An analysis of spatial and socio-economic determinants of tuberculosis in Hermosillo, Mexico, 2000–2006

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SETTING: The city of Hermosillo, in Northwest Mexico, has a higher incidence of tuberculosis (TB) than the national average. However, the intra-urban TB distribution, which could limit the effectiveness of preventive strategies and control, is unknown.

METHODS: Using geographic information systems (GIS) and spatial analysis, we characterized the geographical distribution of TB by basic geostatistical area (BGA), and compared it with a social deprivation index. Univariate and bivariate techniques were used to detect risk areas.

RESULTS: Globally, TB in the city of Hermosillo is not spatially auto-correlated, but local clusters with high incidence and mortality rates were identified in the northwest, central-east and southwest sections of the city. BGAs with high social deprivation had an excess risk of TB.

DISCUSSION: GIS and spatial analysis are useful tools to detect high TB risk areas in the city of Hermosillo. Such areas may be vulnerable due to low socio-economic status. The study of small geographical areas in urban settings similar to Hermosillo could indicate the best course of action to be taken for TB prevention and control.

KEY WORDS: tuberculosis; social deprivation; geographic information systems; Mexico

WHILE TUBERCULOSIS (TB) prevalence has stabilized in the world, and is even declining in some regions, the volume of cases continues to grow, as indicated by the 9.2 million new cases reported in 2006.1 In the last 5 years, TB morbidity has decreased by 17% in Mexico, while mortality has decreased by 30%. Nonetheless, 18,000 new cases occur in the country annually (incidence 14.1 per 100,000 population) and the disease kills more than 2000 people every year. Most of the cases are concentrated in just 23 of the country’s 2425 municipalities, one of which is Hermosillo, in Mexico’s Sonora state.2

Despite numerous efforts to control the disease, TB is still a public health problem in the state of Sonora. During the last 5 years, TB incidence (25.2/100,000) in Sonora was higher than the national average, while the mortality rate for the same period (3.4/100,000) exceeded the national rate (2.6/100,000) and placed the state in seventeenth position among the 32 Mexican states.3 In general, the intra-urban distribution of TB is not known at the national level, as most studies have focused on the analysis of large geographical units (e.g., towns, municipalities or states).4–6

This can limit the effectiveness of prevention and control activities at the urban level.

Although the distribution of TB can be explained by some well-known individual-level factors,7 there is growing evidence that contextual factors (e.g., physical quality of the environment, social segregation, patterns of contact and population density) are good predictors of existing patterns.8,9 For this reason, the utilization of innovative methods, such as molecular epidemiology studies,1,10 to identify factors associated with the transmission of TB11 is highly recommended. Due to their high technological sophistication, these methods are not always available in developing countries. A first step to such studies is the description of the spatial patterns of TB using geographic information systems (GIS) and spatial analysis techniques applied to small geographical areas such as census tracts, postal zones or urban blocks.12

The present study aimed to describe the distribution of TB at the census-tract level (basic geostatistical area [BGA]) in the city of Hermosillo, Sonora, and identify whether the distribution is associated with low socio-economic status.

METHODS

Using an ecological approach, this study examined the relationship between the incidence of TB morbidity and mortality and socio-demographic factors in the
capital city, Hermosillo, from 2000–2006. Hermosillo is the largest, most populated city in the state of Sonora, and also has the highest TB burden. In 2006, the city had an estimated population of 631 697 and was considered to have a very low level of social deprivation.13

The socio-economic profile of each BGA, small geographical subdivisions containing 25–50 city blocks and averaging 2500 inhabitants, was delineated using a social deprivation index (SDI) built with data from the XII Population and Housing Census.14 The index has been used in other local studies and includes information on income level, school education, housing quality, overcrowding and car availability.15,16 The index was calculated using the principal components technique and categorized BGAs into five strata of deprivation: 1) very low, 2) low, 3) medium, 4) high and 5) very high. Strata were obtained using the Dalenius and Hodge method,17 which provides strata boundaries that minimize the coefficient of variation given a fixed sample size and a fixed number of strata. The SDI was mapped for the city’s 254 BGAs that were established in 2000.

All study procedures were reviewed by the Institutional Review Board of the University of Sonora.

Data sources
TB cases were obtained from two sources: 1) death certificates with the basic cause given as any form of TB (codes A15–A19 of the 10th revision of the International Classification of Diseases); and 2) a structured form named ‘Epidemiological study of cases of TB’ (codes A15–A19 of the 10th revision of the International Classification of Diseases); and 2) a structured form named ‘Epidemiological study of cases of TB’, used nationally to compile demographic, clinical and epidemiological data.18 The cases were geo-referenced to each BGA, without identifying any of the subjects’ addresses. The denominators used to estimate incidence were obtained from the National Population Council.19

Analysis
TB morbidity and mortality rates were estimated for each BGA. The rates were then incorporated into geodemographic maps. The spatial clustering of TB was examined using the Moran I index, which measures similarities between neighboring areas. The Besag and Newell method, useful for areas with a small population size, was used to identify local clusters.20 A local conglomerate was determined when 12 cases were identified on a 1 km buffer, based on the median cases of all BGAs ± 1 standard deviation.

The relationship between the SPI and TB mortality rates was assessed using a bivariate local index of spatial association (LISA). We also examined the relationship between the SDI and TB incidence rates using a Poisson regression model. Arc View® version 9.0 (Environmental Systems Research Institute, Redlands, CA, USA) and TerraSeer version 1.6.008 (TerraSeer, Ann Arbor, MI, USA) were used to conduct the spatial analysis. The regression models were evaluated using STATA® 10 (Stata Corp, College Station, TX, USA). All P values were run for two-tailed Ho test. P ≤ 0.05 was considered statistically significant.

RESULTS
During the study period, 1167 TB patients had a fixed address in Hermosillo, although only 1011 (86.6%) of these were new cases. Of the 1011 patients, only 903 were geo-located (89.3%), as the remaining patients did not provide accurate address information. The 903 new TB cases accounted for a cumulative incidence of 18.2/100 000. The annual mortality rate was 1.6/100 000 (n = 68). TB incidence trends during 2000–2006 showed slight increase ($R^2 = 0.29$), while mortality remained stable ($R^2 = 0.016$).

A large proportion of TB cases (66.0%) were males, 38.3% of whom lived in BGAs classified as areas of ‘high’ and ‘very high’ deprivation. This proportion was similar ($P = 0.4843$) to that observed in women (37.2%). Similar percentages of male and female case were identified in BGAs of medium and low levels of deprivation.

Three of every four patients were aged 20–64 years, and only a quarter of the cases had health insurance, a condition that remained stable throughout the study period (Table 1).

Social deprivation
The SPI was calculated for 228 of the city’s 254 BGAs. The remaining BGAs were either not residential or

Table 1 Selected characteristics of incident cases of tuberculosis, Hermosillo, Mexico, 2002–2006*

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>%</th>
<th>P value†</th>
</tr>
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<tbody>
<tr>
<td>Overall incidence</td>
<td>903</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>596</td>
<td>66.0</td>
<td>&lt;0.0000</td>
</tr>
<tr>
<td>Female</td>
<td>307</td>
<td>34.0</td>
<td></td>
</tr>
<tr>
<td>Age group, years</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>&lt;1</td>
<td>4</td>
<td>0.4</td>
<td>&lt;0.0000</td>
</tr>
<tr>
<td>1–4</td>
<td>10</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>5–9</td>
<td>7</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>10–19</td>
<td>73</td>
<td>8.1</td>
<td></td>
</tr>
<tr>
<td>20–29</td>
<td>187</td>
<td>20.7</td>
<td></td>
</tr>
<tr>
<td>30–39</td>
<td>164</td>
<td>18.2</td>
<td></td>
</tr>
<tr>
<td>40–49</td>
<td>161</td>
<td>17.8</td>
<td></td>
</tr>
<tr>
<td>50–64</td>
<td>170</td>
<td>18.8</td>
<td></td>
</tr>
<tr>
<td>≥65</td>
<td>127</td>
<td>14.1</td>
<td></td>
</tr>
<tr>
<td>Health care service</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without health care service</td>
<td>673</td>
<td>74.5</td>
<td>&lt;0.0000</td>
</tr>
<tr>
<td>With health care service</td>
<td>230</td>
<td>25.5</td>
<td></td>
</tr>
<tr>
<td>Health care level notifier‡</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Health center</td>
<td>448</td>
<td>49.6</td>
<td>NS</td>
</tr>
<tr>
<td>Hospital</td>
<td>455</td>
<td>50.4</td>
<td></td>
</tr>
</tbody>
</table>

*Includes only the city of Hermosillo and not the entire municipality.
†Based on a χ² statistic for equal proportions.
‡Urban health centers or rural areas. Hospitals at any level (basic, general or specialty).
NS = not significant.
were not incorporated for reasons of confidentiality (<20 homes or <50 inhabitants). BGAs classified as low-level deprivation were the most frequent (38.2%), although 58 BGAs (22.9%) were classified as high and very high social deprivation. The SDI was shown to be spatially correlated (Moran’s $I = 0.6181$, $P < 0.001$), and tended to form spatial clusters of high and very high deprivation in the northwest, centre-east and southwest of the city.

**TB and social deprivation**

The highest morbidity rate (26.3/100 000) was identified in the highly deprived stratum followed by the medium deprivation stratum (18.0/100 000). The highest mortality rate (2.5/100 000) occurred in the highly deprived BGAs (Table 2). Highly deprived BGAs almost quadrupled (odds ratio = 3.9) their TB excess risk compared to very low deprivation BGAs, while high deprivation BGAs had twice the excess risk. A similar pattern was observed among middle and low deprivation BGAs when compared with BGAs classified as very low deprivation (Table 3).

**Spatial analysis**

In general, there was no spatial autocorrelation of TB morbidity rates (Moran’s $I$ value = 0.0591, $P = 0.001$). Given the low index value, the authors found no significant clusters when using LISA univariate analysis. However, we detected 24 significant local conglomerates in the northwest, central-east and southwest of the city using the Besag and Newell method (Figure 1). After assessing the correlation of the SDI and TB morbidity rates, the authors found a significant Moran’s $I$ index ($P = 0.001$), but very close to zero (0.0756), which explains the spread observed in Figure 1. Most of the conglomerates were found in BGAs classified as having high and very high levels of deprivation, although some low deprivation BGAs located in the city centre presented significant groupings.

We obtained a low Moran’s $I$ value (0.0281, $P = 0.001$) for mortality distribution, which is also why no global spatial autocorrelation was observed.

### Table 2: Distribution of tuberculosis morbidity and mortality by residential census, Hermosillo, Mexico, 2000–2006

<table>
<thead>
<tr>
<th>Level of social deprivation*</th>
<th>Cases n (%)</th>
<th>Morbidity rate†</th>
<th>Incidence ratio‡</th>
<th>Deaths n (%)</th>
<th>Mortality rate†</th>
<th>Mortality ratio‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hermosillo (global)§</td>
<td>903 (100)</td>
<td>18.2</td>
<td>—</td>
<td>68 (100)</td>
<td>1.6</td>
<td>—</td>
</tr>
<tr>
<td>Very high</td>
<td>68 (7.5)</td>
<td>14.2</td>
<td>2.12</td>
<td>3 (4.4)</td>
<td>0.6</td>
<td>1.02</td>
</tr>
<tr>
<td>High</td>
<td>265 (29.3)</td>
<td>26.3</td>
<td>3.93</td>
<td>25 (36.8)</td>
<td>2.5</td>
<td>4.22</td>
</tr>
<tr>
<td>Intermediate</td>
<td>180 (19.9)</td>
<td>18.0</td>
<td>2.69</td>
<td>18 (26.5)</td>
<td>1.8</td>
<td>3.03</td>
</tr>
<tr>
<td>Low</td>
<td>340 (37.6)</td>
<td>14.8</td>
<td>2.21</td>
<td>21 (30.9)</td>
<td>1.0</td>
<td>1.60</td>
</tr>
<tr>
<td>Very low</td>
<td>50 (5.5)</td>
<td>6.7</td>
<td>Reference</td>
<td>1 (1.5)</td>
<td>0.6</td>
<td>Reference</td>
</tr>
</tbody>
</table>

*Based on socio-economic status, estimated using data from the XIIth National Census of Population and Housing, 2000.
†Per 100 000 population.
‡Rate ratio (morbidity and mortality).
§Refers only to the city of Hermosillo, not rural localities of the municipality.

### Table 3: Excess TB risk by level of social deprivation, Hermosillo, Mexico, 2000–2006*

<table>
<thead>
<tr>
<th>Level of social deprivation</th>
<th>Rate ratio</th>
<th>Standard error</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>2.2</td>
<td>0.338</td>
<td>1.66–3.00</td>
</tr>
<tr>
<td>Intermediate</td>
<td>2.7</td>
<td>0.429</td>
<td>1.96–3.67</td>
</tr>
<tr>
<td>High</td>
<td>3.9</td>
<td>0.602</td>
<td>2.88–5.28</td>
</tr>
<tr>
<td>Very high</td>
<td>2.1</td>
<td>0.392</td>
<td>1.45–3.03</td>
</tr>
<tr>
<td>Very low</td>
<td>Reference</td>
<td>—</td>
<td>—</td>
</tr>
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</table>

*Based on a Poisson regression model, which incorporated 228 census tracts. The reference level was the lowest stratum of social deprivation. The significance of the model was tested by $\chi^2$ (likelihood ratio) = 110.64, $P < 0.0001$. Includes only the city of Hermosillo and not the entire municipality. CI = confidence interval.

**Figure 1** Local clusters of deprivation index and TB rates, by residential census tract, Hermosillo, Mexico, 2000–2006. BGA = basic geostatistical area; TB = tuberculosis.
However, bivariate LISA analysis (SDI-mortality rate) identified 13 significant conglomerates (Figure 2) in the northwest, central-east and southwest of the city. The Moran index obtained by bivariate analysis was very small (0.0191), which explains the observed dispersion.

**DISCUSSION**

In general, this research identified a slight rise in TB morbidity during the study period. It is not clear which factors are associated with this pattern, but it is possible to infer that a combination of factors related to the effectiveness of TB control, socio-economic factors and cultural behavior in certain areas of the city favor the transmission of TB. Accordingly, studies that use GIS and spatial analysis as methods, such as this one, have demonstrated their usefulness in identifying high-risk areas in small units (e.g., neighborhoods, urban blocks, census blocks).12,21,22 These findings indicate that although TB in Hermosillo does not follow a spatial autocorrelation pattern, there are clusters of cases and deaths in BGAs in the northwest, center-east and southwest sections of the city, which is useful in understanding intra-urban disparities in TB distribution.

The authors would therefore recommend caution when using BGAs in Mexico for spatial analysis as, although they have been useful in various public health programs, the rapid growth experienced by cities in Mexico has generated heterogeneity in their size. This heterogeneity is difficult to control for during statistical procedures, and can cause misleading results in spatial studies. A method that can help to overcome this problem is the Besag and Newell technique, which uses points (e.g., centroids) that intersect all geographical planes of the interest variable, contributing to the detection of conglomerates that are not easily identifiable by other methods.20 This method is simple but has the limitation that the threshold is arbitrary. This study was limited by the fact that the threshold was defined using the case median and the standard deviation; however, given that the event did not follow normal distribution, other more sophisticated methods (e.g., statistical ‘scanning’ of space-time)21,23 may be required in future regional research.

A significant finding of our study is that half \( (n = 12) \) of the TB conglomerates are located in geographical areas of high and very high social deprivation, meaning that the distribution of TB in Hermosillo is related to the underlying socio-economic context, consistent with other research in the field.8,9,22 This indicates that TB is distributed unevenly according to the immediate social environment, regardless of the country’s general level of social development.24,25 Another interesting fact is that BGAs with a very high deprivation level had an incidence rate (14.2/100 000) similar to those BGAs with very low deprivation. This could be the result of under-reporting of cases and limited access to health care, a common situation in populations of high social vulnerability,10 and not necessarily due to a low incidence of TB in areas with the highest levels of poverty. Specific studies to identify cases in these BGAs are needed in Hermosillo.

It can also be observed that BGAs with low and medium deprivation have an incidence which is twice the magnitude when compared with the stratum of very low deprivation. This could be a demographic effect, as slightly more than 50% of Hermosillo’s entire population are concentrated in middle and upper-middle class neighborhoods. This pattern is not unique to Hermosillo; a study in Brazil also found that the highest TB rates were concentrated in urban middle-class neighborhoods.26

It is possible that the spatial pattern of TB in Hermosillo reflects unequal urban development, with homes that have lower socio-economic status than the BGA average, a fact that has already been reported in other studies.27 It is also likely that by using smaller units such as urban blocks, subtle differences that were not easily detected at the census-block level could have been identified, as pointed out by Krieger et al.12 It is possible that indicators that are closer to individuals and their contexts give a better picture of the spatial distribution of the disease. Spatial analysis of TB could...
therefore be complemented by a parallel study of individual biological and context-related factors, as is done in multi-level analyses. The spatial analysis of TB in Hermosillo could be strengthened by further research mapping of the *M. tuberculosis* DNA. DNA mapping is useful for identifying spatial conglomerates of different sizes, something difficult to achieve with simple geo-referencing, particularly when the conglomerates are small (2–4 cases).

**CONCLUSIONS**

TB in Hermosillo is distributed heterogeneously among different socio-economic strata, with an increasing incidence in BGAs of high social deprivation, followed by medium and low deprivation areas. This study demonstrates that spatial analysis is a useful approach for the identification of geographical clusters of TB, and can help decision makers and field staff direct prevention and control interventions for case detection, outbreak identification and patient follow-up to the city’s high-risk areas. The study of spatial conglomerates not only meets the epidemiological imperative of detecting TB aggregates and identifying risk factors but it is also of high operational value, as it is inexpensive and can be replicated with ease in any of the geographic and administrative units of regional and national health systems. Once deployed, it can be systematized for the study of other health events.

**References**


TB and social deprivation in Hermosillo, Mexico


RÉSUMÉ

CADRE : La ville de Hermosillo au Nord-Est de Mexique connaît une incidence de la tuberculose (TB) supérieure à la moyenne nationale, mais on ne connaît pas avec précision la distribution intra-urbaine de cet événement, ce qui peut limiter l’efficacité des stratégies de prévention et de lutte.

MÉTHODES : On a caractérisé la distribution géographique de la TB au moyen de systèmes d’information géographique (SIG) et de l’analyse spatiale à la fois par aires de distribution dans la ville (BGA) liées à un indice de marginalité sociale. On a utilisé des techniques unifactorielles et bifactorielles pour détecter les zones de risque.

RÉSULTATS : Dans l’ensemble, la TB dans la ville d’Hermosillo n’a pas une auto-corrélation spatiale, mais on a pu identifier des conglomérats locaux d’incidence et de mortalité dans le nord-est, le centre-est et le sud-est de la ville. Les BGA particulièrement marginalisées sur le plan social connaissent un excès de risque de TB.

DISCUSSION : Les SIG et l’analyse spatiale sont des outils utiles pour détecter les zones de risque élevé de TB dans la ville de Hermosillo. De nombreuses zones peuvent être vulnérables par suite du faible statut socio-économique. L’étude de petites zones géographiques dans des conditions similaires à celles d’Hermosillo pourraient orienter les actions de prévention et de lutte des programmes de TB.

RESUMEN

INTRODUCCIÓN: La ciudad de Hermosillo, en el Noroeste de México, tiene una incidencia por tuberculosis (TB) superior al promedio nacional, pero no se conoce con precisión la distribución intraurbana del evento, un factor que puede limitar la eficacia de estrategias de prevención y de control.

MÉTODOS: Mediante sistemas de información geográfica (SIG) y análisis espacial se caracterizó la distribución geográfica de la TB por área geoestadística básica (BGA), vinculándola a un índice de marginalización social. Se emplearon técnicas unifactoriales y bifactoriales para detectar áreas de riesgo.

RESULTADOS: Globalmente, la TB en la ciudad de Hermosillo no está espacialmente autocorrelacionada, pero conglomerados locales de incidencia y mortalidad fueron identificados en el noroeste, centro-este y suroeste de la ciudad. Los BGA con alta marginalización social tuvieron un exceso de riesgo de TB.

DISCUSIÓN: Los SIG y el análisis espacial son herramientas útiles para detectar áreas de alto riesgo de TB en la ciudad de Hermosillo. Tales áreas pueden ser vulnerables debido a un bajo estatus socioeconómico del contexto. El estudio de pequeñas áreas geográficas en escenarios similares a Hermosillo puede orientar acciones de prevención y control de los programas de TB.
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