worldwide can be attributed to four specific countries: India, Indonesia, Myanmar, and the Philippines according to the Global Tuberculosis Report 2022 [19]. Within the local context, a significant share of the Filipino population with tuberculosis consists of individuals aged 0-24 years, accounting for 27.3%. In addition, young Filipinos between the ages of 10 and 24 frequently spend their time in densely populated environments, such as schools, which significantly increases their likelihood of spreading infections. Individuals in the age range of 10-24 years in the Filipino population have exhibited a higher tendency to cease tuberculosis treatment compared to individuals above the age of 24 [17]. Locally, several efforts have been implemented to eradicate tuberculosis. These include expanding the screening process in high-risk neighborhoods and prisons located in regions with a high prevalence of the disease. Additionally, regular tuberculosis screening is conducted for individuals living with HIV in treatment centers.

1.3 Potential effects of geographical conditions

Geographic conditions may be a key factor in the spread of the disease. A study in Iran determined that the prevalence varied across different geographical circumstances. The extra dry areas had the greatest average TB cumulative incidence rate [20]. Furthermore, [21] highlighted the need for health authorities to pay attention to the ineffectiveness of current policies and actions, particularly in the identified hot spots of TB. These areas are characterized by poor socioeconomic conditions and high population density. [21] provided evidence of the presence of distinct high-risk areas for TB that are associated with low socioeconomic conditions, overpopulation, and extreme weather conditions. Once these areas are identified, they may be effectively targeted for intervention by policymakers. [21] also suggested conducting additional research that employs geographical, temporal, and spatiotemporal analysis to identify areas and populations that are susceptible to TB.

Additionally, stated that transmission of TB typically occurs within a household or community, resulting in heterogeneous spatial patterns. However, apparent spatial clustering of the disease could reflect ongoing transmission or co-location of risk factors and can vary considerably based on the type of data available, the analysis methodologies used, and the population dynamics underlying the apparent clustering.

1.4 Objectives of the study

This article will use geographical information systems (GIS) to enhance visualization and understanding. The aim is to establish an evidence-based to (1) determine if clusters of TB significantly exist in the region during different periods, and (2) to identify any hotspots of TB cases in the most recent data on TB. This is relative to the local and global calls to address the spread of TB.

2 Methodology

2.1 Study Setting

The selected study setting is Central Luzon Region, popularly known as Region III in the Philippines. The coordinates of Region III are 6° 34' 19.247" N 58° 27' 46.8" W. The region comprises seven provinces, namely Aurora, Bataan, Bulacan, Nueva Ecija, Pampanga, Tarlac, and Zambales, together with two Highly Urbanized Cities populous cities, specifically Angeles City and Olongapo City. Figure 1 shows the map of Central Luzon by province.

Fig. 1. Map of Region III (Central Luzon) and its location in the Philippines

The Department of Health Central Luzon Center for Health Development (DOH CLCHD) is requesting assistance from various sectors to reduce and eventually eradicate the number of TB cases among Filipinos. This study somehow addresses this concern in this region. The population of the area, as determined by the 2020 Census, was 12,422,172. This constituted 19.97% of the populace residing in the Luzon Island cluster and 11.39% of the overall population of the Philippines. Based on these figures, the population density is computed to be 567 individuals per square kilometer. The total land area of Region III is 2,147,036 hectares. The DOH Office of Region III was contacted to obtain the TB case data per municipalities and cities for the years 2019, 2020, and 2021. Data has been collected for all temporal periods by each municipality and city. Additionally, the shapefiles needed to create the GIS were obtained from the website of the United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA n.d.), and the mapping and spatial data analyses were conducted using ArcGIS Pro 3.0.1. Figure 2 shows the map of Region III by municipalities and cities.
2.2 Hot Spot and Cold Spot Analysis

This research will also contain a hot spot optimization analysis. To qualify as a statistically significant hot spot, a feature must possess a substantially high value and be contiguous with other features that also have high values. In this context, hence, a hot spot of TB cases in Region III is a municipality or a city with a high number of cases that is neighboring some municipalities or cities that have high numbers of cases as well. A cold spot, on the other hand, is the opposite. Note that being categorized as a hot spot or cold spot is relative to the data used for the analysis and would intuitively always vary.

The Getis-Ord $G'_i$ Analysis [22] will be to determine a hot spot (or cold spot). The $G'_i$ statistic, according to [23], is a method that analyzes how strongly or lowly concentrated a characteristic is in each location, hence designating the area as a hot spot or a cold spot. The $G'_i$ statistic based on Getis and Ord's study in 1995, following the works of [24], which is already a standardized value, is given by

$$G'_i = \frac{\sum_{b \neq i} h_{i,b} \chi_i - \overline{p} \sum_{b \neq i} h_{i,b}}{S_p \sqrt{\sum_{b \neq i} h_{i,b}^2}}$$

(1)

The TB cases denoted by $\chi_i$ in or municipality or city $b$ with its associated spatial weight provided by $h_{i,b}$ between $a$ and $b$, from $G$ total number of municipalities and cities. The $\overline{p}$ component denotes the mean number of TB cases in $G$, $\overline{p} = \sum_{i=1}^{G} \chi_i / G$ while $S_p$ denotes the standard deviation given by: $S_p = \sqrt{\sum_{i=1}^{G} \chi_i^2 / G - \overline{p}^2}$.

In addition, comparison of the spots clustering from year to year, i.e., 2019 to 2020, and 2020 to 2021 were also presented visually.

3 Results and Discussion

Figure 3, Figure 4, and Figure 5 show the map of Region III with the actual number of TB cases for the years 2019, 2020, and 2021. For the year 2019, Figure 3 shows that San Jose in Tarlac, and Carranglan in Nueva Ecija are the cities with the lowest cases that range between 1-38 only. However, Bocaue and Sta. Maria in Bulacan, Angles City, Pampanga, City of Tarlac, and Cabanatuan City in Nueva Ecija were found to have the highest number of TB cases ranging from 1,737 to 3,013 (shaded in dark brown).

Figure 4 illustrates that for 2020, Lapaz, Tarlac, Sto. Domingo, Nueva Ecija, Angeles City, Pampanga, and Bocaue, Bulacan are the municipalities with the highest number of TB cases. The cases range from 1,306 to 2,170. On the other hand, the municipalities with the lowest TB cases range between 20-51 only, are the following: San Jose in Tarlac, San Felipe in Zambales, General Tinio, Dipaculao, Dinalugan, and Dilasag from the province of Nueva Ecija.

For the year 2021, Figure 5 shows the number of TB cases. The municipalities with high cases are Lapaz and Sto. Domingo in Tarlac, and Angeles City in Pampanga. The number of cases ranges between 2,219 and 3,825. On the other hand, the municipalities with the lowest number of TB cases ranging from 26 to 83 are San Jose in Tarlac, Cabangan in Zambales, Calumpit in Bulacan, Victoria, Lupao, Licab, Guinina and Llnera in Nueva Ecija, Dinalunga, Dilasag and Casiguran in Aurora.
It can be noticed that the number of cases increase every year, as depicted in all the maps in Figure 3, Figure 4, and Figure 5. The ranges per category increase for each year, leaving 2021 with the highest number of TB cases. This result supports the claim of WHO in their report about Global Tuberculosis in 2021. According to their report, more individuals died from tuberculosis in 2020, with considerably fewer people being identified, treated, or given TB preventative treatment than in 2019, and overall spending on key TB treatments declining. As an aside, the WHO 2021 global TB report stated that the COVID-19 pandemic has reversed years of worldwide success in combating TB, and TB mortalities have increased for the first time in over a decade.

Figure 6 visualizes the Getis-Ord Analysis that determines if a municipality or city is a hot spot or cold spot for 2019. It was shown that Sta. Maria, Bulacan was an identified hot spot with a 99% confidence level. The City of Tarlac was determined as a hot spot as well with 95% confidence level.

In Figure 7, the analysis shows that Santa Ignacia in Tarlac is a hot spot with a 99% confidence level, as well as Bocaue, Bulacan. While Minalin, Pampanga, and Llanera in Nueva Ecija are hot spots with a 95% confidence level.

In Figure 8, 4 municipalities were identified as hot spots with a 99% confidence level. Bocaue in Bulacan, Angeles City in Pampanga, and Santa Ignacia and Santo Domingo in Nueva Ecija.

Comparing the changes in spots for each year, Figure 9 depicts the result. It was shown that the City of Tarlac changed from a significant hot spot in 2019 to a still hot spot but not significant in 2020. In the figure, the City of Tarlac was shaded red but with grid lines. The same changes happened in the municipality of Sta. Maria in

Fig. 5. Map of Region III with number of TB cases, 2021

Fig. 6. Getis-Ord Analysis for TB Spots in 2019

Fig. 7. Getis-Ord Analysis for TB Spots in 2020

Fig. 8. Getis-Ord Analysis for TB Spots in 2021

Fig. 9. Comparison on changes of spots from 2019-2020
Bulacan. The rest of the municipalities (Bocaue, Minalin, Sta. Ignacia, and Sto. Domingo) went from cold spots in 2019 to hot spots in 2020.

The comparison between 2020 and 2021 is shown in Figure 10. Angeles City changed from a cold to a hot spot from 2020 to 2021. On the other hand, some municipalities did not change their status from hot spot in 2020 to still hot spot in 2021. These municipalities are Sta. Ignacia, Sto. Domingo and Bocaue in Bulacan Province.

![Fig. 10. Comparison of changes of spots from 2020-2021](image)

To analyze whether the TB cases have significant clustering, a summary is shown in Figure 11. The report implies that only the year 2019 (left) has a significant clustering of TB cases. The years 2020 (right) and 2021 (bottom) have random occurrences as shown in Table 1. This means that the TB cases in 2019 have a highly significant clustering while the years 2020 and 2021 have random non-significant clustering.

**Table 1. Summary of Getis-Ord Analysis**

<table>
<thead>
<tr>
<th>Year</th>
<th>Getis Ord</th>
<th>z-score</th>
<th>p-value</th>
<th>Clustering</th>
</tr>
</thead>
<tbody>
<tr>
<td>2019</td>
<td>0.0094</td>
<td>2.86</td>
<td>0.004</td>
<td>Non-random</td>
</tr>
<tr>
<td>2020</td>
<td>0.0079</td>
<td>0.42</td>
<td>0.67</td>
<td>Random</td>
</tr>
<tr>
<td>2021</td>
<td>0.008</td>
<td>0.49</td>
<td>0.62</td>
<td>Random</td>
</tr>
</tbody>
</table>

![Fig. 11. Getis-Ord Analysis Report for 2019, 2020, and 2021 from left to right](image)

A potential association between the surge in the total number of cases in 2019 and the occurrence of El Niño in the same year. According to the study by [25], there is a significant association between El Niño and the TB cases in Peru. The inversely proportional relationship between the TB and the Oceanic Niño Index may be owing to its aerial transmission, which renders it more susceptible to climate effects. However, in the Philippines, there is no direct relationship between the two but there may be some indirect effects. El Niño may raise the risk of TB by worsening some Filipinos' living conditions and health state. This may partly explain the significant clustering of TB cases in 2019.

On the other hand, the non-significant results in the years 2020 and 2021 can be attributed to the pandemic years. According to [26], due to the difficulty in providing and obtaining basic TB services, many persons with TB were undiagnosed and untreated. The reported number of new cases of tuberculosis declined from 7.1 million in 2019 to 5.8 million in 2020. Although there was a modest recovery to 6.4 million in 2021, this was still far lower than pre-pandemic levels. According to the 2022 Global TB Report of the WHO, an estimated 10.6 million individuals became infected by TB in 2021, a 4.5% rise from 2020, and 1.6 million people died from TB, including 187,000 among HIV-positive people. Between 2020 and 2021, the burden of drug-resistant tuberculosis grew by 3%, with 450,000 additional cases of rifampicin-resistant TB in 2021. This is the first time in many years that a rise in the number of people falling ill with tuberculosis and drug-resistant TB has been reported. The COVID-19 pandemic in 2021 disrupted numerous services, including TB response, but its impact on TB response has been particularly severe. In addition, the spread of the disease may have been mitigated due to the wearing of facemasks and lockdowns. The reasons for regional and country variation in TB notification trends between 2019 and 2020 include differences in when they were first affected by the COVID-19 pandemic, the severity of the impact, the extent to which restrictions were implemented and followed, and the capacity and resilience of health systems. Figure 12 shows the significant drop in reported TB case notifications in 2020 per month, relative to the mean level of 2019 (indicated by the blue dashed line) in the Philippines as seen in a WHO Report (2021).
4 Conclusion

This study provided GIS and spatial analyses for the TB cases in Region III for the years 2019, 2020, and 2021. Getis-Ord analysis was done to determine if clustering of TB cases exists in the region for all periods. It was shown that only the year 2019 has a significantly high clustering. The years 2020 and 2021 were found to have random occurrences only but may have been impacted by the COVID-19 pandemic, particularly due to potential underreporting. Additionally, the changes in the spots were also presented virtually. The significant hot spots may be further studied due to the climatic anomalies brought by an episode of the El Niño phenomenon that occurred from the last quarter of 2018 up to the third quarter of 2019. The reporting of the cases and the treatment were heavily affected by the restrictions and shifting of the focus of the Philippine health care system during that time. Thus, even if the cases shot up, the treatment declined, and the clustering occurred randomly.

5 Recommendation

Based on the result, the local government units (LGUs) should focus on the mitigation program in the municipalities identified as hot spots. Moreover, coverage of screening and initiation of TB treatment should be widened since the identified hot spots were from different provinces of Region III. In addition, the LGUs should require more TB screening at the household level and among people living with HIV. TB case mapping is a useful tool for the geographical characterization of tuberculosis, the findings of which enable a better knowledge of TB distribution and the places most at risk of infection. This could potentially aid in the optimal resource allocation of LGUs and international organizations.

References

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