

Land Use Patterns Reveal Urban TB Hotspots: A Spatial-Temporal Study in Penang, Malaysia

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In rapidly urbanizing Penang, Malaysia, tuberculosis (TB) remains a critical public health threat. We spatially mapped 4,015 cases (2015–2017) to link disease hotspots with land use. GIS-based spatial statistics (Moran's I and Getis-Ord G_i^*) revealed significant clustering in densely populated districts. Hotspots in George Town aligned with residential, commercial, and transit corridors, underscoring how population density and mobility shape urban TB transmission. Integrating this spatial perspective into surveillance and planning enables targeted interventions. Our findings demonstrate the value of geography-informed strategies for controlling TB in rapidly evolving cities.

Keywords: Geographic Information System (GIS); Hotspot Analysis; Land Use; Moran's I Analysis; Trend Analysis; Tuberculosis; Tuberculosis Hotspot Mapping

Introduction

Tuberculosis (TB) remains a pressing global health issue, despite concerted efforts to curb its spread. The World Health Organization (WHO) declared TB a global health emergency in 1993, underscoring the urgent need for action (World Health Organization (WHO) 2007). While a decline in the number of tuberculosis cases has been observed since 2006, and the incidence rate has decreased since 2001, the overall burden of the disease remains substantial, posing a

persistent challenge to public health systems worldwide. Tuberculosis continues to rank among the top three infectious diseases globally, alongside HIV and malaria (World Health Organization (WHO) 2007). In 2019 alone, an estimated 10 million new TB cases were reported globally, reaffirming its status as a major public health threat (World Health Organization (WHO) 2020). In TB is not only highly contagious but also frequently fatal, particularly in resource-limited settings where healthcare infrastructure may be insufficient to manage the disease burden effectively (Lima et al. 2019).

In Malaysia, the situation mirrors global trends, with TB cases rising consistently over the years. In 2016, the number of reported TB cases reached 25 747, with 1 945 deaths, a notable increase from the 24 220 cases and 1 696 deaths reported in 2015 (Kementerian Kesihatan Malaysia (KKM) 2016). This upward trend highlights the persistent public health challenge that TB poses within the country. Malaysia's evaluation of its KKM Strategic Plan (2011-2015) revealed the country's inability to meet its TB reduction targets, with TB notification rates climbing from 68.4 cases per 100 000 population in 2010 to 79.6 cases per 100 000 in 2015. Additionally, the TB cure rate, a key performance indicator (KPI), remained below the target of 85%, with cure rates of 78% in 2014 and 79.6% in 2015 (Kementerian Kesihatan Malaysia (KKM) 2016). The increasing incidence and suboptimal cure rates underscore the need for more effective public health interventions and a deeper understanding of the spatial and temporal dynamics of TB transmission. This study focuses on the spatial and temporal analysis of tuberculosis hotspots in Penang, Malaysia, from 2015 to 2017, with an emphasis on land use patterns, in order to provide critical insights for targeted TB control efforts.

Literature Review

Spatial studies and spatiotemporal analyses have evolved significantly over the past four decades, with early developments laying the foundation for the contemporary application of disease mapping in epidemiological research (Howe 1989). The work of Elliott et al. (1996) has been instrumental in defining spatial and temporal patterns of disease incidence and mortality, a field now referred to as geographic epidemiology. This approach not only emphasizes spatial relationships but also incorporates demographic variables such as age, race, and gender, facilitating a more comprehensive understanding of disease distribution. Geographic epidemiology thus highlights the intersection of spatial and temporal factors in analyzing disease occurrences. A critical aspect of spatial analysis in epidemiology is the identification of disease patterns whether clustered, random, or dispersed commonly referred to as spatial patterns. Tobler's First Law of Geography (1970), which asserts that "everything is related to everything else, but near things are more related than distant things," is foundational in understanding spatial interactions (Tobler 1970). This principle suggests that proximity plays a crucial role in disease transmission, with areas adjacent to a disease hotspot being more likely to experience spread. This concept is particularly relevant to infectious diseases like tuberculosis (TB), where spatial proximity can influence the likelihood of transmission to neighboring areas.

Previous studies in Malaysia have demonstrated the utility of GIS in TB research. For instance, Abdul Rasam et al. (2018) and Abdul Rasam et al. (2017) mapped TB risk areas in Shah Alam using knowledge driven models and explored the influence of socio-environmental factors in Peninsular Malaysia. Similarly, Mohidem et al. (2021) and Mohidem et al. (2023) identified and validated spatial clustering of