

ENVIRONMENTAL DETERMINANTS OF SOIL-TRANSMITTED HELMINTH INFECTIONS IN PALEMBANG SCHOOLCHILDREN: A SPATIAL ANALYSIS

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ABSTRACT

Environmental Determinants Of Soil-Transmitted Helminth Infections In Palembang Schoolchildren: A Spatial Analysis.

Soil-transmitted helminth (STH) infection remains a public health concern in tropical urban settings. Understanding its spatial distribution and relationship with environmental determinants is important for targeted control. This cross-sectional spatial study included 294 primary school children (grades III and IV) from 18 districts of Palembang, Indonesia. Schools and participants were selected using two-stage cluster sampling. Stool specimens were examined using the direct smear method with eosin staining. District-level population density, latrine coverage, and piped water access were obtained from official statistics. Spatial autocorrelation was assessed using Global Moran's I, Local Indicators of Spatial Association (LISA), and bivariate LISA. The overall STH prevalence was 16.7% (49/294 children). Most districts had low prevalence (<20%), while Ilir Barat Dua (41.2%), Ilir Barat Satu (35.3%), and Kertapati (29.4%) showed moderate prevalence (20-50%). Global Moran's I indicated significant positive spatial autocorrelation for latrine coverage ($I = 0.190$; $p = 0.043$), but not for population density ($I = -0.135$; $p = 0.078$) or piped water access ($I = -0.049$; $p = 0.449$). LISA mapping identified localized clusters of higher STH prevalence in areas with inadequate latrine coverage. STH endemicity in Palembang is low to moderate, but localized clusters remain. Sanitation, particularly latrine availability, was the main environmental factor associated with spatial clustering, whereas population density and piped water access showed no significant spatial association. Targeted sanitation improvement, hygiene education, and spatially guided surveillance are recommended.

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INTRODUCTION

Soil-transmitted helminth (STH) infections—caused by *Ascaris lumbricoides*, *Trichuris trichiura*, and hookworms—remain among the most common neglected tropical diseases in warm and humid settings where sanitation is inadequate ^(1,2). Despite global declines due to preventive chemotherapy and improved WASH (water, sanitation, and hygiene) programs, STH infections still affect an estimated 1.5 billion people worldwide, predominantly school-aged children ⁽³⁾. In Indonesia, national mass deworming programs have been in place since

2017, but local prevalence remains high and heterogeneous, ranging from 2.5% to over 60% across regions, with some rural districts on Samosir Island reporting rates of 46.8%–66.7% (4,5).

Spatial analysis has emerged as a valuable tool for understanding heterogeneity in infectious disease transmission. Global Moran's I evaluates whether disease or exposure values are spatially autocorrelated, while Local Indicators of Spatial Association (LISA) identify local clusters and spatial outliers (6,7). Previous studies have linked STH infection to sanitation, water access, household hygiene, and settlement characteristics, but the strength of these associations may vary by local context (8).

Palembang, a major urban center in South Sumatra, consists of 18 districts with diverse settlement patterns and infrastructure coverage. Official statistics indicate high average latrine and piped water coverage, but earlier local surveys reported moderate STH prevalence among schoolchildren in selected areas (9). The novelty of this study lies in integrating epidemiological data with Global Moran's I and LISA-based spatial analysis to identify STH clusters and their environmental correlates in an urban Indonesian context. This study aimed to analyze the spatial distribution of STH infection among elementary school children in Palembang and to examine its association with population density, latrine coverage, and piped water access to support targeted intervention planning.

MATERIALS AND RESEARCH METHODS

This observational study used a cross-sectional design with a spatial analytical component. It was conducted from June to November 2025 in Palembang, the capital of South Sumatra Province, Indonesia. Palembang comprises 18 districts (kecamatan) and has a population of more than 1.6 million. The city has a tropical climate with high rainfall and humidity, conditions that can support the survival of STH eggs and larvae in contaminated soil.

The target population was pupils aged 8 to 10 years attending state primary schools. The sample size was determined using a single-population proportion approach, assuming an expected STH prevalence of approximately 20%, a 95% confidence level, and 5% absolute precision. After allowing for cluster sampling and possible non-response, the required sample was adjusted to approximately 294 participants. A two-stage cluster sampling method was then applied. In the first stage, schools were selected from the 18 districts in proportion to district size. In the second stage, pupils in grades III and IV at selected schools were invited to participate. Inclusion criteria were attendance on the survey day and written guardian consent. Children who had received anthelmintic medication during the preceding three months were excluded.

Demographic data were collected using questionnaires, while environmental data were obtained from official statistics. Each participant provided a fresh stool specimen, which was examined within four hours in the laboratory. The direct smear method with eosin staining was used to detect STH eggs or larvae (10). Duplicate smears were examined by trained microscopists, and discrepant findings were reviewed by a senior parasitologist. Although direct smear is practical and commonly used in field-based public health surveys in Indonesia, its lower sensitivity for light-intensity infections may lead to underestimation of the true prevalence (11).

District-level environmental variables for 2024 were obtained from the Palembang Statistics Bureau and included population density (persons per km²), latrine coverage (percentage of households with improved latrines), and piped water access (percentage of households receiving tap water) (12). These variables were selected because they represent core environmental health determinants related to STH transmission: crowding and settlement pressure, sanitation availability, and household water access. Other relevant factors, including latrine quality, latrine utilization, water quality, footwear use, handwashing

practices, soil type, rainfall, and socioeconomic status, were not available at the same spatial scale and were therefore considered as limitations.

Spatial weight matrices were constructed using queen contiguity among districts. Global Moran's I was used to assess spatial autocorrelation of STH prevalence and environmental variables, with significance tested using Monte Carlo permutation tests ($p < 0.05$). LISA and bivariate LISA were used to identify local clusters and spatial outliers. In LISA interpretation, high-high clusters indicate areas with high values surrounded by areas with similarly high values, low-low clusters indicate low values surrounded by low values, and high-low or low-high categories indicate spatial outliers. For protective variables such as latrine coverage and piped water access, the direction of interpretation was considered in relation to STH prevalence. Spatial mapping and overlay analysis were conducted using ArcGIS and GeoDa to identify distribution patterns and spatial risk levels of STH infection in Palembang City.

RESEARCH RESULTS AND DISCUSSION

Prevalence and spatial distribution of STH

Among the 294 pupils examined, 16.7% (49/294) were found to harbor at least one species of soil-transmitted helminth (STH). *Ascaris lumbricoides* was the most commonly identified species, followed by *Trichuris trichiura*. District-level mapping showed that most areas were in the low-prevalence category (<20%), including Bukit Kecil, where no cases were detected. Three districts, Ilir Barat Dua, Ilir Barat Satu, and Kertapati, showed moderate prevalence rates of 41.2%, 35.3%, and 29.4%, respectively (Figure 1). These districts are located along the Musi River and include densely populated neighborhoods and market areas where sanitation conditions may vary. No district had high prevalence (>50%). Overall, Palembang showed low to moderate endemicity; however, the moderate clusters indicate persistent localized transmission despite ongoing sanitation improvement and deworming programs (Table 1).

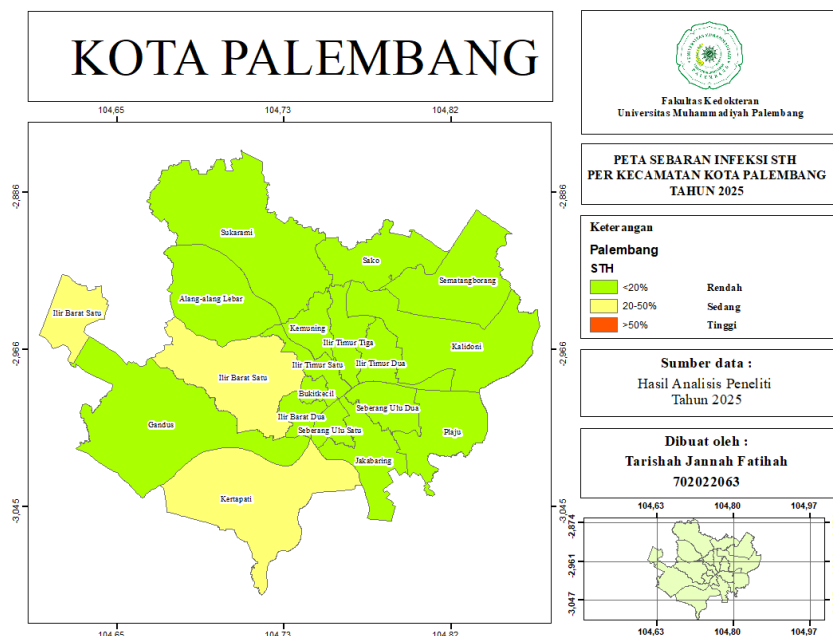


Figure 1. Spatial distribution of soil-transmitted helminth infection by district in Palembang City, 2025. The map shows low-prevalence districts (<20%) and moderate-prevalence districts (20-50%). Ilir Barat Dua, Ilir Barat Satu, and Kertapati showed moderate prevalence, indicating localized areas of higher transmission.

Table 1. Bivariate Local Indicators of Spatial Association (LISA) analysis of environmental factors associated with STH infection in Palembang City, 2025.

No.	Variables	Moran's I	E[I]	P-Value	Z-score
1.	Population density	-0,135	-0,0588	0,078	-1,3474
2.	Latrine coverage	0,190	-0,0625	0,043	1,86
3.	Piped water access	-0,049	-0,0588	0,449	0,0955

Table 1 summarizes the spatial autocorrelation results for the selected environmental variables. The following subsections interpret each variable in relation to STH distribution to clarify the epidemiological relevance of the spatial findings.

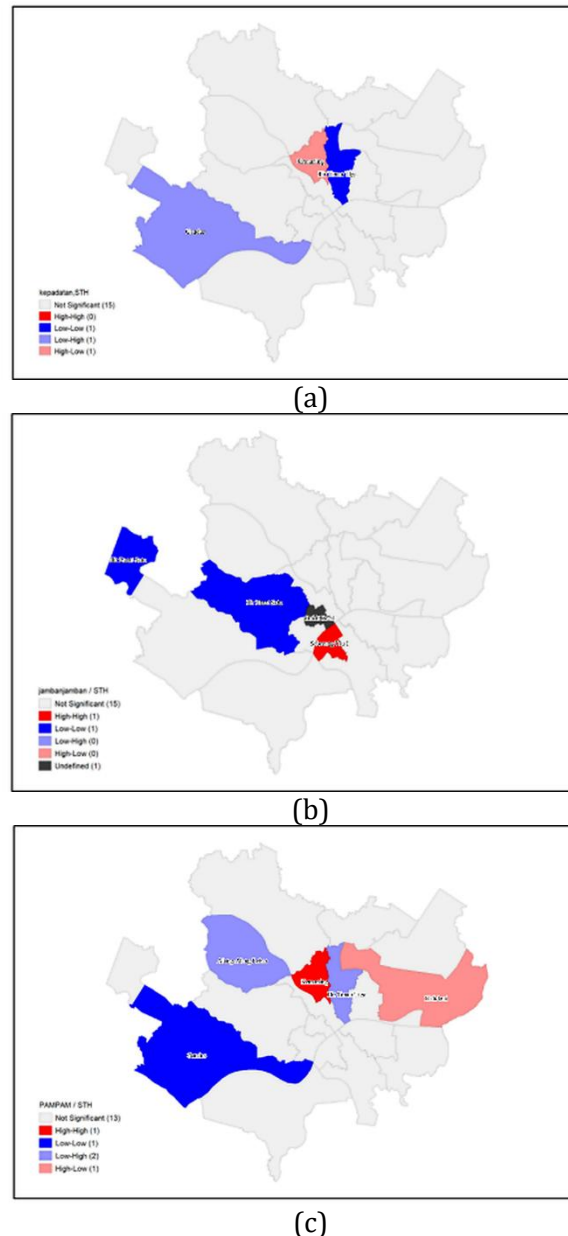


Figure 2. Bivariate LISA cluster map of population density (a), latrine coverage (b), and piped water access (c) in relation to STH infection. The map identifies spatial clusters and outliers, illustrating significant associations between low sanitation coverage and high STH prevalence, while population density and piped water access show no consistent spatial relationship

Relationship with population density

Population density across districts varied from 1,220 to 11,603 persons per km². Global Moran's I for density was -0.135 (expected -0.059; $p = 0.078$), suggesting a dispersed, non-significant spatial pattern in relation to STH prevalence. Local Moran's I identified Ilir Timur Tiga (low density, and low prevalence), Gandus (low density surrounded by high prevalence districts), and Kemuning (high density surrounded by low prevalence districts) as spatial outliers (Figure 2). These findings align with a study in Guatemala, which indicated that population density alone is not sufficient to explain STH risk in Palembang⁽³⁾. In Indonesian urban settings, high-density districts may include both well-serviced residential areas and informal or riverside settlements with different sanitation conditions. Therefore, localized sanitation quality and behavior may be more important than density itself in determining transmission risk^(6,13-15).

Relationship with latrine coverage

Latrine coverage ranged from 66.4% in Kertapati to 100% in several districts. Global Moran's I for latrine coverage was 0.190 (expected -0.062; $p = 0.043$), indicating significant positive spatial autocorrelation. High-high clusters were observed in Seberang Ulu I, where poor latrine coverage coincided with high STH prevalence whereas low-low clusters reflected areas with better sanitation and lower prevalence (Figure 2). Bivariate LISA demonstrated a strong spatial correlation between inadequate latrine coverage and elevated STH prevalence. These findings support global^(16,17) and Indonesian evidence that improved sanitation reduces STH risk⁽¹⁸⁻²⁰⁾. Nevertheless, latrine availability does not necessarily indicate adequate latrine quality, maintenance, or consistent use. Shared, poorly maintained, or intermittently used latrines may continue to permit environmental contamination even in districts with apparently high coverage.

Relationship with piped water access

Piped water access was generally high, exceeding 85% in most districts, except in Plaju, where it ranged from 61% to 85%. Global Moran's I for piped water access was -0.049 (expected -0.059; $p = 0.449$), indicating no significant spatial association with STH prevalence. Bivariate LISA showed no consistent pattern, although sporadic high-high clusters in Kemuning and low-low clusters in Gandus were observed (Figure 2). These results suggest that piped water access alone does not predict STH distribution. Because this study did not directly assess microbiological water quality, household water storage, or treatment practices, the interpretation of piped water access remains indirect and should be made cautiously. Variations in water quality and household practices, including storage, boiling, and handwashing, may still influence infection risk (2).

Hygiene behaviour and socio-economic context

In our study, the moderate prevalence observed in certain districts with high latrine coverage may be attributed to poor personal hygiene or instances of open defecation by transient populations, such as market vendors. Furthermore, socio-economic factors, including household income, parental education, and family size—recognized determinants of STH—were not collected, yet they may contribute to the observed variability in prevalence. Environmental conditions, such as precipitation, soil type, and humidity, significantly influence the distribution of STH. For example, a cross-sectional study conducted in Timor-Leste revealed that high rainfall and sandy-loam soils were associated with an increased risk of moderate- and heavy-intensity *N. americanus* infections. In contrast, alkaline soils were found to reduce the risk of *Ascaris* infections⁽²¹⁾.

Although our survey did not directly measure hygiene practices, existing literature highlights the significance of individual and household behaviors in the transmission of STH^(22,23). For instance, an Ethiopian study revealed that children who did not wash their hands before

meals had 3.8 times higher odds of STH infection compared to those who practiced regular handwashing⁽⁷⁾. Additionally, awareness of STH transmission and the availability of separate toilets for males and females also played a role in influencing infection risk.

While our survey did not evaluate nutritional status or personal hygiene practices, prior research indicates that environmental and WASH factors substantially influence the risk of STH. A school-based study in Kenya, employing classification and regression tree analysis, demonstrated that students with inadequately maintained latrines had double the likelihood of STH infection compared to their counterparts with cleaner latrines. Moreover, increased water availability at educational institutions correlated with reduced infection rates⁽²⁴⁾. In Ethiopia, the risk of infection diminished with enhanced community sanitation coverage, whereas households without adequate latrines experienced increased likelihoods of hookworm and *T. trichiura* infections⁽²⁵⁾. These findings substantiate our conclusion that sanitation is the principal environmental factor influencing the aggregation of STH cases.

Strengths and limitations

This study is one of the first to integrate epidemiological and spatial analyses of STH infection in an urban Indonesian context. The two-stage cluster sampling approach improved district representation, and the use of official environmental data allowed practical linkage with public health planning. However, several limitations must be acknowledged. First, the direct smear method has limited sensitivity for light infections, so the true prevalence may have been underestimated. Second, the cross-sectional design prevents causal inference. Third, behavioral factors, socioeconomic status, nutritional status, latrine quality, latrine use, and direct water quality measurements were not assessed, although they are relevant to STH transmission. Fourth, population density and sanitation indicators were analyzed at the district level, which may mask within-district variability and introduce ecological fallacy if district-level associations are interpreted as individual-level risks. Future studies should include household- or village-level WASH indicators, behavioral surveys, and more sensitive parasitological methods to refine spatial risk mapping.

Policy implications

The findings indicate that sanitation is the most important modifiable environmental factor for STH control in Palembang. Operationally, moderate-risk districts, especially Ilir Barat Dua, Ilir Barat Satu, Kertapati, and areas with lower latrine coverage along the Musi River, should be prioritized for sanitation-based interventions. Recommended actions include improving latrine construction and maintenance, verifying latrine functionality and use, strengthening community-led total sanitation, promoting safe water storage and household treatment, and intensifying school-based hygiene education on handwashing, footwear use, and regular deworming. Spatial risk mapping should be incorporated into routine surveillance to guide resource allocation, monitor hotspot changes, and evaluate intervention coverage. Annual mass drug administration should be maintained in moderate-risk districts, while low-risk areas may focus on surveillance, health education, and rapid response to emerging clusters.

CONCLUSIONS AND RECOMMENDATIONS

Among elementary school children in Palembang, the prevalence of STH infection was 16.7%, indicating low to moderate endemicity. Spatial analysis identified localized clustering of STH infection associated with inadequate latrine coverage, whereas population density and piped water access were not significant spatial determinants. These findings emphasize that sanitation improvement, supported by hygiene promotion and routine deworming, remains essential for interrupting transmission. The integration of Global Moran's I and LISA provides practical value for hotspot identification and targeted intervention planning in urban

settings. Future studies should incorporate behavioral, socioeconomic, and water quality indicators to strengthen the interpretation of spatial risk patterns.

ETHICAL APPROVAL

This study obtained ethical approval from the Bioethics, Humanities and Islamic Medicine Committee (KBHK) of the Faculty of Medicine, Universitas Muhammadiyah Palembang, under reference number 103/EC/KBHKI/FK-UMP/XI/2025.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the research reported in this paper.

AUTHOR CONTRIBUTIONS

TP: conceptualisation and study design; TJF: data collection; PE and NQ: statistical analysis; AG: manuscript writing and literature review. All authors read and approved the final manuscript.

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