Georeferencing of tuberculosis and its relationship to social determinants in a Colombian city (2012-2019)

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Abstract

Introduction: tuberculosis is a significant public health challenge and is the second cause of infectious mortality worldwide. It mainly affects low-income countries. In Colombia, high social inequality (34.7% poverty – 14.28% with unsatisfied basic needs, 3.8% in extreme poverty and 4.17% with overcrowding) potentiates these risks. The objective was to analyze the interaction between social determinants and tuberculosis.

Methods: this was a descriptive ecological study using geospatial analysis. It analyzed the geographical distribution of tuberculosis cases in Villavicencio, along with their relationship to sociodemographic determinants, using georeferencing tools, cluster analysis and spatial statistics.

Results: there were geographical clusters of tuberculosis cases associated with more densely populated areas, overcrowding, multidimensional poverty, informal settlements and migration. Areas adjacent to the Guatiquía and Ocoa Rivers concentrated the clusters with the highest incidence, correlated with social vulnerability settings.

Discussion: social determinants continue to play a central role in tuberculosis transmission. Factors like overcrowding, multidimensional poverty, forced migration, domestic violence, gaps in basic hygiene and limited access to healthcare services are associated with a higher burden of disease. These findings highlight the need for public health interventions targeting vulnerable populations and prospective studies to provide a more in-depth individualized analysis. **(Acta Med Colomb 2025; 50. DOI: https://doi.org/10.36104/amc.2025.4701).**

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Introduction

Controlling tuberculosis continues to be a major public health challenge. According to the World Health Organization (WHO) it is the second most common cause of infectious disease mortality worldwide, mainly affecting low-income countries (1).

In 2019, 1.4 million annual deaths were reported, with a prevalence of 10 million cases. In the Americas, 87% of these cases were concentrated in 10 countries; Colombia had the sixth highest incidence, with a rate of 27.3 cases per 100,000 inhabitants. Within the country, the city of Villavicencio had the sixth highest number of reported cases (2).

Various strategies have been implemented to mitigate the impact of tuberculosis, focusing on controlling the disease's risk factors. Previous studies have found that social determinants like poverty, overcrowding, migration, violence, population density, and unemployment contribute to the onset, dissemination, and difficulties in controlling tuberculosis (3,4).

These risk factors are especially relevant in Colombia, as it is one of the most unequal countries in Latin America, with a poverty index of 34.7%, 14.28% of the population having unmet basic needs, 3.8% living in extreme poverty and 4.17% living with overcrowding (5). Given the impact of these causal determinants, we must use approaches that help analyze tuberculosis in relation to the social, economic and demographic context.

Georeferencing is a valuable tool for identifying spatial distribution, patterns of occurrence, and risk factors within the epidemiological surveillance system, helping design effective intersectoral interventions to mitigate the disease.

The purpose of this study was to analyze the spatial distribution of tuberculosis in a Colombian city from 2012-2019, and its relationship with certain determinants of health.

Method

This was a descriptive ecological study comparing the geographical distribution of tuberculosis with the population's sociodemographic determinants. A database was created from the medical records of patients diagnosed with tuberculosis (identified using the ICD-10 code) at a tertiary care hospital in the city of Villavicencio between 2012 and 2019. Based on the demographic information, the location and temporal distribution of the cases were mapped using georeferencing methods. These findings were then compared to social and statistical data, as well as heat maps provided by the National Administrative Department of Statistics (DANE, in Spanish).

Data analysis and tabulation were done using Epidat 4.2. Georeferencing was employed to both qualitatively and quantitatively analyze the sociodemographic variables. The "Magna-SIRGAS Origen Villavicencio 2011" coordinate system was used (the city's official reference system) (ESRI, 2020). The cartographic information for the maps (city limits, communes and neighborhoods) was obtained from the official ArcGIS Online platform. Out of 361 cases identified, 289 (80%) were successfully georeferenced, while the rest were unable to be mapped due to inconsistencies in the addresses or incomplete data.

ArcGIS platform tools were used to evaluate the spatial distribution of tuberculosis cases in the study population, including clustering and the Nearest Neighbor Index. Subsequently, atypical value analysis was applied using the Anselin Local Moran's I algorithm, which identifies statistically significant high incidence clusters (hot spots), low incidence clusters (cold spots) and spatial outliers.

Although the study design is a descriptive ecological approach, the incorporation of spatial statistical techniques allows significance tests to be run to determine whether the observed case distribution differs from complete spatial randomness. In this context, the null hypothesis was the absence of spatial clustering (random distribution) and the alternative hypothesis was the presence of significant clusters, which could suggest the existence of underlying factors associated with disease transmission or risk. The results were able to determine whether the null hypothesis should be accepted or rejected.

Results

The study population, consisting of 361 individuals diagnosed with tuberculosis, was analyzed. Georeferencing was accomplished in 80% of the cases within the study period (2012-2019) (Figure 1). Of the total population, 36.01% (n=130) were females, with a median age of 39 years (range: 15-89 years), while 63.99% (n=231) were males, with a median age of 47 years (range: 10-94 years). Comorbidities were found in 36.6% of the cases, with 2.3 times greater prevalence in males than females (Table 1).

Among the females, 5.38% had HIV, 1.54% had chronic pulmonary disease, and 13.08% had diabetes mellitus. There were no reported cases of kidney disease, immunosuppression or cardiovascular disease in this group. Among the males, 8.23% had HIV, 2.16% had cardiovascular disease, 21.64% had chronic pulmonary disease, 0.86% had kidney disease, 11.69% had diabetes and 1.39% were immunosuppressed due to medications.

Table 1. *Comorbidities of patients with tuberculosis, by sex.*

Disease	Females (%) Total: 130	Males (%) Total: 231
HIV	7 (5.38)	19 (8.23%)
Diabetes	17 (13.08%)	27 (11.69%)
Pulmonary disease	2 (1.54)	50 (21.64%)
Kidney disease	0 (0%)	2 (0.86)
Heart disease	0 (0%)	5 (2.16%)
Immunosuppression	0 (0%)	3 (1.35%)
Subtotal	26 (19.95%)	106 (45.93%)
Total population	361 (36.6%)	

HIV: human immunodeficiency virus

Between 2012 and 2019, the population density of communes C3, C4, C5, and C6 decreased, and the average density of the neighboring communes increased. This displacement led to a reduction in high-density tuberculosis clusters and increased non-significant case distribution in other areas like C1, C2, and C7 (Figure 2).

Popular, Brisas de Guatiquía, Villa Suárez, Centro and Caney communes reported the highest number of tuberculosis cases. Comparing this data with the DANE's georeferenced information (6) showed that these areas had the highest concentration of tuberculosis cases per block. These zones also had a high prevalence of comorbidities like hypertension, diabetes, ischemic heart disease, chronic pulmonary disease and cancer.

Spatial analysis also incorporated social characteristics like population density, overcrowding, the high risk of intergenerational cohabitation, and age over 60, all associated with the distribution of tuberculosis cases in the city.

According to the DANE (7), the Multidimensional Poverty Index shows that the areas with the highest levels of poverty, affecting 60 to 80% of the general population, are mainly located in communes close to the Guatiquía River, such as Popular, Brisas de Guatiquía and Villa Suárez. Superimposing this data on the tuberculosis distribution map showed that these localities had the highest prevalence of the disease. This association suggests a relationship between tuberculosis and populations with unsatisfied basic needs, characterized by overcrowding, inadequate housing, limited access to health care, reduced household financial capacity and limited access to education.

Discussion

Tuberculosis control continues to be a global and national public health challenge, included within the sustainable

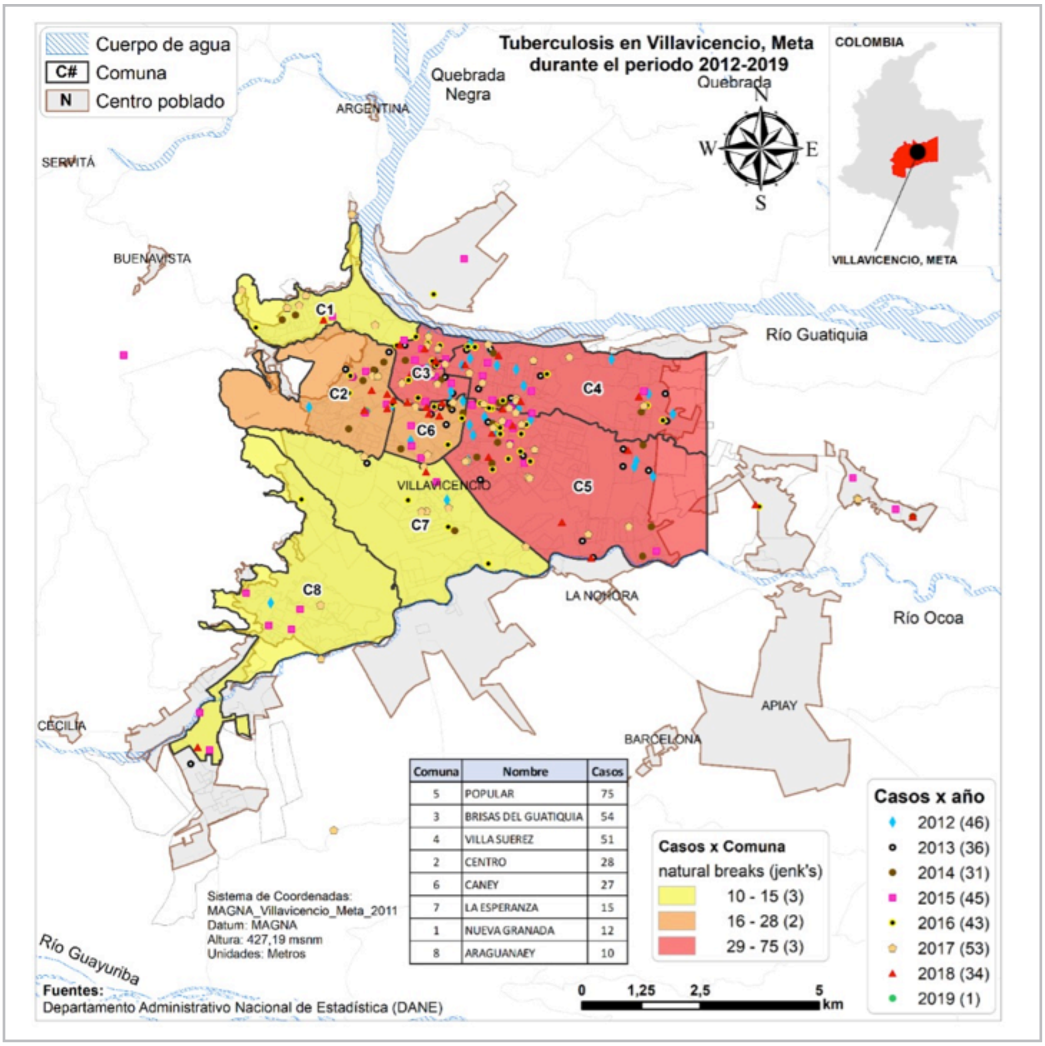

Figure 1. *Location of tuberculosis cases in a Colombian city, 2012-2019*.

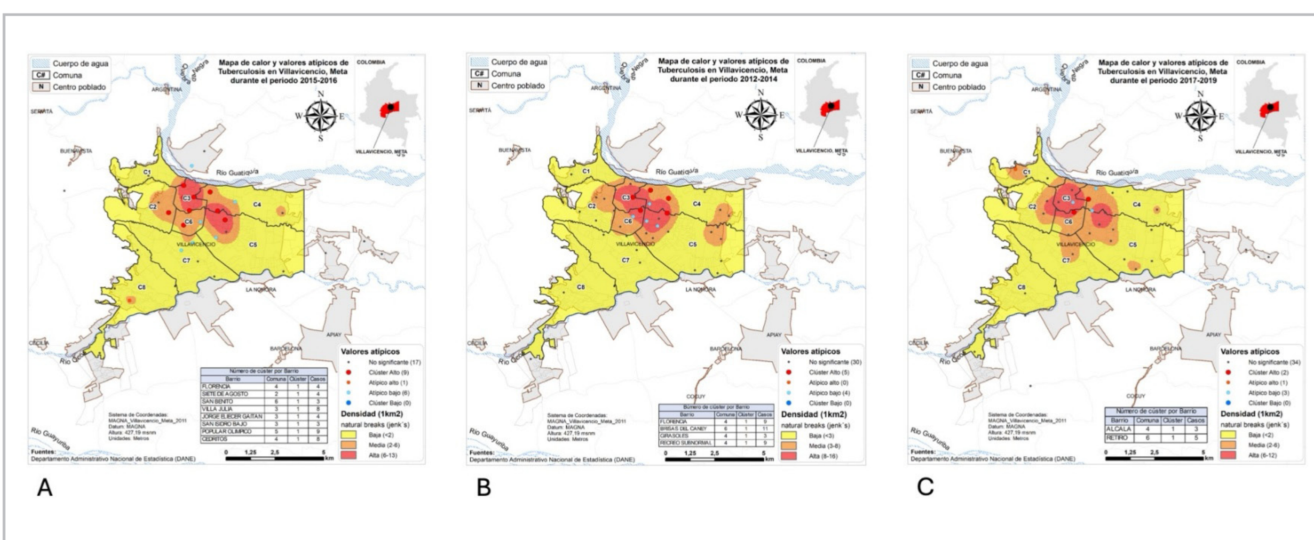

Figure 2. *Analysis of clusters (hot spots) of tuberculosis cases in a Colombian city, 2012-2019*.

development goals (SDGs) established in 2015 to reduce its incidence by 90% and mortality by 95% by 2035 (8). However, the annual reduction in mortality between 2000 and 2017 was only 2.5%, far from the projected annual goal of 12% (9, 10). Although multiple strategies focusing on social determinants —like poverty, overcrowding, migration and violence— have been implemented to mitigate the burden of the disease, there have been few advances (11, 12).

Overcrowding, defined as a condition in which three or more people share the same room (13), has been strongly associated with an increased prevalence of tuberculosis, reaching an incidence up to 20 times greater than that of the general population, with a 90% annual risk of transmission (14). In Villavicencio in 2018, 15.4% of the households (23,245) were comprised of five or more people, 19.6% (29,515) were comprised of four people, and 22.6% (33,995) were comprised of three people. At the department level, Villavicencio is the city with the highest number of households with mitigable (14,581) and unmitigable (1,112) overcrowding (15). Furthermore, 65% of those who are overcrowded live in shared housing, and Meta has the highest population density of the region, with 350.9 inhabitants per km^2 (16).

This study found a correlation between the incidence of tuberculosis, high population density along the Guatiquía River, and overcrowding. The Popular, Brisas de Guatiquía and Villa Suárez communes reported the highest number of cases, mainly in single-parent homes or multi-family dwellings, conditions that aggravate overcrowding and contribute to domestic violence. It is relevant to note that these populations include individuals affected by forced displacement, homelessness, and demobilization processes related to the armed conflict (17). These figures continue to be relevant as known risk factors for tuberculosis transmission, with an annual risk of infection of up to 90% under these conditions (14-16).

Exposure to untreated wastewater has also been associated with a higher risk of tuberculosis infection compared to the general population (18). Although significant clusters were not identified in this study, an established spatial distribution was found, especially along the Ocoa River, in Communes 5 and 8, where 8% of the population does not have access to a sewer system. Kalpana Chandra et al. (2018) have suggested that chronic respiratory tract exposure to toxic and irritant substances could predispose to tuberculosis and aggravate the severity of the disease (19).

As far as poverty, the communes close to the Guatiquía River, which had a higher prevalence of tuberculosis, also recorded the highest levels of multidimensional poverty, according to the DANE's geospatial analysis. Gutiérrez García et al. (2019) reported that these areas are characterized by informal settlements, slums, and poverty levels affecting up to 91.5% of the population (17). Our findings showed a correlation between the areas with the highest incidence of tuberculosis and the areas with the highest poverty according to the DANE (17).

Despite this, it is important to update this discussion in light of recent multidimensional poverty data reported for 2024. The DANE report shows a sustained reduction in national multidimensional poverty, reaching 11.5%, nationally, with a 20.3% prevalence in the Amazonía-Orinoquía region, where the department of Meta is located (20). In this region, multidimensional poverty dropped 3.8 percentage points compared to 2023 but continues to be the highest in the country outside of areas like Vichada and La Guajira. Although there is a national decreasing trend, high levels of deprivation persist among poor households, with an average of 42.7% deprivation in Amazonía-Orinoquía (20) and sustained impact on the risk of communicable diseases like tuberculosis.

Compared to our original study period (2012-2019), in which we reported a strong relationship between poverty and tuberculosis clusters, the current data confirms that Meta continues to concentrate approximately 2.5% of tuberculosis cases in the country (21). Although economic growth and poverty reduction policies show progress, broad vulnerable sectors persist in the communes affected by the disease, especially among migrants and displaced people who settle in peripheral areas with high population density and limited basic sanitation (17, 18, 22).

Migration continues to be a central component of the analysis. Villavicencio is still a point of convergence for internal migration and international migrants, especially Venezuelans, in areas close to the Guatiquía, Ocoa and Negro Rivers (17, 22). These populations have cumulative risk factors - overcrowding, poverty, casual labor, healthcare access barriers and a higher risk of multi-resistant tuberculosis transmission - that correlate with the clusters found in the geospatial analysis (17). Dhavan et al. (2017) indicate that factors like the high risk of transmission, delayed care seeking, treatment interruptions and inadequate treatment regimens contribute to an increased resistance to antitubercular drugs in migrant populations (23).

Domestic violence, previously noted as an indirect factor affecting adherence to antitubercular treatment (24, 25), continues to be relevant as a contextual determinant in communes like Commune 8, which has historically reported the highest rates of domestic violence (26). The spatial-temporal overlap found between the periods with the most violence and the increase in tuberculosis cases between 2015 and 2016 continues to be consistent with social fragmentation phenomena that foster disease progression and transmission (27, 28).

Comparing our historical findings with the most recent national epidemiological data (21), it is important to highlight the overall growth in the incidence of tuberculosis in Colombia. Between 2019 and 2024, incident cases went from 14,902-20,832, reflecting an increase in the incidence rate from 28.2-36.7 cases per 100,000 inhabitants (21). Although this increase could be interpreted as an actual increase in the burden of disease, part of this growth can be attributed to strengthening of the country's diagnostic capacity with the introduction of molecular tests with high sensitivity and specificity, as well as the use of artificial intelligence in digital x-ray reading, as stipulated in Resolution 227 of 2020 (21).

However, it is important to recognize the limitations of our study. First, the ecological nature of the analysis does not allow individual causal relationships to be established, leading to a risk of ecological fallacy in interpreting spatial correlations based on population clusters without having individualized sociodemographic information.

Second, approximately 20% of the cases recorded during the study period were excluded due to incomplete georeferenced information, which may have introduced selection bias affecting the accuracy and representativity of the spatial patterns identified.

Third, although the geospatial patterns found maintain their contextual relevance, the temporal validity of the findings could be partially restricted, considering that the analysis was done with data from 2012-2019, while the Villavicencio population has continued to experience significant changes between 2020 and 2025, related to migration, urban sprawl, informal settlement transformations and changes in socioeconomic conditions.

Finally, the recent increase in the national incidence of tuberculosis reported by the National Institute of Health in 2024 is influenced by both a potentially real increase in transmission as well as strengthening of the country's diagnostic capacity with the incorporation of molecular tests and artificial intelligence in x-ray screening. This diagnostic growth may have allowed the identification of previously underdiagnosed cases during the study period, making it difficult to directly compare the incidence trends over time.

Overall, our findings continue to highlight the central role of social determinants: poverty, overcrowding, migration, poor sanitation and violence in the tuberculosis transmission dynamics in Villavicencio. However, the demographic, methodological and technological changes seen in recent years underscore the need for prospective studies updated with the integration of individual data and dynamic georeferenced follow up to refine the design of targeted public health policies for the effective control of the disease in vulnerable populations.

Conclusion

Our findings confirm that, beyond the classic biological factors like immunosuppression and lung disease, social and structural determinants play a fundamental role in tuberculosis transmission in urban settings like Villavicencio. Factors like overcrowding, multidimensional poverty, forced migration, domestic violence and poor living and basic sanitation conditions are spatially related to high incidence clusters of the disease found along the Guatiquía and Ocoa Rivers.

Although the spatial patterns found during the study period (2012-2019) continue to be relevant, the most recent national epidemiological data show an increase in the number of tuberculosis cases reported in Colombia and the department of Meta. This increase is partially influenced by a strengthened diagnostic capacity, the introduction of more sensitive molecular tests, and the use of artificial intelligence in x-ray screening, which has allowed previously underdiagnosed cases to be detected. At the same time, although multidimensional poverty has dropped progressively at the national and regional level, according to 2025 data from the DANE, the Amazonía-Orinoquía region (where Villavicencio is located) continues to experience high levels of deprivation, perpetuating structural vulnerability conditions.

Despite these associations, the inherent limitations of the ecological design, lack of individualized sociodemographic information, and partial loss of georeferenced data restrict the ability to establish direct causal relationships. Therefore, it is essential to conduct prospective epidemiological studies that include individual and longitudinal analyses, as well as real-time spatial surveillance systems to better understand the complex interaction between the social, environmental and clinical determinants of tuberculosis.

Comprehensive management of these social determinants, along with ongoing strengthening of diagnostic and surveillance capacity, are essential for progressing toward the goals of controlling and eliminating tuberculosis, especially in vulnerable urban settings like Villavicencio.

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