Spatial autocorrelation analysis of non-communicable diseases: unveiling hidden patterns and hotspots of hypertension in the Yogyakarta Special Region

Vivi Lusiana[1], *Muhammad* Arif Fahrudin Alfana[1]*

[1]Department of Environmental Geography, Faculty of Geography, Gadjah Mada University, Yogyakarta-Indonesia

Abstract. The increasing impact of Non-Communicable Diseases (NCDs), especially hypertension, on global mortality has prompted increased scrutiny, with NCDs disproportionately contributing to epidemiological transitions and economic challenges, especially in low- and middle-income countries in Southeast Asia. Hypertension requires dominant health interventions because hypertension cases in the Special Region of Yogyakarta, Indonesia dominate other diseases. Therefore, this study addresses the spatial dynamics of hypertension in the Yogyakarta Special Region using spatial autocorrelation techniques. Total population and number of hypertension sufferers is collected from surveillance data and processed through GeoDa. Descriptive quantitative analysis was conducted on hypertension prevalence and spatial distribution of hypertension through quantile maps, Global Moran's I, and Local Moran's I (LISA). Findings show a spatial clustering pattern of hypertension prevalence, both hotspots and spatial outliers which has evolved in the period 2019 to 2022. There was significant spatial clustering of hypertension cases, with high-high and low-low prevalence area patterns providing insight into the geographic distribution of risk factors for hypertension prevalence. This study emphasizes the application of novel spatial analysis in public health surveillance in Indonesia, underscoring the effectiveness of spatial autocorrelation techniques in identifying high-risk areas, and as an important step in developing public health strategies and policies.

1 Introduction

Non-Communicable Diseases (NCDs) are increasingly under the global health spotlight, with the World Health Organization reporting NCDs to be responsible for 71% of deaths worldwide in 2016 [1]. The impact is disproportionately severe in low- and middle-income countries, particularly in Southeast Asia, where a rising trend in NCD cases is observed [2,3]. NCDs significantly contribute to the epidemiological transition in these nations, increase mortality, and impose a substantial economic burden, thus impeding human development [4].

* Corresponding author: arif.fahrudin@ugm.ac.id

Hypertension is a major contributor to NCDs and is characterized by blood pressure levels exceeding normal ranges. This condition increases the risk of other NCDs such as coronary heart disease [5,6,7], stroke [8,9], and acute kidney disease [10,11]. Without early detection and proper management, long-standing hypertension may lead to irreversible organ damage [12].

Despite the high stakes, spatial analysis of hypertension is underexplored in Indonesia. Spatial studies can elucidate hypertension clustering, inform targeted interventions, and enhance understanding of the condition [13]. These studies are also vital for government and stakeholders for optimal health service delivery [14].

The prevalence of hypertension in Indonesia was reported at 25.8% in 2013, increasing to 34.1% by 2018 [15], with 51.3 million adults diagnosed in 2019 [16]. Spatial analysis methods to depict hypertension prevalence have been employed in various regions [13,17-22], showing a clustering of cases that advises targeted interventions.

In the Yogyakarta Special Region, hypertension is the disease with the most cases for the last 6 years [23-29], but few spatial autocorrelation studies have been conducted. Spatial autocorrelation allows to quantitatively measure spatial linkages and detect hypertension hotspots that can contribute to prioritizing more effective health programs. The current research aims to apply spatial autocorrelation techniques to hypertension data from the Yogyakarta Special Region to identify patterns, risk factors, and inform public health interventions. The study's novelty lies in its application of these methods to a new regional context, providing a deeper understanding of hypertension's geographical dynamics and contributing to the body of knowledge on the spatial aspects of public health in Indonesia.

2 Materials and Methods

2.1 Materials

The primary data utilized in this study were sourced from the surveillance records of hypertension cases provided by the Health Departments across all regencies and cities in the Yogyakarta Special Region. The materials for analysis encompassed comprehensive datasets detailing the incidence of hypertension, demographic variables, healthcare accessibility, and geographical coordinates necessary for spatial analysis.

2.2 Sample Preparation

Data preprocessing involved the standardization of records to ensure consistency across the datasets from different municipalities. This included the normalization of demographic data against population numbers to enable accurate prevalence rate calculations. The prevalence of hypertension in this study is a description of people with hypertension in a population at a certain time and region. Subsequently, the data were geocoded and matched with the corresponding administrative regions for spatial analysis.

2.3 Experimental Setup

The software GeoDa was employed for spatial data analysis. The experimental setup involved configuring the software to recognize the geographic boundaries of the administrative regions within Yogyakarta Special Region. The spatial weight matrix was generated to reflect the adjacency and potential spatial relationships between the regions.

2.4 Parameters

The spatial parameters under investigation included the number of hypertension cases and the spatial autocorrelation of these cases within the province. Quantile Maps were used to visualize the distribution of hypertension cases, while the Moran's I and Local Indicators of Spatial Association (LISA) were computed to quantify and identify spatial patterns of clustering and outliers.

The primary parameters measured were the prevalence rates of hypertension. To determine the spatial autocorrelation of these rates, Moran's I was calculated using the formula:

$$I = \frac{N}{\sum_i \sum_j w_{ij}} \frac{\sum_i \sum_j w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_i (x_i - \bar{x})^2} \quad (1)$$

Where N is the number of spatial units indexed by i and j, w_{ij} is an element of the spatial weight matrix, x is the variable of interest (incidence rate), and $\bar{x}$ is the mean of x.

Local Moran's I (LISA) was computed to identify clusters and outliers, using the formula:

$$I_i = \frac{(x_i - \bar{x})}{S^2} \sum_j w_{ij}(x_j - \bar{x}) \quad (2)$$

Where S^2 is the variance of x and all other terms are as previously defined.

Hypertension prevalence is a clustered spatial pattern if the Moran's I is significantly positive and LISA identified the presence of hotspot (high-high) or coldspot (low-low) clusters. Spatial outliers indicate areas with hypertension prevalence that are different from surrounding areas as indicated by high-low or low-high LISA results.

Hypertension prevalence and spatial distribution of hypertension are the variables investigated in this study. Both variables were analyzed with spatial autocorrelation techniques to determine the spatial distribution of hypertension prevalence and provide an overview of spatial autocorrelation patterns, hotspot clusters, and hypertension spatial outliers.

2.5 Statistical Analysis

A quantitative descriptive analysis was performed to interpret the spatial patterns observed. The Moran's I was used to detect global spatial autocorrelation, indicating the overall tendency of hypertension cases to cluster spatially. LISA analysis was conducted to identify local clusters of high-high and low-low values, providing insights into localized patterns. The robustness of the identified clusters was assessed statistically to ensure the validity of the patterns observed.

Quantitative descriptive analysis was applied to the standardized data to examine the distribution and central tendency. For the spatial analysis, the Moran's I statistic was interpreted to assess the degree of spatial autocorrelation, with values ranging from -1 (indicating perfect dispersion) to +1 (perfect correlation), and values close to 0 suggesting random spatial patterns. The LISA statistics were further utilized to discern local spatial autocorrelation, identifying clusters of similar values (high-high or low-low) and spatial outliers (high-low or low-high). These calculations allowed for the identification of statistically significant spatial clusters and outliers of hypertension prevalence. The results from the LISA analysis were visualized using maps to illustrate the geographic locations of these clusters and outliers. Statistical significance was determined using permutation tests with a set significance level.

3 Result and Discussion

3.1 Spatial Distribution of Hypertension in Special Region of Yogyakarta

The spatial distribution of hypertension sufferers within the Yogyakarta Special Region in the years 2019 and 2022 reveals significant geographical disparities (See Fig. 1). Different colors are used to illustrate the range of hypertension prevalence in various regions in Yogyakarta Special Region and to facilitate visualization of the spatial distribution and intensity of hypertension prevalence. Deeper colors indicate areas with the highest prevalence of hypertension and vice versa. In 2019, the highest concentration of cases falls within the [11602 - 15231] range, mostly affecting districts in the west and east. In 2022, the highest case bracket [11938 - 14283] shows a marked increase and a broader spatial spread, indicating an upward trend in hypertension prevalence over the three-year period. It is evident that certain regions consistently exhibit higher rates of hypertension, which could be indicative of underlying socio-economic, environmental, or healthcare access factors at play.

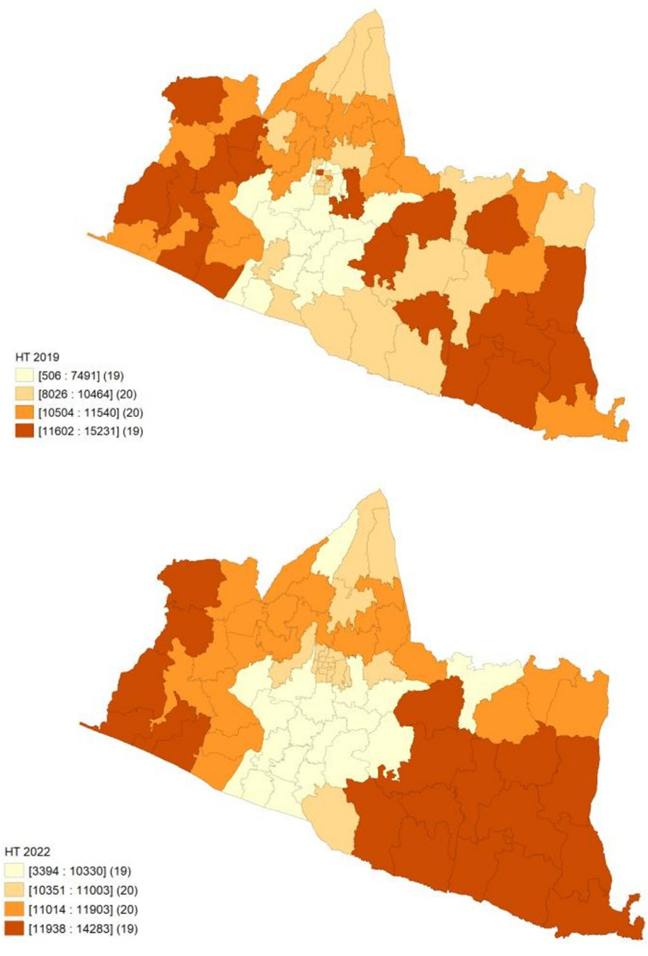

Fig. 1. Spatial Distribution of hypertension sufferers in the Yogyakarta Special Region, 2019 and 2022.

The observed increase in hypertension cases from 2019 to 2022 can be justified through several lenses. First, demographic shifts such as aging populations are known to contribute to higher hypertension rates. Secondly, lifestyle changes, possibly accelerated by the global pandemic, might have led to increased sedentary behavior and poorer diets, exacerbating hypertension risks. Thirdly, improved health awareness and reporting could partially account for the increased numbers due to better diagnosis and monitoring. Each of these potential factors is supported by various strands of the literature which identify similar trends in non-communicable disease prevalence following global health crises.

Comparing these findings with existing literature underlines the consistency with global trends in hypertension increases. Literature suggests that urbanization and associated lifestyle changes play significant roles in this upsurge. The significance of these findings lies in their implication for public health policy and resource allocation. The geographic spread of hypertension emphasizes the need for targeted interventions in hot-spot areas and suggests that factors beyond individual lifestyle choices, possibly systemic issues such as healthcare access, may be contributing to these patterns. Understanding these spatial distributions is crucial for the implementation of effective, location-specific health interventions.

3.2 The Moran's I Statistics for Hypertension Prevalence in Yogyakarta Special Province

The Moran's I statistics for hypertension prevalence in Yogyakarta Special Region show a positive value for both 2019 and 2022, at 0.306 and 0.511 respectively. This indicates a level of spatial autocorrelation in hypertension cases, with a stronger autocorrelation in 2022. The scatterplots depict the correlation between the number of hypertension cases in a district and the average number in neighboring districts, with the 2022 data displaying a more pronounced clustering trend as evidenced by the steeper slope.

The positive Moran's I values signify that districts with high (or low) numbers of hypertension sufferers are more likely to be surrounded by districts with similarly high (or low) numbers. An increase in Moran's I value from 2019 to 2022 indicates an increase in this clustering effect over time, potentially reflecting changes in public health initiatives, regional healthcare policies, or socio-economic dynamics. This increase could also indicate that the factors influencing hypertension are becoming more unevenly distributed or that intervention strategies have not been able to reduce the impact of hotspots.

Compared to other studies measuring the spatial distribution of health-related phenomena, these Moran's I values are relatively modest. Still, the existence of spatial autocorrelation is significant, as it challenges the assumption that health outcomes are randomly distributed. The novelty of these findings lies in the detected shift in spatial patterns over a three-year period, which points to dynamic changes in public health landscapes. Understanding these changes is vital for tailoring health interventions and can help to improve resource allocation by identifying areas with the greatest need or best response to interventions. The insights from these analyses contribute to the evolving field of health geography by providing empirical evidence of non-random distribution of health outcomes, potentially influenced by a mixture of environmental, social, and economic factors.

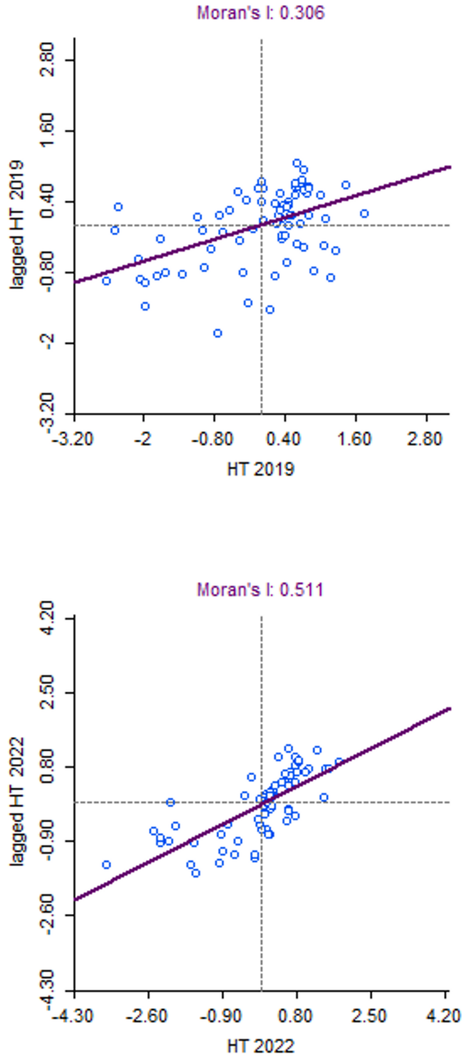

Fig. 2. Moran's I Hypertension in the Yogyakarta Special Region, 2019 and 2022.

3.3 Local Indicators of Spatial Association (LISA) Maps of Hypertension

The Local Indicators of Spatial Association (LISA) maps for hypertension in the Yogyakarta Special Region for 2019 and 2022 display distinct clusters of high-high and low-low hypertension values (See in Figure 3). In 2019, there are prominent high-high clusters and low-low hypertension clusters, indicating areas with high hypertension prevalence surrounded by similar districts and vice versa. The 2022 map shows an increase in high-high clusters and low-low clusters, suggesting a shift towards areas with higher or lower prevalence of hypertension. The absence of high-low outliers in 2022 implies a more homogenized spatial pattern compared to 2019, where there were such instances.

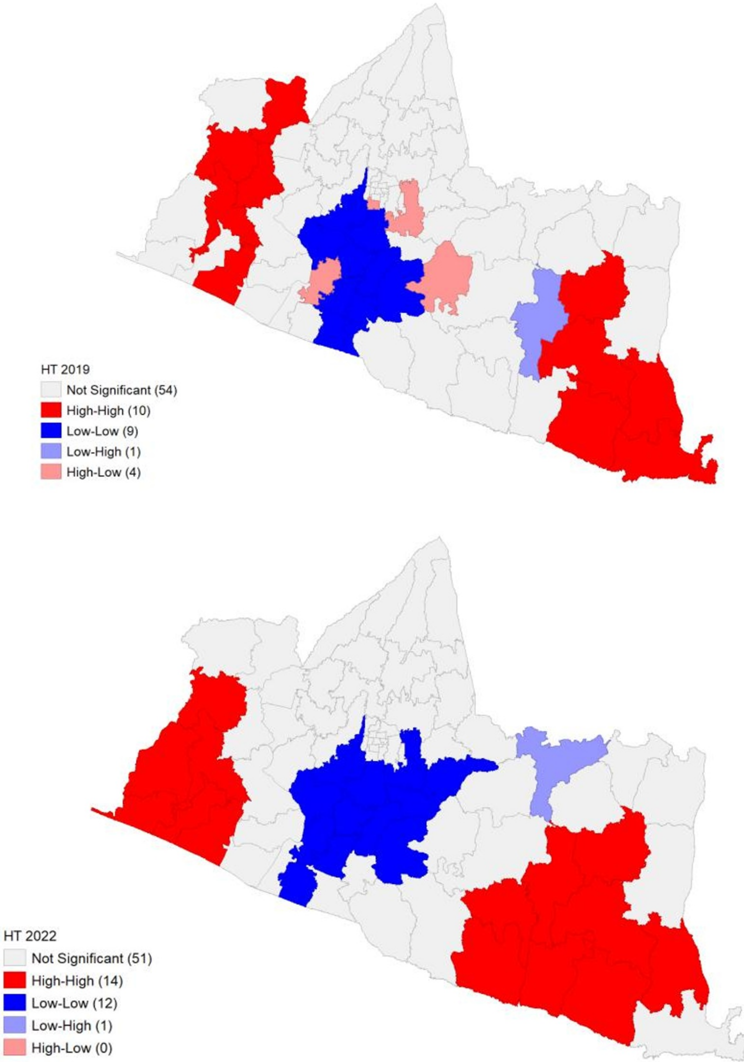

Fig. 3. LISA Hypertension in the Yogyakarta Special Region, 2019 and 2022.

The shift from high-high to low-low clusters over the three-year span may suggest the effectiveness of health interventions and policies targeting hypertension control and prevention. It could also reflect changes in socio-economic conditions, possibly improving access to healthcare or healthier lifestyle choices in previously high-prevalence areas. This interpretation is consistent with public health literature that emphasizes the impact of localized health initiatives and socio-economic development on disease prevalence.

Comparing the LISA clusters between 2019 and 2022 with existing geographic health studies reveals the dynamic nature of disease patterns in relation to public health interventions. The novelty in these findings lies in the spatial-temporal analysis which tracks the evolution of hypertension prevalence. This offers insights into the effectiveness of public health strategies and could serve as a model for other regions facing similar challenges. The ability to visually and statistically capture this evolution over time is invaluable for policymakers and health professionals, as it underscores the importance of geographically targeted health interventions and the need for ongoing surveillance to adapt strategies as community health landscapes change.

The application of spatial autocorrelation analysis in Yogyakarta Special Region found a significant pattern in the prevalence of hypertension. The application contributes to additional insights regarding non-communicable diseases (NCDs) in low- and middle-income countries. The findings also revealed differences in spatial clustering where hypertension prevalence was significantly higher or lower than the regional average. Furthermore, these findings are particularly important given the global emphasis on NCDs, which as reported by the World Health Organization, are the leading cause of death worldwide.

By employing GeoDa software and integrating the Quantile Map, Moran’s I, and Local Indicators of Spatial Association (LISA), this study not only mapped the distribution of hypertension, but also qualitatively assessed the strength of spatial relationships between hypertension prevalence. Thus, hypertension prevalence clusters may play a role in health policy making and focusing regionally tailored interventions. It is beneficial to direct resources and efforts to areas with high hypertension prevalence based on these findings.

The novelty of this study lies in its approach to understanding hypertension in Indonesia—a country facing a rapid rise in NCDs. By deploying spatial analytical methods, the research provides actionable insights for healthcare stakeholders to formulate targeted preventive measures and allocate resources more efficiently.

These conclusions advocate for the continued use of spatial analyses in public health to navigate the complex landscape of NCDs and to inform policies that can tackle the uneven distribution of health-related risks and outcomes. The ultimate goal is to reduce the hypertension burden and improve overall health in the Yogyakarta Special Region and similar contexts worldwide.

4 Conclusion

This study’s integration of spatial analysis into the examination of hypertension prevalence in Yogyakarta Special Region has revealed distinct patterns of clustering, both in terms of high-high and low-low areas of prevalence, across the time frame of 2019 to 2022. The Local Indicators of Spatial Association (LISA) analysis conducted for 2019 and 2022 has allowed for the identification of statistically significant clusters of hypertension cases. These clusters, which reflect areas with either higher or lower cases than expected under spatial randomness, have changed over the analyzed period, indicating a dynamic health landscape influenced by multifactorial determinants.

The results suggest a spatial dependency in hypertension prevalence, with notable areas of high prevalence (high-high clusters) persisting over time, alongside regions of low prevalence (low-low clusters). The persistence of these clusters may point to the entrenched nature of the social determinants of health in these regions, such as access to healthcare, lifestyle factors, and socio-economic conditions. Notably, the LISA maps for 2022 show a diffusion of high-prevalence clusters, which could be indicative of changing health patterns, possibly due to policy interventions, healthcare strategies, or other unmeasured factors.

The novelty of this research lies in its detailed spatial examination of hypertension, a step forward in public health surveillance, providing a granular view of how hypertension is distributed across a geographic area. These findings underscore the importance of geospatial analysis in understanding the complexities of disease distribution and the need for geographically tailored public health strategies. They also call for continuous monitoring of disease patterns to identify emerging clusters of health concerns, ensuring timely and effective public health responses.

Overall, the study contributes to the field of health geography and public health by demonstrating the applicability of geospatial analysis in understanding and addressing non-communicable diseases. The implications of these findings are far-reaching, offering a foundation for future studies to explore the underlying causes of these spatial patterns and to develop targeted interventions to reduce the burden of hypertension within the region.

This study was conducted at the subdistrict level, which may not be detailed enough to reveal micro variations in hypertension prevalence. More detailed data, such as data per neighborhood or village, may provide a better understanding of the spatial distribution of hypertension. This study only focuses on identifying the spatial distribution of hypertension and does not rule out the possibility of uncontrolled variables affecting the spatial distribution of hypertension, such as access to health services, lifestyle factors, and socioeconomic conditions.

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