APPLICATION OF SPATIAL ANALYSIS WITH GETIS-ORD GI* METHOD AND LOCAL INDICATOR OF SPATIAL AUTOCORRELATION (LISA) ON POPULATION DENSITY DATA OF LAMPUNG PROVINCE

(Thesis)

By

RANI TIAS SARTIKA
2117031122

FACULTY OF MATHEMATICS AND NATURAL SCIENCES
LAMPUNG UNIVERSITY
BANDAR LAMPUNG
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ABSTRACT

APPLICATION OF SPATIAL ANALYSIS WITH GETIS-ORD GI* METHOD AND LOCAL INDICATOR OF SPATIAL AUTOCORRELATION (LISA) ON POPULATION DENSITY DATA OF LAMPUNG PROVINCE

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RANI TIAS SARTIKA

Population Density is an important indicator in regional planning because it reflects the pressure of space, infrastructure, and public services. This case study uses Population Density data of Lampung Province in 2023 to 2024 using the Getis-Ord Gi* method and Local Indicator of Spatial Autocorrelation (LISA) with Queen Contiguity type spatial weighting matrix approach and correlation matrix. The results of this study indicate that the distribution of population density is unevem and dominated by low density areas. Although there was an increase in average density from 2023 to 2024, the spatial pattern still shows a spread distribution and does not form significant clusters. Based on the Getis-Ord Gi* analysis, no significant hotspot were found, but Metro City and South Lampung District were consistently identified as coldspot with a significant level of 95% and 90%. In contrast, the LISA analysis identified local spatial patterns that were consistent with hotspot in West Lampung, West Tulang Bawang, and Right Way District. Also, coldspots in Bandar Lampung City, Metro City, South Lampung District, and East Lampung show local spatial autocorrelation in several district, such as in the variabel unemployment, food balance, traffic congestion. Overall, the results of this study indicate that population density in Lampung Province does not form a strong cluster pattern locally in supporting public policy.

Keywords: Population Density, Getis-Ord Gi*, LISA, Spatial Autocorrelation, Queen Contiguity, Lampung Province.

ABSTRAK

PENERAPAN ANALISIS SPASIAL DENGAN METODE *GETIS-ORD GI DAN *LOCAL INDICATOR OF SPATIAL AUTOCORRELATION* (LISA) PADA DATA KEPADATAN PENDUDUK PROVINSI LAMPUNG**

Oleh

RANI TIAS SARTIKA

Kepadatan Penduduk merupakan indikator penting dalam perencanaan wilayah karena mencerminkan tekanan ruang, infrastruktur, dan layanan publik. Studi kasus penelitian ini menggunakan data Kepadatan Penduduk Provinsi Lampung pada tahun 2023 hingga 2024 menggunakan metode *Getis-Ord Gi** dan *Local Indicator of Spatial Autocorrelation* (LISA) dengan pendekatan matriks pembobotan spasial tipe *Queen Contiguity* dan matrix korelasi. Hasil penelitian ini menujukkan bahwa distribusi kepadatan penduduk tidak merata dan didominasi oleh wilayah berkepadatan rendah. Meskipun terjadi peningkatan rata-rata kepadatan dari tahun 2023 hingga 2024, pola spasial tetap menunjukkan penyebaran yang tesebar dan tidak membentuk klaster yang signifikan. Berdasarkan analisis *Getis-Ord Gi**, tidak ditemukan *hotspot* yang signifikan, namun Kota Metro dan Kabupaten Lampung Selatan secara konsisten teridentifikasi sebagai *coldspot* dengan tingkat signifikan 95% dan 90%. Sebaliknya analisis LISA mengidentifikasi pola spasial lokal yang konsisten dengan *hotspot* di Kabupaten Lampung Barat, Tulang Bawang Barat, dan Way Kanan. Selain itu, *coldspot* di Kota Bandar Lampung, Kota Metro, Kabupaten Lampung Selatan, dan Lampung Timur menunjukkan adanya autokorelasi spasial lokal pada beberapa wilayah, seperti pada variabel pengangguran, keseimbangan pangan, kemacetan lalu lintas. Secara keseluruhan, hasil penelitian ini menunjukkan bahwa kepadatan penduduk di Provinsi Lampung tidak membentuk pola klaster yang kuat secara spasial lokal dalam mendukung kebijakan publik.

Kata Kunci : Kepadatan Penduduk, Autokorelasi Spasial, *Getis-Ord Gi**, *LISA*, Autokorelasi Spasial, *Queen Contiguity*, Provinsi Lampung.

APPLICATION OF SPATIAL ANALYSIS WITH GETIS-ORD GI* METHOD AND LOCAL INDICATOR OF SPATIAL AUTOCORRELATION (LISA) ON POPULATION DENSITY DATA OF LAMPUNG PROVINCE

By

RANI TIAS SARTIKA

Thesis

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Student Name : Rani Tias Sartika

ID Number Of Student : 2117031122

Study Program : Mathematics

Faculty : Mathematics and Natural Sciences

APPROVAL

1. Supervisory Committee

Dr. Khoirin Nisa, S.Si., M.Si.	**Misgiyati, S.Pd., M.Si.**
NIP. 19740726 200003 2 001	**NIP. 19850928 202321 2 032**

2. Head of Mathematics Department

Dr. Aang Nuryaman, S.Si., M.Si.
NIP. 19740316 200501 1 001

VALIDATED BY

1. Examination Committee

Head	: **Dr. Khoirin Nisa, S.Si., M.Si.**	....
Secretary	: **Misgiyati, S.Pd., M.Si.**	....
Examiner Non-Supervisor	: **Drs. Nusyirwan, M.Si.**	....

2. Dean of the Faculty of Mathematics and Natural Sciences

Dr. Eng. Heri Satria, S.Si., M.Si.
NIP. 197110012005011002

Thesis Defense Date: **May 14, 2025**

STUDENT THESIS STATEMENT

The undersigned below :

Name : **Rani Tias Sartika**

ID Number Of Student : **2117031122**

Major : **Mathematics**

Thesis Title : **Application of Spatial Analysis With Getis-Ord Gi* Method And Local Indicator of Spatial Autocorrelation (LISA) On Population Density Data of Lampung Province.**

Hereby declare that this thesis is the result of my own work and all writings contained in this thesis have followed the rules of scientific writing at the Lampung University.

Bandar Lampung, 14 May 2025
Author,

Rani Tias Sartika

BIOGRAPHY

Rani Tias Sartika was born in Bandar Lampung City, Lampung Province on July 16, 2003. She is the third of three children of Mr. Husin Rusli and Mrs. Syamsiyah. She has two older sisters named Eka Rahma Saputri, S.Pd. and Bella Melli Yovana, S.Pd. respectively.

Rani Tias Sartika started elementary school at SDN 1 Perumnas Way Kandis in 2009-2015. Then took junior high school education at SMPN 19 Bandar Lampung in 2015-2018 and continued his high school education at Bina Mulya Senior High School Bandar Lampung in 2018-2021.

In 2021, Rani Tias Sartika continued her undergraduate education at the Department of Mathematics, Faculty of Mathematics and Natural Sciences, Lampung University through the Lampung University Expanded Access to Education (PMPAP) route. During her time as a student, the author joined various organizations, namely Expert Staff for Women's Empowerment of BEM FMIPA Lampung University for the 2022 period, Expert Staff for the Advocacy and Student Welfare Office of BEM FMIPA Lampung University for the 2023 period, and Staff for the Domestic Ministry of BEM U KBM Lampung University for the 2023 period.

From December 2023 to February 2024, Rani Tias Sartika conducted a Practical Lecture (KP) or Internship at the Central Bureau of Statistics of Bandar Lampung City as a form of self-development and applying the knowledge gained during lectures. Furthermore, from June to August 2024 the author also conducted a Real Work Lecture (KKN) in Karang Anyar Village, Labuhan Maringgai District, East Lampung District.

DEDICATION

By expressing my utmost praise and gratitude to Allah SWT who has given me His grace, guidance, and gifts. With great pride, the author presents this simple work with full sincerity as an offering of love and affection to:

Father and Mother

I would like to thank my father and mother for all the prayers, support, and love that you have given. Thank you for always accompanying and supporting me with blessings and prayers in every step the author takes.

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"With difficulty there is ease, so when you have finished a task, do it with all diligence."

(Q.S Al-Inshirah: 6)

"Verily, Allah will not change the condition of a people until they change their own condition."

(Q.S Ar-Rad: 11)

"Allah will not burden a person but according to his ability"

(Q.S Al-Baqarah: 286)

"Dream on, knowing that God will embrace those dreams"

(Andrea Hirata - Edensor)

"If you do not fight, you cannot win"

(Eren Jeager- Attack on Titan)

"Waking Up Together With You"

(Ardhito Pramono)

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May Allah SWT reward all the kindness that has been given in the best possible way. Hopefully, this thesis can provide benefits for the readers. The author realizes that this thesis writing is far from perfect. Therefore, criticism and suggestions are highly expected to improve this work.

Bandar Lampung, 14 May 2025
Author,

Rani Tias Sartika

TABLE OF CONTENTS

Page

LIST OF TABLES

Table **Page**

LIST OF FIGURE

Image Page

I. INTRODUCTION

1.1 Background and Issues

Geographic Information System (GIS) is a system that is used analyze a spatial data by examing and exploring data from the space dimension. Spatial data analysis cannot be done globally, meaning that each location has its own characteristics. Most of the analysis approach is an exploration of data presented in the form of thematic maps. This analysis involves spatial data to obtain added value, extraction and new spatial information (Igarta & Handayani, 2020). According to Marx, et al. (2014), spatial autocorrelation is very important to get a pattern of distribution of relationships or correlations between observed locations, namely spatial autocorrelation. Testing spatial autocorrelation can be done globally or locally. Globally using the Moran Index, Geary's Ratio, and Getis G methods. While the global spatial autocorrelation is by using Getis-Ord Gi* and Local Indicator of Spatial Autocorrelation (LISA) method.

The Getis-Ord Gi* method is an analysis used to determine the location of the clustering center (hottest area). The degree of clustering is indicated by the probability value (p-value) and standard deviation (z-score). This analysis method calculates the Gi* value by considering the value of surrounding objects (Simanungkalit et al., 2024).

According to Osadebey, et al. (2019), LISA is the relationship between an observation location and another observation. It can provide information that adjacent areas have similar values or form a clustered distribution. Based on BPS Lampung Province (2022), that one of the provinces in Indonesia that has significant demographic and socio-economic diversity is Lampung Province. Lampung Province is one of the provinces located at the southern tip of Sumatera Island with an area of 35.376 km^2 consisting of 15 District/City. With the highest level of community welfare at 50.22%, Kota Metro shows good access to basic services.

Bandar Lampung City, and West Lampung show that the level of community welfare is lower, indicating that there are challenges in providing basic services to the community that need to be improved. Meanwhile, the unemployment rate in Lampung Province varies, for example Bandar Lampung has the highest unemployment rate at 45.19% (BPS Lampung Province, 2024). Mesuji and West Coast recorded the lowest community unemployment rate at 3.04%. Regions with the highest population density may face greater challenges in labor supply. Traffic congestion is one of the main problems, one of which occurred in Central Lampung, which recorded the highest traffic congestion rate of 175.14%.

Population density has a relationship between social and economic aspects. Bandar Lampung City and Metro City have higher population density, while West Coast District is lower. Based on BPS Lampung Province (2024), this research uses Getis-Ord Gi* and LISA methods to analyze the distribution of Population Density in Lampung Province. This method is used to determine the description and characteristics of the tendency of clustering patterns involving spatial or regional. The weighting matrix used is a Queen Contiguity type matrix, where neighboring areas are determined based on the intersection of the sides of the border and the intersection of the corners of the borders of other regions. Previously there has been research that uses the following method presented in the table below:

Table 1. Previous Research Getis-Ord Gi* and LISA

No.	Research and Title	Methods	Research Results
1.	Azizah Nurhidayah (2020) "Spatial Analysis of the Spread of Dengue Fever (DHF) with the Getis-Ord Gi* Method and Local Indicator of Spatial Autocorrelation (LISA)".	Getis-Ord Gi* and Local Indicator of Spatial Autocorrelation (LISA) methods on the spread of Dengue Fever in Bandar Lampung City in 2018.	The results showed that the calculation of spatial autocorrelation of the spread of DHF disease that occurred in Bandar Lampung City in 2018 with the Local Indicator of Spatial Autocorrelation (LISA) method did not have a relationship between observation areas in each sub-district in Bandar Lampung City. From the results of mapping with the Getis Ord-Gi* method, the highest distribution of DHF disease is in 5 sub-districts of Panjang, Rajabasa, Tanjung Senang, Sukarame, and Sukabumi. While for mapping with the LISA method there are 4 sub-districts of Rajabasa, Tanjung Senang, Sukarame, and Sukabumi. So that both methods have a cluster distribution pattern.

No.	Research and Title	Methods	Research Results
2..	Sinta Bimantari (2021) "Spatial Analysis of the Spread of (COVID-19) with the Getis-Ord Gi* and Local Indicator of Spatial Autocorrelation (LISA) method.	Getis-Ord Gi* and Local Indicator of Spatial Autocorrelation (LISA) methods on the spread of COVID-19 in Lampung Province.	The results showed that there is spatial autocorrelation in the spread of COVID-19 using (LISA) there is a relationship between regencies / cities with other regencies / cities in July. Meanwhile, for the Getis-Ord Gi* method, the spread of COVID-19 occurred in March 2020 to February 2021 for the Bandar Lampung and Central Lampung areas, and both methods obtained that the pattern of the spread of COVID-19 in Lampung Province was random.
3.	Habinuddin (2021) "Spatial Autocorrelation Analysis on the Spread of Dengue Fever in Bandung City".	Getis-Ord Gi* Method and Local Indicator Of Spatial Autocorrelation (LISA)	The results showed that with the Moran Scatterplot Index and Local Indicator of Spatial Autocorrelation (LISA) testing, it was found that the areas prone to the spread of DHF were Kiaracondong, Antapani sub-districts in the (HH) High-High quadrant, Cidadap, Mandalajati sub-districts were in the (LH) Low-High quadrant, and Astana Anyar, Sumur Bandung, Regol and Andir sub-districts were categorized as safe areas, because they were in the (LL) Low-Low quadrant.

No.	Research and Title	Methods	Research Results
4.	Hadisti Hayati (2024) "Spatial Analysis of the Distribution of Malaria Cases in East Kalimantan Using the Moran Index and Local Indicator of Spatial Autocorrelation".	Getis-Ord Gi* Method and Local Indicator of Spatial Autocorrelation (LISA)	The results showed that the distribution pattern of the average number of malaria cases in East Kalimantan in 2018 - 2022 was a cluster pattern in each district / city. Moran Index testing does not occur spatial autocorrelation globally in the data on the average number of malaria cases. LISA test results show that there is a relationship between the average number of malaria cases in 2018 to 2022 in West Kutai, North Penajam Paser, and Balikpapan City with the neighboring district/city.

So the author is interested in choosing this research by using the Getis-Ord Gi* and Local Indicator of Spatial Autocorrelation (LISA) methods with the research title "Application of Spatial Analysis With Getis-Ord Gi* and Local Indicator of Spatial Autocorrelation (LISA) Method On Population Density Data of Lampung Province" aims to identify the spatial autocorrelation of population density distribution in Lampung Province in 2023 to 2024.

1.2 Research Objectives

The objectives of this research are:

1. Identifying spatial autocorrelation of population density distribution in Lampung Province using Getis-Ord Gi* and LISA method.
2. Obtaining the spatial distribution pattern of population density in Lampung Province.

1.3 Research Benefits

The expected benefits in this research

1. Can provide insight for the community regarding the dynamics of Population Density in Lampung Province.
2. Can be a reference for future researchers for other types of data using the Getis-Ord Gi* and LISA method.

II. LITERATURE REVIEW

2.1 Spatial Analysis

Spatial analysis is a process of analysis that pays attention to the location and distance of an object in the research data. This method allows researchers to understand patterns, relationships, and data distribution based on geographic location according to Hadisti, et al. (2024). According to Faiz, et al. (2011), spatial analysis is data related to geographic location consisting of latitude-longitude and region. Spatial analysis consists of three groups, namely visualization, exploration, and modeling. Visualization is the process of presenting analysis results in the form of graphs, diagrams, or other visualizations to provide information on the results of an analysis.

Exploration is the process of processing data analysis with the aim of finding the results of statistical method analysis. Meanwhile, modeling is the concept of causal relationships using methods from spatial data sources and non-spatial data to predict spatial patterns Pfeiffer, et al. (2008). Meanwhile, according to Rumengan, et al. (2019), spatial analysis is a method to find and describe a level or pattern of a spatial phenomenon, so that it is easily understood better. By doing spatial analysis, it is expected to provide deep insight into geographic phenomena and support better decision making in various fields.

2.2 Spatial Data

Spatial data is geographic information used to describe the location and physical characteristics of an area. According to Pfeiffer, et al. (2008), Spatial data is data related to geographically based locations consisting of regions and latitudes. Because spatial analysis of spatial data cannot be done worldwide and each location has unique characteristics. The analysis approach largely consists of data exploration, which is presented in thematic form. Thematic maps, also referred to as statistical maps or special purpose maps, show variations in the use of space from geographic distributions such as climate or population density that may cause geographic dispersion.

According to Yenusi, et al. (2020), location information can be known from two sources, namely:

1. Neighborhood relationship

   Neighborhood relationships are usually formed from maps and are expected to depict a high degree of spatial dependency when compared to widely separated spatial units, which are usually formed from maps.

2. Distance

   The distance a location lies within a given space with latitude and longitude. This data is used to calculate the distance between points in space. The strength of spatial dependency is expected to decrease with distance.

2.3 Spatial Pattern

In spatial analysis there are spatial patterns or spatial patterns that can be seen in spatial analysis in the form of area patterns and point patterns or point petterns. Spatial analysis includes a spatial model, which is a model related to the placement of objects or the placement of objects on the earth's surface. Spatial models can be represented as point models and area models (Anselin, 1995). According to Wen, et al. (2010), spatial models describe geographically dispersed phenomena and comparisons with other phenomena. Spatial patterns can be expressed using spatial autocorrelation. Spatial autocorrelation is a spatial analysis technique to measure the degree of relationship in data affected by space. Data is said to be spatially autocorrelated if the observations x_1, $x_{2,\ldots,}x_n$ show spatial interdependence. Thus, spatial autocorrelation is used to distinguish locations and their attributes or certain variables.

In this case, spatial statistics is a widely used tool to describe and analyze spatial patterns, which are geographical objects that occur and change at a location. In addition, it can also compare object patterns in a location with object patterns in other locations. Then the following are the forms of spatial pattern data distribution, including :

a. Random is where some areas are randomly located in some locations. The position of an area is not affected by the position of other areas.
b. Dispersed is where each area is evenly distributed and far apart from the other areas.
c. Clustered is where several areas form a group and are close to each other.

2.4 Z-Score Test

According to Ramadhania & Achyani (2024), z-score is a statistical measure that shows how far a value is from the average in standard deviation units. With the following formula:

$$Z= \frac{X-\mu}{\sigma} \tag{2.1}$$

By:

X = Population density value per district/city

μ = Average population density

σ = Standard deviation of population density

Z-score hypothesis test:

1. Test Hypothesis
   - H_0 = There is no significant difference
   - H_1 = There is a significant difference
2. Significant Level (α) = 5% = 0.05
3. Test statistics
4. Critical Value (seen from the normal distribution table)
5. Decision
   - If |Z| > 0.05 then reject H_0
   - If |Z| < 0.05 fails to reject H_0
6. Conclusion

The following guidelines are used to determine the hottest area and coldest area based on the z-score value:

Table 2. Interpretation guide for z-score hotspot analysis value

No.	Z-score	Interpretation
1.	< 2,58	99% chance of districts becoming coldspot.
2.	-2.58 to -1.96	95% chance of districts becoming coldspot.
3.	-1.96 to -1.65	90% chance of districts becoming coldspot.
4.	-1.65 to 1.65	Nothing significant.
5.	1.65 to 1.96	90% chance of districts becoming hotspot.
6.	1.96 to 2.58	95% chance of districts becoming hotspot.
7.	> 2,58	99% chance of districts becoming hotspot.

The result of this method is a distribution hotspot map that presents high and low population density objects to find out which districts/city are hotspots, coldspots, and neutral areas in Lampung Province. Hottest area is defined as an area surrounded by objects with high clustering values, then the lowest area is defined by objects with lower clustering values to become Coldest area.

According to Nejadrekabi, et al. (2021), Gi* statistics produces a dataset in the form of z-score. The z-score value is positive and statistically significant, the larger it is, the more intense the cluster of high z-score values (hotspot) will be. While the z-score value is negative and statistically significant, the more intense the cluster of low z-score values (coldspot).

2.5 Contiguity Matrix

Contiguity matrix is a matrix that describes the relationship between locations. The value in the matrix of the i-th row and j-th column is C, and the element (i, j) is 1 if region i is adjacent or directly adjacent to region j. If region i is not adjacent to region j then the element (i, j) is 0 (Lutfi & Aidid, 2019).

$$c_1 = \sum_{j=1}^{n} cij \qquad (2.2)$$

By:

n = Number of locations in the geographic system

c_i = Total value of i-th row

c_{ij} = Values at row i and column j

$$\mathbf{C} = \begin{pmatrix} c11 & c12 & \cdots & c1n \\ c21 & c22 & \cdots & c2n \\ \vdots & \vdots & \ddots & \vdots \\ cn1 & cn2 & \cdots & cnn \end{pmatrix}$$

According to Yenusi, et al. (2020), there are generally three types of boundary interactions or intersections, as follows:

1. Rook Contiguity

   Rook Contiguity is an observation area where the edges are intersecting and the angle is not taken into account. An illustration of rook contiguty is seen in Figure 1, where units B1, B2, B3, and B4 are neighbors of unit A.

	Unit B2	
Unit B1	Unit A	Unit B3
	Unit B4	

Figure 1. Rook Contiguity.

2. Bishop Contiguity

Bishop Contiguity is an observation area where corners are tangent and edges are not taken into account. An illustration for bishop contiguity can be seen in Figure 2, where units C1, C2, C3, and C4 are neighbors of unit A.

Unit C1		Unit C2
	Unit A	
Unit C4		Unit C3

Figure 2. Bishop Contiguity.

3. Queen Contiguity

Queen Contiguity is an observation area based on edges that intersect each other and angles are also taken into account. An illustration of queen contiguity can be seen in Figure 3, where units B1, B2, B3, and B4 as well as C1, C2, C3, and C4 are neighbors of unit A.

Unit C1	Unit B2	Unit C2
Unit B1	Unit A	Unit B3
Unit C4	Unit B4	Unit C3

Figure 3. Queen Contiguity.

Queen Contiguity is one of the approaches used in this research to determine the weighting matrix. In an n x n weighting matrix, each element of the matrix describes the closeness measure between the i-th and j-th observations

The following is Figure 4 of the weighting matrix using queen contiguity. This illustration uses five observation regions. For regions that are common side or common vertex with the region of interest, the matrix element is given 1 for other regions, while the weighting matrix element is given 0.

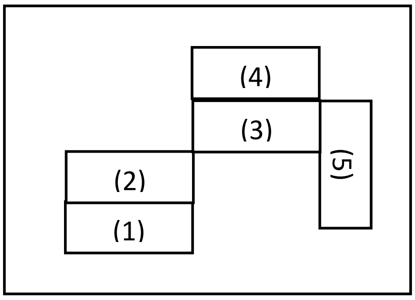

Figure 4. Contiguity Matrix Illustration.

The weighting matrix using queen contiguity that can be formed from Figure 4 is as follows (Yuriantari & Hayati, 2017).

$$\boldsymbol{W} = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 \\ 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \end{pmatrix}$$

2.6 Spatial Weighting Matrix

The spatial weighting matrix or contiguity matrix is a matrix that expresses the relationship of the n x n observation areas and is symbolized by **W**. To calculate the standardized matrix, the spatial weighting matrix is required so that the number of rows is equal to one or unity and the general form is :

$$\mathbf{W}_{ij} = \frac{\mathrm{Cij}}{\mathrm{Ci}} \tag{2.3}$$

By:

$\mathbf{W}_{ij}$ = Spatial weighting matrix value at row i and column j

c_{ij} = The contiguity matrix value at the i-th row and j-th column

c_i = Total contiguity matrix value at row i

$$\mathbf{W} = \begin{pmatrix} c11/c1 & c12/c1 & \cdots & c1n/c1 \\ c21/c2 & c22/c2 & \cdots & c2n/c2 \\ \vdots & \vdots & \ddots & \vdots \\ cn1/cn & cn2/cn & \cdots & cnn/cn \end{pmatrix} = \begin{pmatrix} w11 & w12 & \cdots & w1n \\ w21 & w22 & \cdots & w2n \\ \vdots & \vdots & \ddots & \vdots \\ wn1 & wn2 & \cdots & wnn \end{pmatrix}$$

The standardized spatial weighting matrix that can be formed from Figure 4 is as follows (Yuriantari & Hayati, 2017)

$$\mathbf{W} = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1/2 & 0 & 0 & 1/2 \\ 1/3 & 0 & 1/3 & 0 & 1/3 \\ 0 & 0 & 0 & 1 & 0 \end{pmatrix}$$

2.7 Spatial Autocorrelation

Spatial autocorrelation is a form of calculation to determine the value of the relationship between regions in a space or self-correlation (Sinta, 2021). Spatial autocorrelation The onset of spatial randomness identifies spatial patterns such as clustered, dispersed, or random. Positive spatial autocorrelation identifies adjacent locations with comparable values and tends to cluster. While negative spatial autocorrelation identifies adjacent locations with different values and tends to be dispersed. And no spatial autocorrelation identifies random location patterns (Marliani, 2021)

According to Yenusi, et al. (2020), the characteristics of spatial autocorrelation are:

1. Spatial autocorrelation occurs if there is a systematic pattern in the spatial distribution of the observed variables.
2. Spatial autocorrelation is positive when two places are closer to each other.
3. Spatial autocorrelation can be negative when the neighboring patterns are not systematic.
4. If there is no spatial autocorrelation, it is indicated by the random pattern of the spatial data.

2.7.1 Getis-Ord Gi*

Getis-Ord Gi* is a statistical tool used to identify the attraction between cities in terms of clustering, which determines whether adjacent regions cluster together.

The clustering pattern observed is the clustering of high or low values of an area against its nearest neighbors. The Getis-Ord Gi* method is used to determine which region is the center of clustering (hottest area). The height of the object in the analysis is indicated by the probability (p-value) and standard deviation (z-score). This analysis method determines the hottest area based on the Gi* value by considering the value of the surrounding objects. The Getis-Ord Gi* formula is as follows:

$$Gi* = \frac{\sum_{j=1}^{n} \mathbf{W}ijXj - \bar{X}\sum_{j=1}^{n} \mathbf{W}ij}{S\sqrt{\frac{n\sum_{j=1}^{n} \mathbf{W}^2ij \; (\sum_{j=1}^{n} \mathbf{W}ij)^2}{n-1}}} \quad (2.4)$$

By:

i = Observation area at the i-th location

j = Observation area at the jth location

Gi* = Getis-Ord statistical value Gi*

n = Number of districts/cities Population Density Lampung Province

x_j = The observed value at the jth location

$\bar{X}$ = Average value of n locations

S = Standard deviation of n locations

$\mathbf{W}_{ij}$ = Spatial weighting matrix value at row i and column j

With $\bar{X}$ the average value of n locations, as follows:

$$\bar{X} = \frac{\sum_{j=1}^{n} xj}{n-1} \quad (2.5)$$

With S being the standard deviation of n locations as follows:

$$S = \sqrt{\frac{n^2\sum_{j=1}^{n} x^2j-(\sum_{j=1}^{n} xj)^2}{n^2}} \quad (2.6)$$

2.7.2 Local Indicator Of Spatial Autocorrelation (LISA)

According to Saputro, et al. (2018), LISA is the relationship between an observation location and other observation locations. LISA can also provide information that adjacent areas have similar values or form a clustered distribution. The advantage of LISA is the combination of objects combined with the z value obtained from the Moran Scatterplot analysis (Wibowo, 2022). The following is the LISA formula:

$$Ii = \frac{zi}{m2} \sum_{i=1}^{n} \mathbf{w}_{ij}\ z_j \quad (2.7)$$

By:

$z_i = (x_i -) \overline{X}$

$z_j = (x_j -) \overline{X}$

$m_2 = \sum_{i=1}^{n} \frac{(xi - \overline{X})^2}{n-1}$

Description:

Ii = Statistical value of Local Indicator of Spatial Autocorrelation (LISA)

n = Number of locations

x_i = Observation value at the i-th location

x_j = The observed value at the jth location

$\overline{X}$ = Average value of n locations

$\mathbf{w}_{ij}$ = Spatial weighting matrix value of i-th row and j-th column.

Testing parameter Ii can be done as follows:

1. Hypothesis

   H_0 : Ii = 0 (There is no spatial autocorrelation at location i)

   H_1 : Ii $\neq$ 0 (There is spatial autocorrelation at location i)

2. Significant Level (α) = 0.05
3. Test Statistics

$$Z_{(i)count} = \frac{Ii - E(Ii)}{\sqrt{var(Ii)}} \tag{2.8}$$

Where var (Ii) is the expected value of LISA:

$$E(Ii) = \frac{wi}{(n-1)} \quad (2.9$$

Where var (Ii) is the LISA variance value:

$$var(Ii)\ E = [Ii^2] - [E(Ii)]^2 \tag{2.10}$$

$E[Ii^2] = A + B$

With:

$$A = \frac{(n-b_2)\sum_{i=1}^{n} w_{ij}^2}{n-1}$$

$$B = \frac{(2b_2-n)\sum_{k=1}^{n}\sum_{h=1}^{n} w_{ik}\ w_{ih}}{(n-1)(n-2)}$$

So:

$var(Ii) = E[Ii^2] - [E(Ii)]^2$

$$var(Ii) = A + B - \left[\frac{w_i}{(n_1)}\right]^2$$

$$var(Ii) = \frac{\left(n - \frac{m_4}{m_2^2}\right)\sum_{j=1}^{n} w_{ij}^2}{n-1} + \frac{\left(\frac{2m_4}{m_2^2} - n\right)\sum_{k=1}^{n}\sum_{h=1}^{n} w_{ik}\ w_{ih}}{(n-1)(n-2)} - \frac{w_i}{(n-1)}$$

$$var(Ii) = w_{(i)}^{(2}\frac{(n-b_2)}{n-1} + 2\ w_{i(kh)}\frac{(2b_2-n)}{(n-1)(n-2)} - \frac{w_i{}^2}{(n-1)^2}$$

With:

$w_i^{(2)} = \sum_{j\neq i} w_{ij}^2, i \neq j$ $\qquad$ $2\ w_{i(kh)} = \sum_{k\neq i}\sum_{h\neq i} w_{ik}\ w_{ih}$

$w_i = \sum_{j\neq i} w_{ij}, i \neq j$ $\qquad$ $m_4 = \sum_{i=1}^{n}\frac{(x-\overline{X})}{n-1}$

$b_2 \quad = \frac{m_4}{m_2^2}$ $\qquad m_2 \quad = \sum_{i=1}^{n} \frac{(x-\overline{X})^2}{n-1}$

4. Test Criteria

   The test will reject the initial hypothesis if the Z_{count} value lies at $[Z_{\text{count}}] > Z_{\left(\frac{\alpha}{2}\right)}$ or the *p-value is* .< α

5. Conclusion

2.8 Moran Scatterplot

Moran Scatterplot is a diagram used to show the relationship between the observed value at the location and the standardized average value (Habinuddin, 2021). There are two axes of the Moran Scatterplot graph, namely the horizontal axis shows the average value of observations at a location, and the vertical axis shows the average value of observations from locations neighboring that location (Yuriantari & Hayati, 2017) The following is an image of Moran Scatterplot, namely:

Figure 5. Moran Scatterplot.

Moran Scatterplot shows four types of spatial relationships between a region and its neighboring regions can be written as follows:

A. Quadrant I HH (High-High) square is an area that shows locations that have high observed values surrounded by locations that have high observed values, located in the upper right part.

B. Quadrant II LH (Low-High) is an area that shows locations that have low observation values surrounded by locations that have high observation values, located in the upper left part.

C. Quadrant III LL (Low-Low) is an area that shows locations that have low observation values surrounded by locations that have low observation values, which are located at the bottom left.

D. Quadrant IV HL (High-Low) is an area that shows locations that have high observation values surrounded by locations that have low observation values, located at the bottom right.

2.9 Thematic Mapping

Thematic mapping is a map that shows the spatial distribution of one or more attributes both qualitative and quantitative in a unit area based on land or region, called map features or map features (Masyhar, 2017). Every form of geographic data has information consisting of four components: geographic position or spatial reference, attribute information, spatial relationships, and time.

A map is a partial or complete picture of the face of the earth both above and below the surface and is presented on a flat plane on a scale from a certain projection systematically. A map is a partial or complete picture of the face of the earth both above and below the surface and presented on a flat plane on a scale from a certain projection systematically.

2.10 Population Density of Lampung Province

Population Density is the ratio between the number of people and the area inhabited (Irham & Putri, 2023). Lampung Province is a province located at the southern tip of Sumatra Island with an area of 35.376 km^2 The province is divided into 15 district/city, with Bandar Lampung City and Metro City as administrative cities, and Bandar Lampung City as the government capital. The population density of Lampung Province has a varying level of distribution between regional areas, mainly due to differences in geographical area and the level of urbanization of each district/city. According to BPS (2023 to 2024), Central Lampung District and Bandar Lampung City recorded high population densities 1.508 People/Km^2 in 2023 and 1.214 People/Km^2 in 2024 respectively. This density tends to correlate with social problems such as unemployment rates and traffic congestion.

Bandar Lampung City shows the highest unemployment rate in the province at 7.44% in 2024, and shows an increasing traffic congestion index from the previous year (Saryoto et al., 2022) . Low-density regions such as West Coast and Mesuji with densities of 172.32 People/Km^2 and 241.60 People/Km^2 in 2024 have different characteristics. These region focus more on community welfare and food security. Food balance in West Coast District increased significantly from 71.71% in 2023 to 76.32% in 2024, while Mesuji District increased significantly from 85.62% in 2023 to 86.21% in 2024. On the other hand, the level of community welfare in destrict with high population density is relatively stable.

Bandar Lampung City obtained that unemployment increased significantly from 1.202% in 2023 to 1.214% in 2024 (Regina et al. 2024). According to Astuti & Yani (2018), obtained that Tanggamus District was 74.19% while that Tulang Bawang District had the highest food balance of 87.51% (Said et al., 2020). Traffic congestion in population density areas such as Central Lampung District reached an index of 1.5% in 2024. The highest community welfare was recorded in Metro City at 2.49% with good access to basic services (Prathama, Nuraini, and Firdausi, 2020).

III. RESEARCH METHODS

3.1 Time and Place of Research

The research was conducted in the odd semester of the 2024/2025 academic year at the Department of Mathematics Faculty of Mathematics and Natural Sciences Lampung University.

3.2 Research Data

The data used in this research is secondary data, namely Population Density data in Lampung Province with a period of 2023 to 2024. This study uses the Getis-Ord Gi* method to help detect hotspots and coldspots while the LISA method to provide insight into local spatial autocorrelation of population distribution patterns in Lampung during 2023 to 2024. Based on the data obtained from the website of the Central Bureau of Statistics (BPS) of Lampung Province and each District/City of Lampung Province which can be accessed at the following link https://lampung.bps.go.id/id

3.3 Research Methods

This research method is used to see the pattern of Population Density of

Lampung Province with Getis Ord-Gi* and Local Indicator Of Spatial Autocorrelation (LISA) method.

This test was assisted by using Rstudio, Qgis, and GeoDA software.

The steps to be taken are as follows

1. Data description analysis.
2. Conducting a Z-Score Test, to identify areas that have a population density that is significantly above or below average.
3. Determining the proximity between districts/city in each region in Lampung Province by creating a contiguity matrix. To determine the proximity between districts/city using a map of Lampung Province and by determining proximity using Queen Contiguity. Lampung Province has 13 districts and 2 city, so the contiguity matrix is 15x15.
4. Determining the spatial weighting matrix obtained from the contiguity matrix. Which will form a standardized matrix.
5. Calculating the Getis-Ord Gi* statistical value.
6. Calculating the value of the Local Indicator of Spatial Autocorrelation (LISA) statistic and testing the I_i parameter and hypothesis,
7. Creating a Moran Scatterplot based on the LISA results from step 6.
8. Creating thematic maps of Population Density 2023 to 2024 using the Getis-Ord Gi* results.
9. Creating thematic maps of Population Density 2023 to 2024 using Local Indicator Of Spatial Autocorrelation (LISA) based on the results of Moran Scatterplot.
10. Analysis of Results.

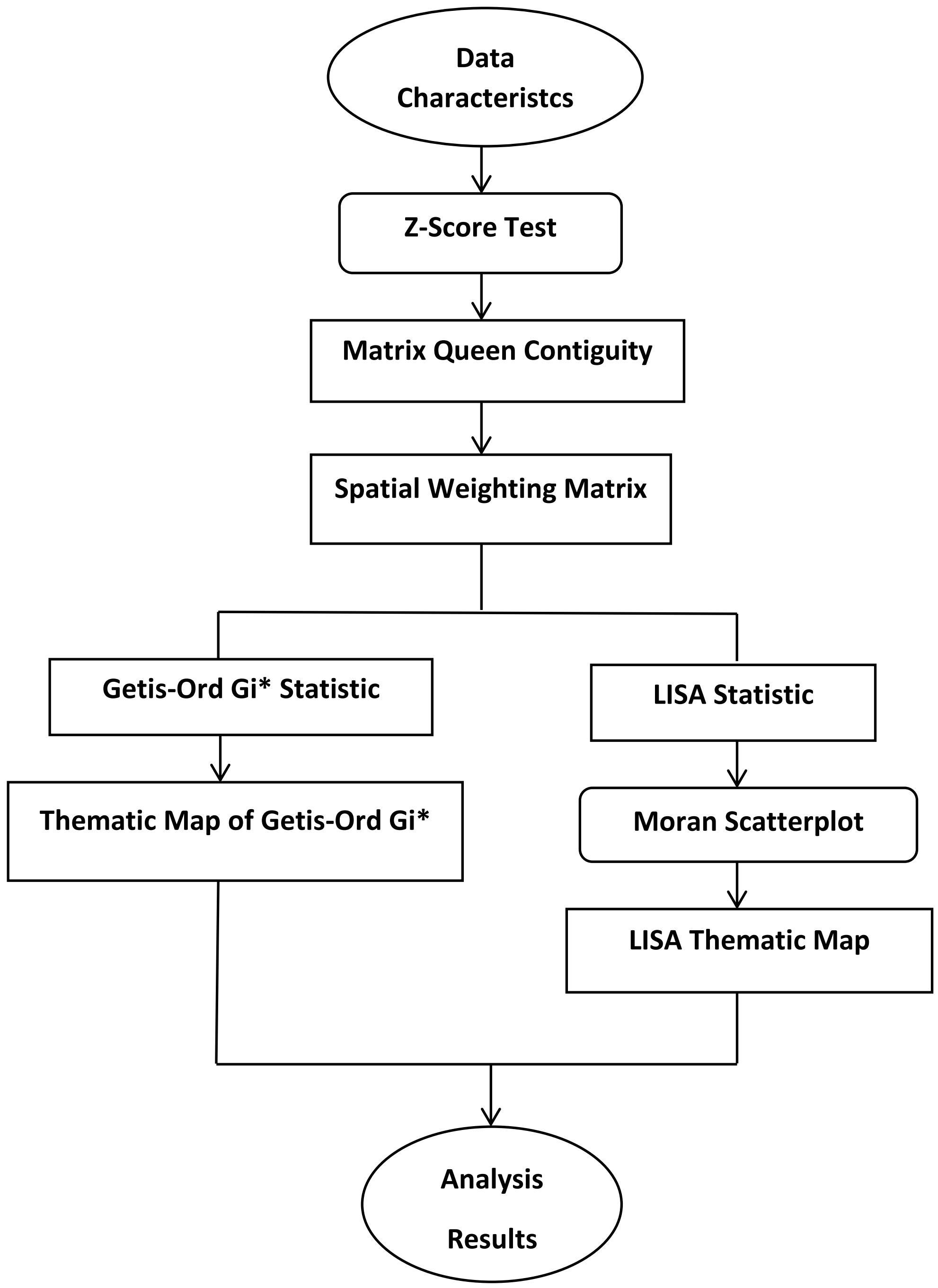

Figure 6. Flowchart of Spatial Analysis Model of Getis-Ord Gi* Method and Local Indicator of Spatial Autocorrelation (LISA).

V. CONCLUSION

Based on the results of Spatial Analysis of population density in Lampung Province from 2023 to 2024, it shows an uneven distribution pattern with a dominance of areas with low density. The data results show that although there was an increase in average density from 2023 to 2024, the spatial pattern still show a scattered population distribution according to the results of the Getis-Ord Gi* and LISA spatial analysis which did not show any significant hotspot. Based on the results of spatial mapping with a spatial weighting apporoach using Queen Contiguity and Correlation Matrix. The results showed that no significant area were found as hotspot (areas with high population density clustering) in 2023 to 2024 based on the Getis-Ord Gi* analysis. Metro City and South Lampung District identification as coldspots with a significant of 95% and 90% respectively, which means that these areas have significantly low population density clustering compared to the surrounding areas.

Then the LISA analysis shows a consistent spatial pattern, with several areas repeatedly identified as hotspots, namely West Lampung District, Pringsewu, West Tulang Bawang, and Right Way. While as coldspots are Bandar Lampung City, Metro City, South Lampung, and East Lampung. The difference in results between Getis-Ord Gi* and LISA shows that local spatial relationships are not always in line with absolute values (an areas will be a hotspot if it has a high value and a surrounded by areas with high values as a whole). For example, Bandar Lampung City is dense in value, but a coldspot due to incomtibility with its neighbors. LISA analysis shows local spatial autocorrelation in several districts/city for other variables related to population density as follows :

- Pesawaran District affects the unemployment rate in 2023.
- Way Kanan district has spatial linkages with food balance in 2023.
- Pringsewu and Tanggamus District show spatial linkages to food balance in 2024.
- And Tulang Bawang, West Tulang Bawang, East Lampung, and Central Lampung District affect the level of traffic congestion in 2023.

However, significant spatial autocorrelation occurred in several district for certain social variables, which indicates that the distribution of population density in Lampung Province forms a pattern that is not strongly clustered spatially or there are no strong points, but there are local linkages in several areas that can be used as a reference for regions and public policies.

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