ISSN 2354-9114 (online), ISSN 0024-9521 (print)
Indonesian Journal of Geography Vol 56, No 2 (2024): 227-240
DOI: 10.22146/ijg.90542 website: https://jurnal.ugm.ac.id/ijg

INDONESIAN JOURNAL OF GEOGRAPHY

RESEARCH ARTICLE

Spatial Distribution Pattern of Covid-19 Cases and Their Characteristics In DKI Jakarta and Surrounding Areas

Dwi Nowo Martono[1*]; Halvina Grasela Saiya[1]
[1] School of Environmental Science, Universitas Indonesia, Indonesia.

Received: 2023-11-09
Revised: 2024-06-25
Accepted: 2024-07-05
Published: 2024-07-31

Key words: COVID-19 Cases, Spatial Characteristics, Autocorrelation, Spatial Regression

Correspondent email:
dwi.nowo11@ui.ac.id

Abstract: The COVID-19 pandemic has significantly affected various countries worldwide, including Indonesia. This study specifically examines the spatial distribution pattern of COVID-19 cases among sub-districts in DKI Jakarta and its neighboring areas. The study investigates the impact of spatial characteristics such as building density, population density, road network connectivity, and accessibility, as well as infrastructure completeness. A spatial regression model was employed to analyze the influence and pattern of COVID-19 case distribution among sub-districts. Spatial modeling indicates that geographic location has an effect on the data, often referred to as the autocorrelation effect. Moran's Index was used to test the relationship between district locations and the number and growth rate of cases. The study findings reveal a positive spatial autocorrelation in the growth rate pattern of COVID-19 cases among sub-districts and clusters in DKI Jakarta and its surrounding areas. The spatial regression model, specifically the Spatial Autoregressive Model (SAR), identifies road connectivity, number of health centers, building density, and population density as spatial variables that significantly influence the rate of COVID-19 cases.

1. Introduction

Indonesia ranked 13th globally in 2021 with 3,871,738 COVID-19 cases and 118,633 deaths, following the US, India, Brazil, Russia, France, the UK, Turkey, Argentina, Colombia, Spain, Iran, and Italy. The pandemic has affected 220 countries across 5 continents since it began in January 2020, with approximately 208.65 million confirmed cases and 4.383 million deaths, and a daily addition of 520,000 cases and 8,000 deaths (Junaedi et al. 2022). Indonesia ranked in the top 5 globally for additional daily cases from July to August 2021 and was also among the top 3 countries with additional daily deaths, which was the highest for several weeks. According to statistical data from the National Statistics Agency (2021), there was a spike in cases from thousands to tens of thousands, and up to 40-50 thousand cases for several weeks in July 2021 when Community Activities Restrictions Enforcement (CARE) was implemented, and mass vaccinations were intensified. However, the prevalence began to decline to 20-30 thousand in August 2021. The daily death rate also increased from hundreds to thousands, repeatedly exceeding the 2,000 deaths per day mark. During July-August 2021, the daily average rate of COVID-19 cases was around 25,000 with 1,500 deaths. The highest daily increase occurred on July 15, 2021, with 56,757 cases, while the peak death rate was recorded on July 27, 2021, with 2,069 deaths. In the second week of August 2021, there was a significant development, along with a high number of first and second-dose vaccine recipients, which was an increasing trend in cure rates. Although the number of daily cases and deaths is still high, the growth rate of cases tends to decline, and the death rate also decreases.

The development of COVID-19 cases varies across different regions, suggesting that both spatial and non-spatial factors could be influencing their number and growth rate. Analyzing these factors and their impact on case increases can help us better understand this relationship. Pandemics are characterized by their spatial distribution, which can be studied using GIS and spatial statistics tools to gain insight into transmission patterns and dynamics. Mathematical models and spatial statistics are also crucial in predicting future conditions. Several studies have explored the use of these models in understanding COVID-19 cases. For example, Guliyev's (2020) research focused on establishing an efficient and consistent model for COVID-19 cases by investigating the strength of the pandemic's spread and effects using spatial panel data. The findings indicated a significant spatial autocorrelation between multiple provinces in China, with cases, deaths, and recoveries reaching a significant level of 5%. Similarly, Kucharski et al. (2020) examined the initial dynamics of transmission and control of COVID-19 cases through mathematical modeling. Gross et al. (2020) conducted comprehensive research on the spatial propagation of COVID-19 cases, utilizing variables such as distance, population, human mobility, and scale of people interaction across Hubei Province and other locations in China. The relationship between density and crowding with stress and prosocial intention in adolescents in dense settlements was explored by Cholidah, Ancok, and Haryanto (1996). The study found that adolescents experience higher levels of stress when they live in denser and more crowded areas. The study also found that density and crowding combined contribute to stress by 17%. In a more recent study by Anderson (2021), it was discovered that population and building densities, as well as the number of COVID-19 cases, had a significant 5% correlation with values of 0.458 and 0.514. However, the PHC coverage parameter with a value of 0.211 did not significantly correlate with positive cases. Another report by Hardianto (2020) on the correlation of population density and the spread of COVID-19 in DKI Jakarta found that while population density was a catalyst, it was not the main contributor to the number and distribution of COVID-19 cases. Finally, Cordes and Castro (2020) analyzed the relationship between COVID-19 cases in white and black/Hispanic areas, taking into account factors such as income and education. The results showed an inverse correlation between race education and income levels.

The spatial characteristics of large urban areas in Indonesia differ from those of small urban and rural areas, as revealed by this research. The observed patterns include building density, road and transportation connectivity, health facilities, area size, number of trade and business facilities such as shopping centers and office buildings, as well as population density. Cities like Jakarta, Semarang, Surabaya, and Bandung have a relatively higher population density compared to other urban areas in the region. Additionally, the size and density of both residential and non-residential buildings are generally greater in these cities.. According to data from the Regional Central Bureau of Statistics (2020), population density varies widely across Indonesian districts. For example, DKI Jakarta has an average density of 14,555 people/km2, while Depok City has 11,635 people/km2, and South Tangerang City has 8,690 people/km2. Similarly, the population density of cities and regencies on Java Island also varies, with East Java having an average of 826 people/km2, West Java 1,394 people/km2, and Central Java 1,058 people/km2. The figures are quite different in D.I.Yogyakarta, where the population density is 1,227 people/km2. Urban areas outside Java Island tend to have smaller populations. In terms of road connectivity, Central Bureau of Statistics data from 2019 and 2020 show that provincial capitals in Java generally have better road access than those outside the island. For example, DKI Jakarta Province has a road length of 9.78 km/km2, Bandung 7.01 km/km2, Surabaya 8.45 km/km2, and Yogyakarta 8.18 km/km2. In contrast, urban connectivity in regional areas is generally below 1, which means that the length of the available road per km2 is less than 1 km. For instance, in Riau Province, Central Kalimantan, East Java, and Central Sulawesi, the length of available roads are 0.28 km/km2, 0.12 km/km2, 0.87 km/km2, and 0.27 km/km2, respectively. These statistics suggest that urban areas tend to be denser than regional cities, as evidenced by the population numbers, density, and vegetation area percentages.

Previous studies have utilized a variety of techniques to explore the relationship and impact of both spatial and non-spatial variables. These methods range from traditional statistical analyses to spatial measurements, such as the Spatial Error Model (SEM), which considers the interconnectivity of regions as objects of observation. Spatial modeling is based on the first Tobler law of geography, which states that proximity has a stronger influence than distance (Tobler 1970). This suggests that the geographic location can significantly affect data analysis, known as the autocorrelation effect. Scholars such as Anselin, LeSage, Kissling Carl, and Fotheringham have made contributions to the research on spatial autocorrection and regression. Additionally, researchers such as Bekti, Revildy, Lestari, Nalita, Samadi, Asdi, and Weku have advanced spatial regression methods and spatial analysis models in the fields of health and public welfare, including topics such as dengue fever, stunting, poverty, and the human development index. Solakha also examined COVID-19 cases in DKI Jakarta and West Java Provinces using spatial analysis methods in Indonesia. However, previous investigations have mainly used administrative boundaries as spatial variables without considering the spatial characteristics of administrative areas

Metropolitan areas in Indonesia, including DKI Jakarta, Bandung, Surabaya, Semarang, Makassar, and Medan, have seen a higher incidence of COVID-19 cases compared to surrounding regions. Additionally, these cities have experienced a faster rate of case growth. This can be attributed to the fact that urban centers serve as hubs for population growth and case transmission to nearby areas. According to data released by the Regional Statistics Agency in 2020, DKI Jakarta had three times the average number of COVID-19 cases compared to its surrounding regions, with a correspondingly faster growth rate (Covid-19 Emergency Service DKI Jakarta 2021). Similar trends have been observed in other major cities, such as Surabaya, Semarang, and Bandung.

This research focuses on the impact of spatial characteristics on the number and rate of COVID-19 cases in DKI Jakarta Province and its neighboring cities, including Depok, Tangerang, South Tangerang, and Bekasi. The study examines a range of variables, such as building density, road connectivity, the number of health centers, hospitals, and shopping centers/malls, as well as population density. What sets this study apart is its innovative approach of analyzing the distribution and transmission dynamics of COVID-19 cases at the district level, while taking into account the influence of spatial features like building and population densities, road connectivity, and the number of shopping centers

2. Methods

The study was conducted in 85 districts from 5 administrative cities in DKI Jakarta, 2 cities in Banten, and 2 cities in West Java, along with surrounding areas such as Tangerang, South Tangerang, Depok, and Tangerang. The data on COVID-19 cases were collected at one to two-week intervals from January 2020 until the end of August 2021. Various official institutions responsible for managing the pandemic, such as the Regional Statistics Agency, COVID-19 case task forces, and Regional Health Offices, provided the data on COVID-19 case numbers. The data on case increases and decreases were obtained from the COVID-19 cases information center website and Central Statistics Agency for each province and district/city. Spatial characteristics such as building density, connectivity, population density, health centers, hospitals, and shopping centers/malls were organized in a matrix format, as shown in Table 1.

The study investigated the distribution and growth rate of COVID-19 cases across different regions by analyzing thematic maps and scatter plots. To test the relationship between the number and growth rate of cases in each district, Moran's Index was used. A weighted matrix was determined using the Queen's adjacency matrix. The value of Moran's Index was calculated using the equation provided by Lee and Wong (2001).

Table 1. Format of characteristic spatial data.

No	District	Characteristics of spatial variables					
		Building Density	Population Density	Connectivity Index	Number of Health Centers	Number of Hospitals	Number of Shopping Centers
1	Cengkareng	var1.1	var2.1	var3.1	var4.1	var5.1	var6.1
2		var1.2	var2.2	var3.2	var4.2	var5.2	var6.2
.		.	.	.	.	.	.
.		.	.	.	.	.	.
.		.	.	.	.	.	.
85	Setu	. var1.85	. var2.85	. var3.85	. var4.85	. var5.85	. var6.85

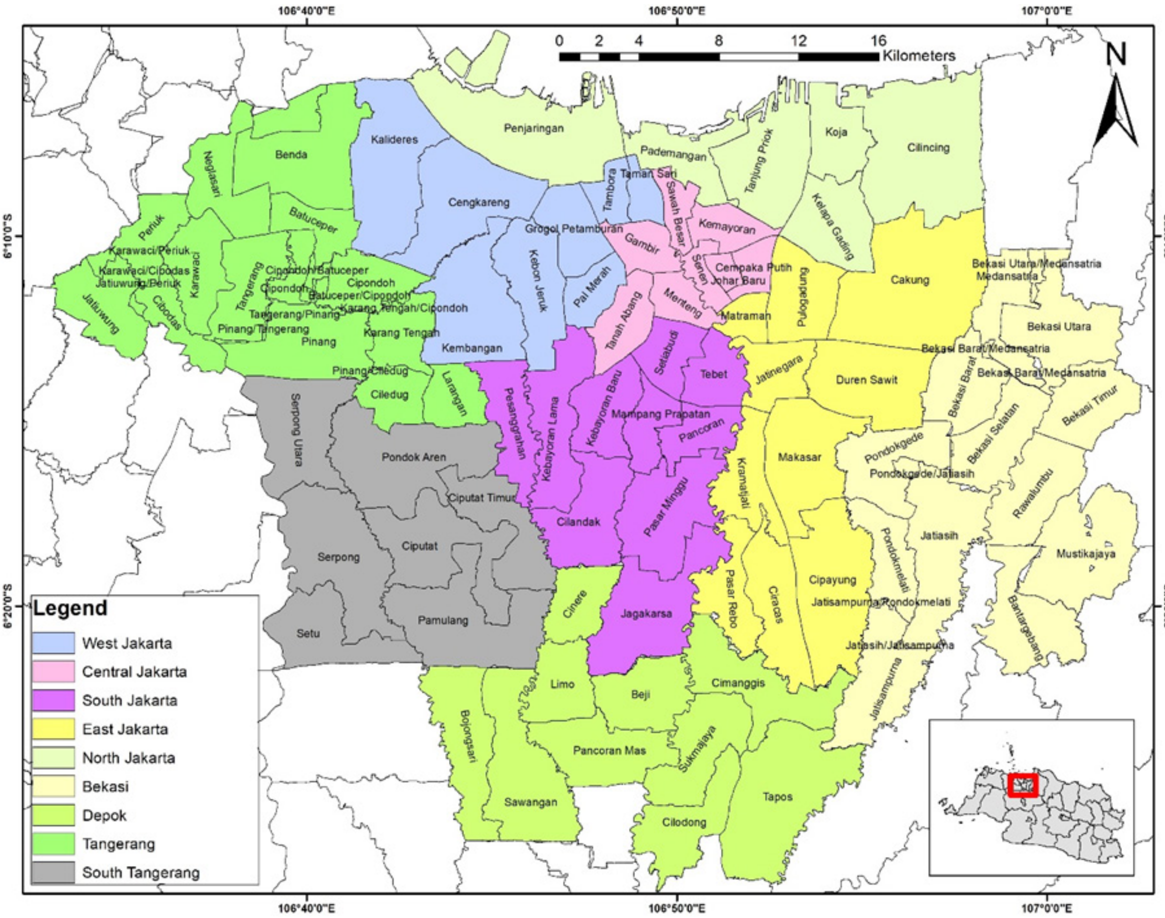


Fig 1. Research location map

$$I = \frac{n}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

n : number of observations
$\bar{x}$: average value of the n locations
x_i : observed value at the i-th location
x_j : observed value at the j-th location
W_{ij}: i-th row j-th column spatial weighting matrix element

The test hypothesis is as follows:
H0: I=0 (No spatial autocorrelation)
H1: I≠0 (There is spatial autocorrelation)

An investigation was conducted to determine if there was a spatial effect on the number and growth rate of COVID-19 cases. Spatial characteristics such as population and building densities, road connectivity, health centers, hospitals, and shopping centers were analyzed using spatial regression, including the Lagrange Multiplier test developed by Yanuari in 2013. This test was used to choose the most suitable spatial regression model, which included the Spatial Autoregressive Model (SAR) and SEM tests as suggested by Bivand et al. in 2021.

The Spatial Autoregressive Test Model assumes that the autoregressive process only applies to the response variable, with y as the response variable, X as the explanatory variable matrix, W as the spatial weight matrix, and ρ as the predictor coefficient of the spatial lag model. The SEM test involves a spatial regression model where $y = X\beta + u$, where $u = \lambda Wu + \varepsilon$, and $\varepsilon = (I - \lambda W)(y - X\beta)$.

The best spatial regression model is evaluated based on factors such as multi-collinearity, strong probability, information criteria R2, and Akaike Information Criteria (AIC).

3. Result and Discussion

Number and distribution rate of cases per district

Distinct patterns have emerged in the distribution of COVID-19 cases across districts in DKI Jakarta, Bekasi City, Depok City, Tangerang City, and South Tangerang. Using the "Natural Breaks Map (Jenks)" classification method, it identified three categories: districts with cases above 2000, between 500-<2000, and less than 500. DKI Jakarta and Bekasi City have a higher concentration of cases categorized as above 2000, while Tangerang, South Tangerang, and Depok Cities have fewer than 500 cases. During January to August 2021, the number of COVID-19 cases per district in DKI Jakarta varied between 500 and 2400 cases, as shown in Figure 2. The Menteng district had the lowest number of cases, while Cengkareng, Duren Sawit, and Tanjung Priok had the highest, with over 2000 cases. During the same period, Bekasi and Depok had an average number of cases per district ranging from 300 to 1650. while, Tangerang and South Tangerang had a relatively low number of cases per district, below 300, as displayed in Figure 3. The West, East, North, and South Bekasi districts had the highest prevalence, with over 1400 cases. These data were obtained from credible sources, including the South Tangerang City COVID-19 Task Force, Depok City Covid-19 Information and Coordination Center, DKI Jakarta Provincial Statistics Agency, Official Information Portal of Covid-19 Tangerang City, Statistics Agency of Bekasi City, Statistics Agency of Depok City, and Statistics Agency of South Tangerang City.

Based on COVID-19 case data collected between January and August 2021 in the research area, four distinct phases were identified in the distribution of cases over time.

The first phase occurred between January and June 2021 and was characterized by a relatively low increase rate of cases. The second phase, which took place from mid-June to early August 2021, saw a significant spike in the number of cases and the third phase occurred from August to early September 2021, during which the rate of cases began to decline. Finally, the normal phase was observed from week II of September to early November 2021, with the addition of cases below 2%, as shown in Figure 4

According to the information presented in Table 2 and Figure 4, it is evident that the cases of COVID-19 in all districts of DKI Jakarta and the surrounding areas increased rapidly from the second week of June 20, 2021. The rate of increase during this period ranged between 10% to 14%. However, Tangerang, South Tangerang, Depok, and Bekasi observed an increase in cases in weeks III and IV of June 2021, specifically on July 5, 2021, with a rise ranging from 10% to 18% per day. The highest accumulation of cases in DKI Jakarta happened in

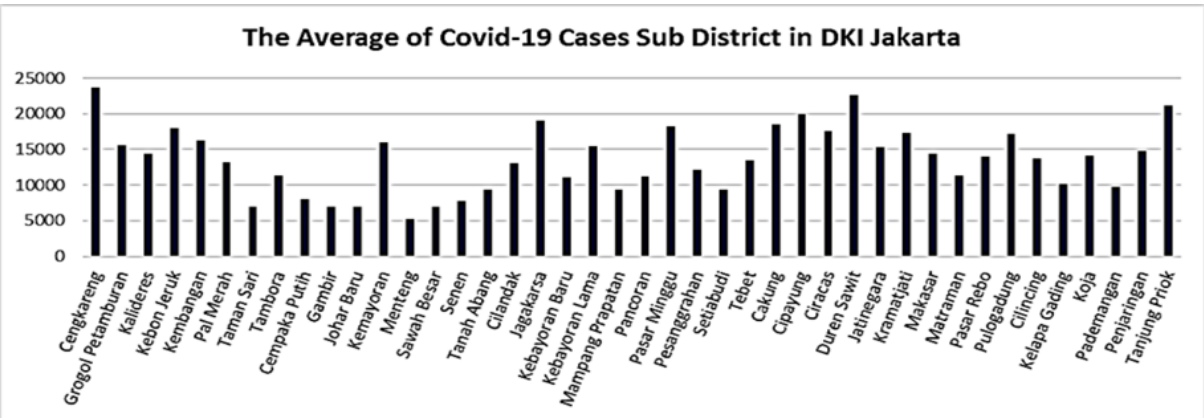


Fig 2. The average number of the COVID-19 cases per district between January to August 2021 in DKI Jakarta

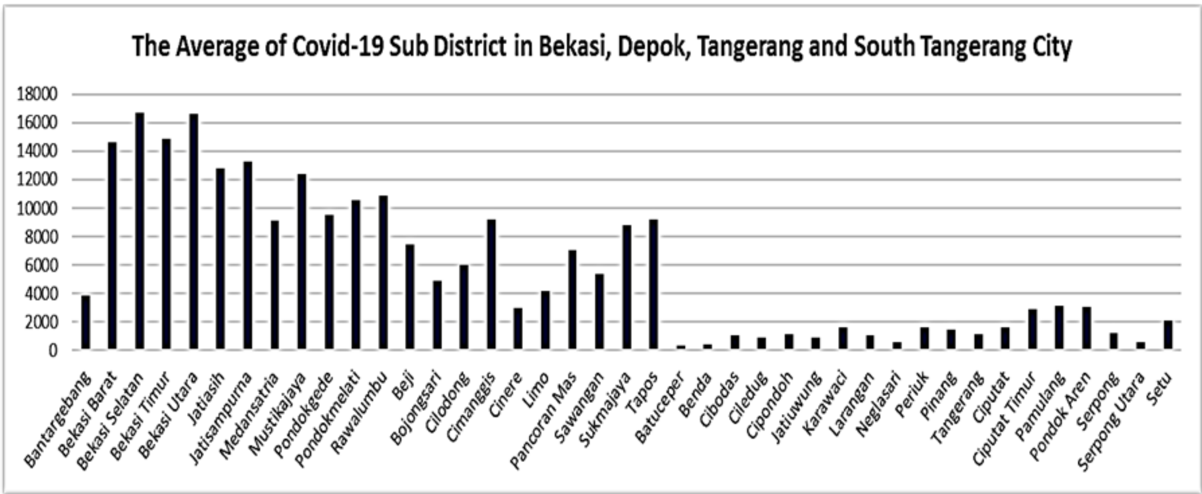


Fig 3. The average number of the COVID-19 cases per district between January to August 2021 in Bekasi, Depok, South Tangerang, and Tangerang cities

weeks II and III of July, while Bekasi and Tangerang cities had the highest cases in weeks II and III of July, respectively. The peak cases of Depok and South Tangerang occurred in week IV of July and week I of August, respectively. These findings suggest that the surge in DKI Jakarta cases occurred one week earlier than in other cities.

During July 2021, all districts in DKI Jakarta witnessed an increase in COVID-19 cases, with growth rates ranging from 10.39% to 14.61%. This rise was due to non-native residents of DKI Jakarta and surrounding regions who went on extended vacations and then returned home. The virus may have spread through ongoing interaction during work hours, as well as commuting to and from work.

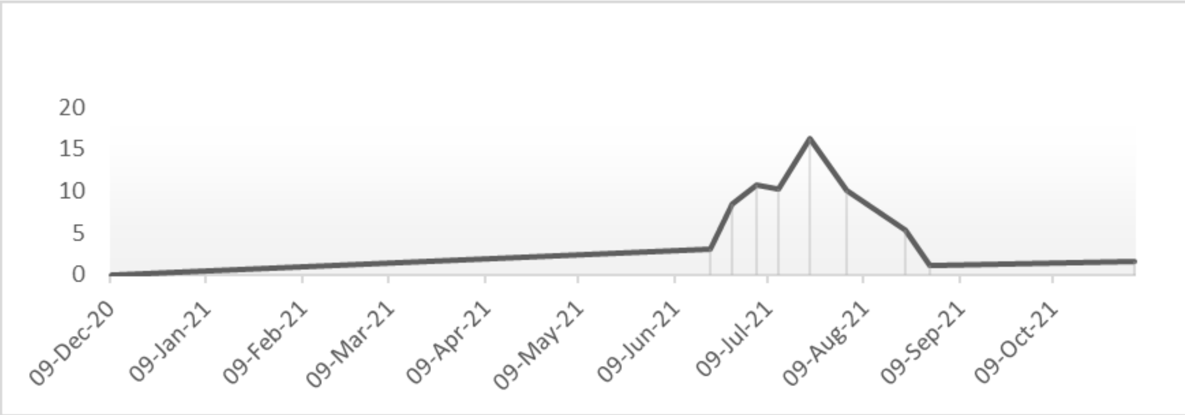


Fig 4. The increased rate pattern of the COVID-19 cases from 9-Dec-20 to 4-Nov-21

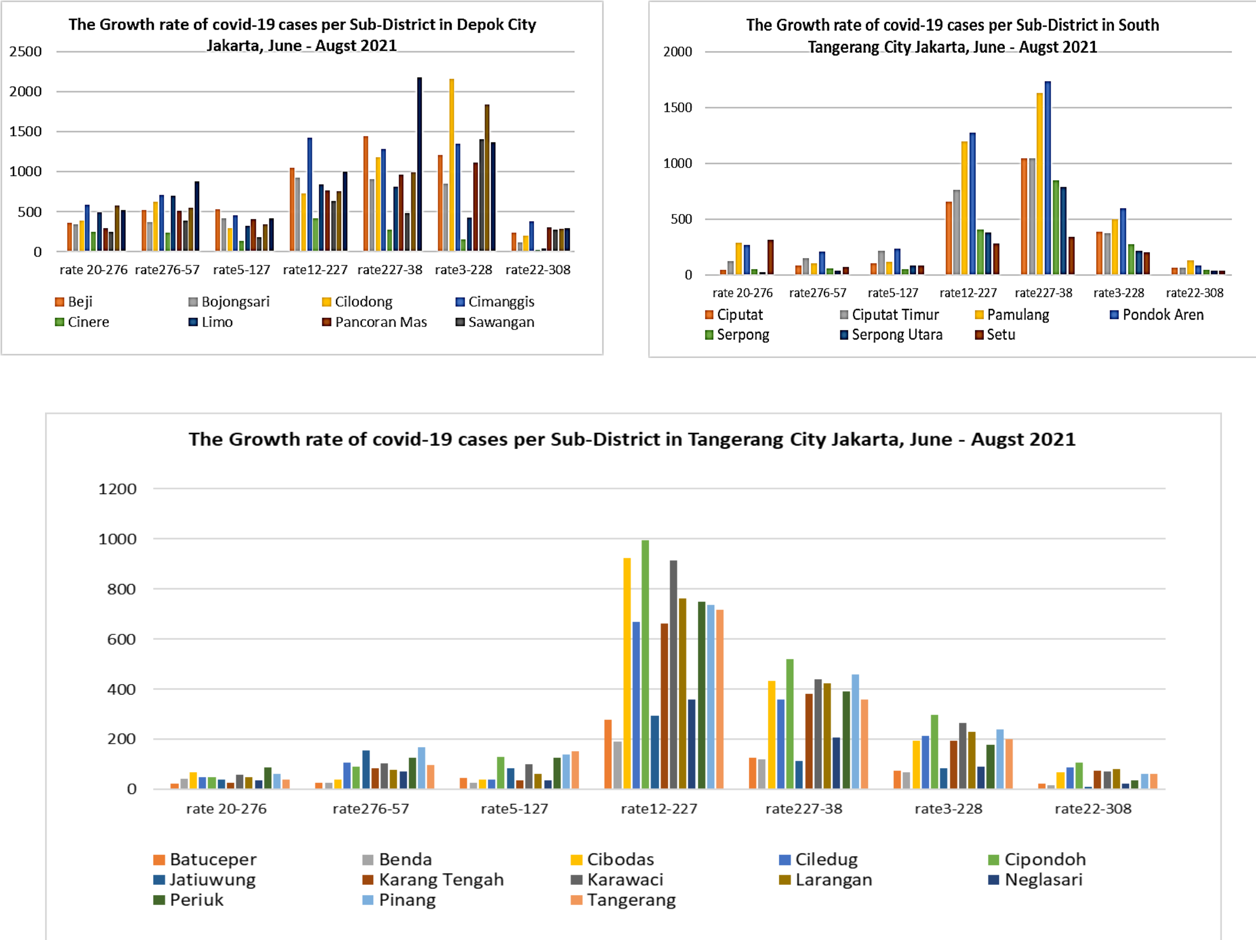


Fig 5. Rate of the COVID-19 Cases Increase per district in DKI Jakarta and Surrounding Areasbetween June to August 2021

Table 2. Rate of the the COVID-19 cases between January to November 2021

City	January - June (%)	June week III-IV (%)	July week I-II (%)	July week II-III (%)	July week III-IV (%)	August week I-II (%)	August week II-III (%)	August week III-IV (%)	August - Nov week I (%)
West Jakarta	3.25	10.58	13.77	14.24	11.56	5.06	2.11	0.28	0.78
Central Jakarta	3.03	8.99	12.94	12.45	11.98	4.95	2.36	0.38	1.20
South Jakarta	3.39	8.09	12.62	12.37	13.65	6.30	3.06	0.50	0.95
East Jakarta	3.39	9.95	12.99	13.76	11.75	6.09	2.93	0.38	0.76
North Jakarta	3.21	10.28	12.82	14.32	11.23	5.69	2.51	0.63	1.36
DKI Jakarta	3.58	10.39	14.26	14.61	13.30	6.20	2.89	0.46	1.18
Bekasi	3.11	6.12	7.24	5.65	9.55	5.87	6.15	1.17	1.69
Depok	2.91	7.84	9.32	5.56	12.00	12.09	11.86	2.06	0.56
Tangerang	2.73	6.20	10.06	7.45	18,40	16.73	8.37	2.57	2.23
South Tangerang	2.50	7.66	5.40	6.67	15.92	11.57	8.88	1.55	3.70

Data processing results

Based on the information presented in Figure 5 and Table 2, it was noticed that the rate of COVID-19 cases in DKI Jakarta and its neighboring areas began to decline in week IV on July 12, 2021, at a daily rate of 6.30%. The decrease persisted until the conclusion of August, with a daily reduction of 0.28%. Conversely, the initial drop in cases in Tangerang, South Tangerang, Depok, and Bekasi occurred during week III of August 2021. The data suggests that the rise and fall of COVID-19 cases in DKI Jakarta occurred earlier than in the surrounding cities. This implies that DKI Jakarta serves as the focal point of COVID-19 cases in the neighboring regions, including Bekasi, Depok, South Tangerang, and Tangerang regions, including Bekasi, Depok, South Tangerang, and Tangerang.

Distribution pattern of cases per district

The number of COVID-19 cases in various districts between December 2020 and August 30, 2021, was analyzed using the Natural Breaks Map method. The method categorized the districts into three groups: Class 1, with the fewest cases, Class 2, with more cases than Class 1, and Class 3, with the highest number of cases. From December 2020 to June 2021, the number of COVID-19 cases per district consistently ranged between 1,300 to 10,000 cases. Tangerang and South Tangerang cities were consistently classified as Class 1, while DKI Jakarta and Bekasi districts were categorized as Class 2 and Class 3. However, from the third week of July until the end of August 2021, several districts in DKI Jakarta, Bekasi, and Depok saw a surge in the number of cases, ranging from 6,700 to 16,000 cases

The data on COVID-19 cases from January to August 2021 in various districts has been analyzed and divided into five groups, as shown in Table 3. Group I includes districts that consistently reported a high number of cases (H). Group II consists of districts that changed from a high category to a medium category (H-M). Group III includes districts that always had a moderate number of cases (M). Similarly, Group IV consists of districts that changed from a medium category to a low category (M-L). Lastly, Group V represents the district with the lowest number of COVID-19 cases (L) for eight consecutive months**Table 3**. Total Distribution Category of the COVID-19 Cases in the Research Area

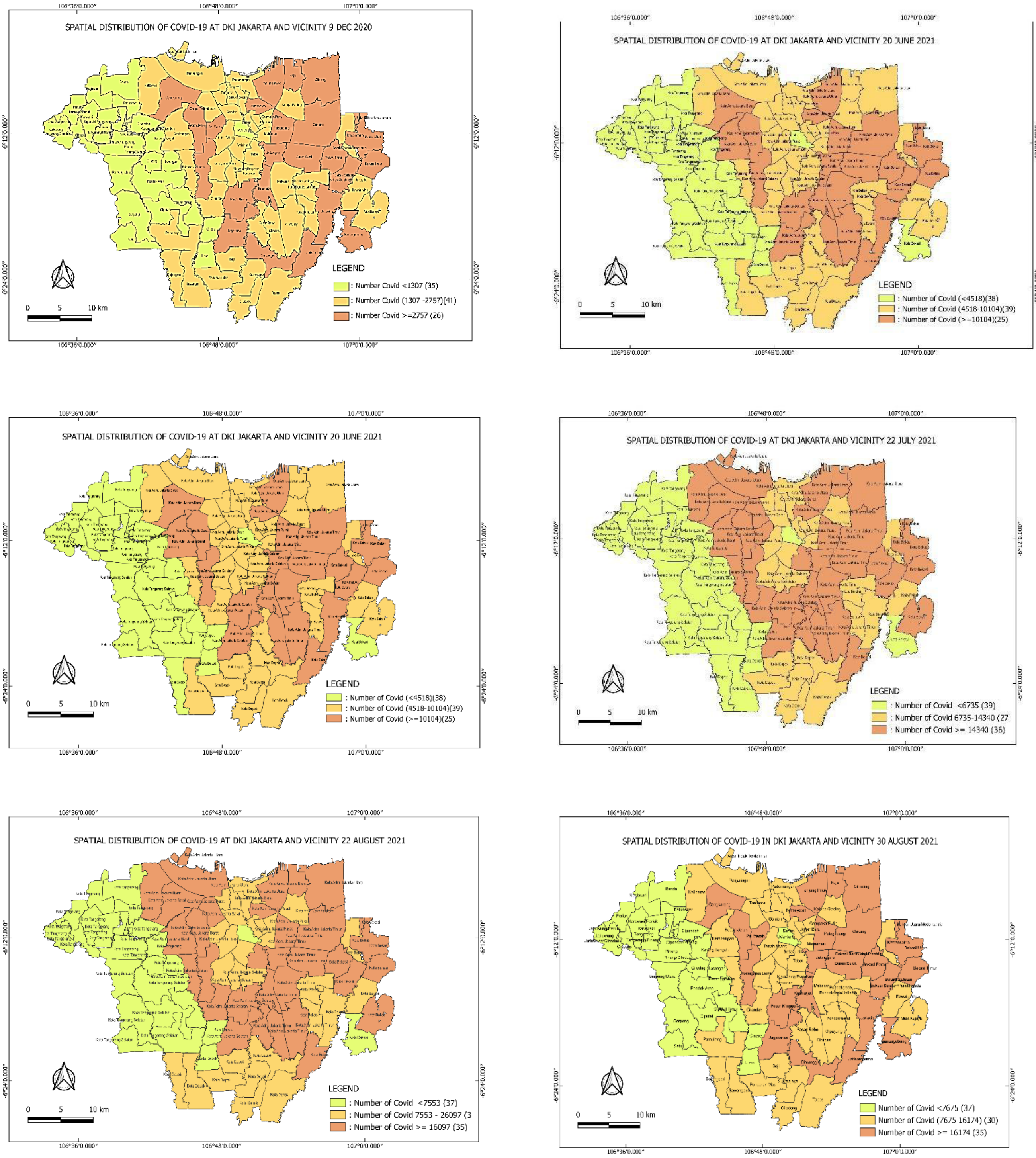


Fig 6. Distribution Pattern of the COVID-19 cases per district in the research area

No	Category	Description	District
1	Relatively Height (H)	The number of the COVID-19 cases is always in the high group position (brown color) during the period 9-12-2020 to 30-8-2021 from 3 classes according to the "Natural Breaks Map" classification.	**DKI**: Kabayoran Lama4. Duren Sawit4. Jagakarsa4. Jatinegara4. Kebun Jeruk4. Cengkareng4. Pasar Minggu4. Kemayoran4. Kramajati4. Pulogadung4. Cakung4. Tanjung Priok4. **Bekasi**: Jatisampurna4. West Bekasi4. North Bekasi4. South Bekasi4.
2	Relatively High - Medium (H-M)	The number of COVID-19 cases has changed. From high to medium during 9-12-2020 to 30-8-2021 from 3 classes according to the "Natural Breaks Map" classification.	**DKI:** Cilincing3t1m, Koja3t1m. Pal Merah2tm. Pasar Rebo2tm. Kembangan3t1m. pesanggrahan2tm. tebet2tm. grogol petamburan2tm. Penjaringan2tm. cilandak3t1m. Kalideres2tm. ciracas3t1m. Kampung Makasar3t1m. cipayung3t1m. **Bekasi:** Medansatria1t3m. Jatiasih2tm. East Bekasi3t1m. Mustikajaya2tm. **Depok:** Cimanggis1t3m.
3	Relatively Medium (M)	The number of the COVID-19 cases is always in the medium group position during the period 9-12-2020 to 30-8-2021 from 3 classes according to the "Natural Breaks Map" classification.	**DKI:** Pademangan4. Matraman4. Sawah Besar4. Mampang Prapatan4. Tamansari4. Tambora4. Gambir4. Pancoran4. Kebayoran Baru4. Kelapa Gading4. Senen4. Cempaka Putih4. Tanah Abang4. Setiabudi4. Johar Baru4. **Bekasi**: Pondok Gede4. Pondok Melati4. Rawalumbu4 **Depok**: Tapos4. Sukmajaya4. Beji4.Cilodong4. Pancoran Mas4.
4	Relatively Medium– Low (M-L)	The number of the COVID-19 cases has changed from medium to low from 9-12-2020 to 30-8-2021 from 3 classes according to the "Natural Breaks Map" classification.	**Depok:** Bojongsari2mr. Sawangan3m1r. **Tangerang:** Pamulang1m3r.
5	Relatively Low(L)	The number of the COVID-19 cases is always at a low position during the period of 9-12-2020 to 30-8-2021 from 3 classes according to the "Natural Breaks Map" classification.	**DKI**: Menteng4. **Bekasi**: Bantargebang. **Depok**: Cinere4. Limo4. **Tangerang**: Neglasari4. Pondok Aren4. Benda4. Cibodas4. Cipondoh4. Jatiuwung4. Karawaci4. Batuceper4. Ciledug4. Pinang4. Karang Tengah4. Tangerang4. Larangan4. Periuk4. **South Tangerang**: Serpong4. East Ciputat4. Ciputat4. North Serpong4. Setu4.

The changes in the H-M or M-L group categories per unit of time were influenced by the policies of the central and local governments to curb the spread of COVID-19 cases. These policies included LSSR, CARE, and the policy of accelerating mass vaccination. The LSSR policy was implemented in Jabodetabek on April 10, 2020, and it effectively suppressed the increase in COVID-19 cases. However, the spike in cases occurred at the end of May due to the Eid al-Fitr holiday, which fell on May 17, 18, and 19, 2021. This was further exacerbated by people returning to their hometowns in weeks III and IV of May from DKI Jakarta, leading to a spike in cases in week III of June 2021. To address this, the government implemented a CARE policy on Java islands and Bali, which began on July 3, 2021. The implementation had a positive effect, resulting in a decrease in the rate of cases from the end of July until November 2021. This was in line with the research by Junaedi et al. (2022), which found that vaccination, especially dose 2, and CARE policy significantly affected the increase in COVID-19 cases, deaths, and recoveries. The effect on recovery was higher than additional cases and deaths. In addition to government policies, other factors that significantly affected the pattern of COVID-19 case distribution were people's interactions during working hours in several cities, including Tangerang, South Tangerang, Depok, and Bekasi, who work in DKI Jakarta every day. This condition had the potential for dispersion in COVID-19 cases in neighboring cities in DKI Jakarta. Furthermore, the type of land use and the location of the districts concerned also affected changes in the number of cases. Based on the land use mapping, the districts included in the high category had land cover dominated by offices, warehouses, business/trading areas, and self-help (planned) settlements, as well as relatively densely populated.

The COVID-19 Cases Task Force has reported an increase in new cases of the SARS-CoV-2 virus in Indonesia, originating from offices or work environments with poor air circulation, lack of social distancing, and failure to wear masks. Menteng, a district in DKI Jakarta, is an exception to this trend, as it has had consistently low case numbers due to its relatively small population, high education levels, and socio-economic status. Although the government's policies have been successful, strict monitoring and continuous evaluation are necessary, particularly in districts with high (H) cases. Local governments at the city, district, village, and neighborhood levels should intensively promote compliance with the 3W guidelines: Wear a mask, Wait for a distance, and Wash hands, as well as accelerate vaccination campaigns to achieve herd immunity

Spatial analysis of cases distribution per district

Based on the results of the Moran index spatial autocorrelation test, the increase in the number and growth rate of COVID-19 cases from January to August 2021 in each municipality in DKI Jakarta Province and its surroundings was influenced by the number and rate of COVID-19 cases in neighboring or adjacent municipalities. Adjacent municipalities with the same value tend to cluster, which is measured based on significant global and local Moran Index values with a confidence level of 5%. Table 4 shows that all Moran Index values are greater than I0 = -0.01 (Moran's expected value), which means that the number and growth rate of COVID-19 cases have positive autocorrelation or are spatially clustered.

Moran's Scatterplot, shown in Figures 7 and 8, visually displays the clustering and distribution patterns between locations. It reveals the relationship between standardized observed values at a location and the average values from neighboring locations (Lee and Wong 2001). The scatterplot is divided into four Quadrants (Portobello and Haddad 2003):

- Quadrant I (High-High) represents districts with high COVID-19 cases surrounded by districts with similarly high cases.
- Quadrant II (Low-High) represents districts with low COVID-19 cases surrounded by districts with high cases.
- Quadrant III (Low-Low) represents districts with low COVID-19 cases surrounded by districts with similarly low cases.
- Quadrant IV (High-Low) represents districts with high COVID-19 cases surrounded by districts with low case

During the examination of clusters utilizing Moran's Scatterplot, it was discovered that the research zone exhibited spatial groupings or clusters. COVID-19 case growth rates were divided into Quadrants I and III, as evidenced by Figures 7 and 8. From the first week of January until the second week of July 2021, most districts in DKI Jakarta and Bekasi were classified in Quadrant I, indicating a substantial spatial correlation among districts with high COVID-19 case growth rates and their surroundings. In contrast, Tangerang, South Tangerang, and Depok were placed in Quadrant III, suggesting that the districts in these cities had a generally low COVID-19 case growth rate. The grouping pattern remained dominated by Quadrants I and III from week IV of July until the end of August 2021. However, a few districts, specifically Cinere, Mampang Prapatan, Limo, Rawalumbu, Jatisampurna, and Setiabudi, were also included in Quadrant II.

Table 4. Spatial autocorrelation of the Moran's Index for the number of confirmed the COVID-19 in DKI Jakarta and surrounding areas

Number of Cases (dd/mm/yy)	Moran's Index	Growth Rate (dd/mm/yy)	Moran's Index
9-12-2020	0.717	9/12/2020 – 20/6/2021	0.683
20-6-2021	0.713	20/6/2021 – 27/6/2021	0.633
27-6-2021	0.708	27/6/2021 – 05/7/2021	0.157
05-7-2021	0.705	05/7/2021 – 12/7/2021	0.622
12-7-2021	0.696	12/7/2021 – 22/7/2021	0.435
22-7-2021	0.675	22/7/2021 – 03/8/2021	0.482
03-8-2021	0.669	03/8/2021 – 22/8/2021	0.594
22-8-2021	0.669	22/8/2021 – 30/8/2021	0.542
30-8-2021	0.671		

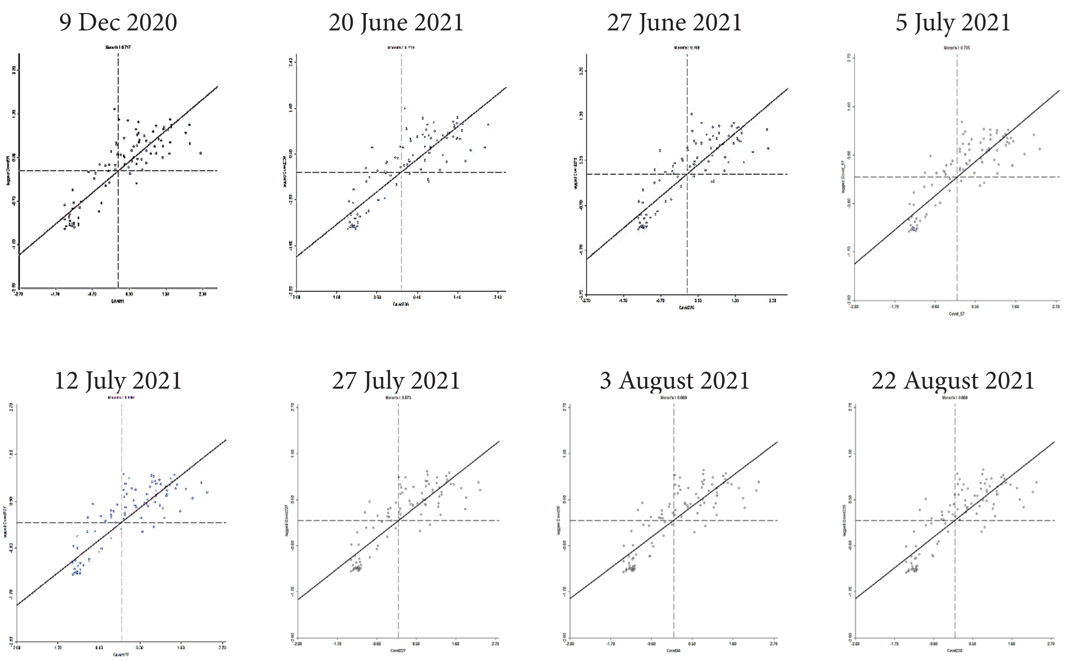


Fig 7. Moran's Scatterplot on the Number of the COVID-19 Cases in Dec 2020 – August 2021

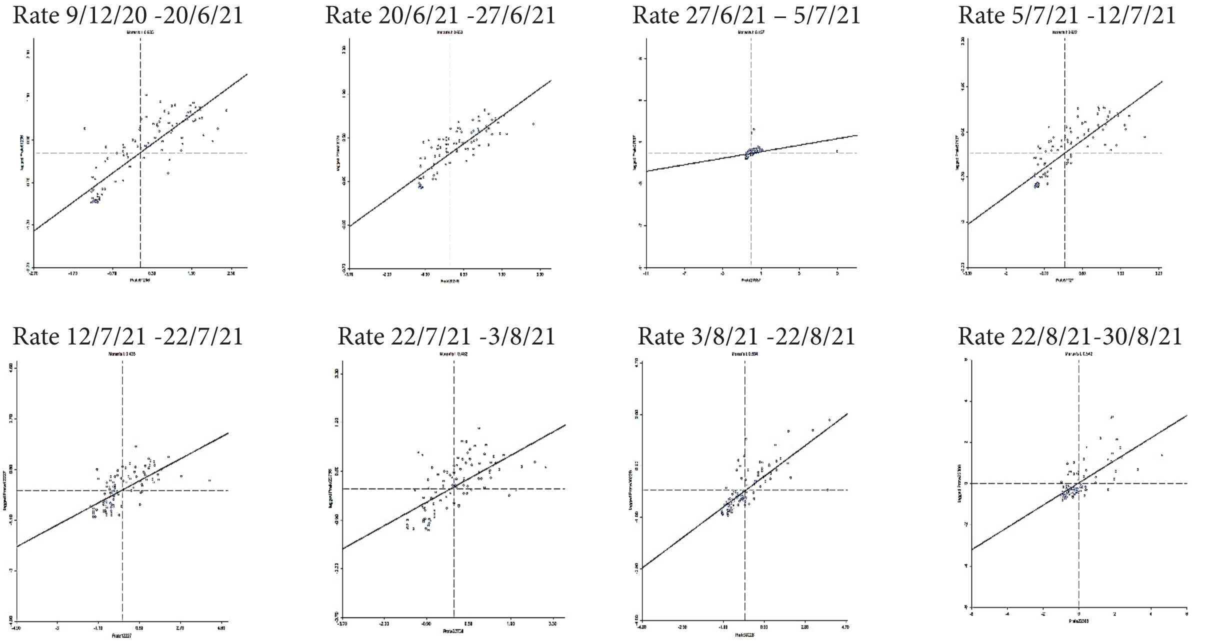


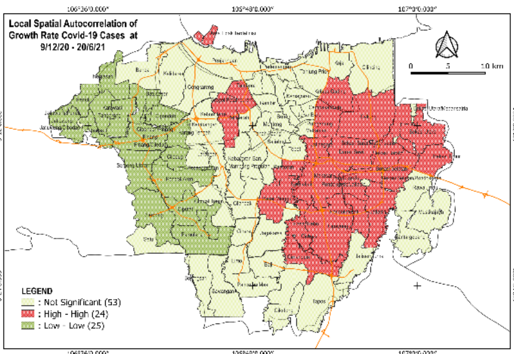
Fig 8. Moran's Scatterplot on the Growth Rate of the COVID-19 Cases in Dec 2020 – August 2021

Table 5. Spatial Grouping of the COVID-19 Cases Increase Rate

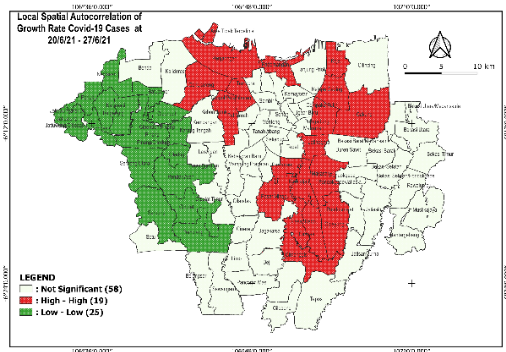
No	(dd/mm/yy)	LISA Cluster Rate of the COVID-19 Cases Increase per district	
1	9/12/20 – 20/6/21	**High - High**:	Includes :Kebun Jeruk, Grogol Petamburan, Pasar Minggu , Pancoran, Jatinegara, Cakung Kampung Makasar, Pasar Rebo, Duren Sawit, Ciracas, Kramatjati, Cipayung, Pulogadung, Kelapa Gading, Jatiasih, Pondok Melati, West, South, North, and East Bekasi, Pondok Gede, Medan Satria, and Cimanggis
		Low – Low:	Districts that have a low number of COVID-19 cases are surrounded by districts that also have a low number of COVID-19 cases. Includes: Tangerang, Cipondoh, Neglasari, Ciledug, Cibodas, Pinang, Periuk, Jatiuwung, Karawaci, Karang Tengah, Batuceper, Pondok Aren, Serpong, Pamulang, North Serpong, and Ciputat
2	20/6/21 - 27/6/21	**High - High**:	Cengakreng, Kebun Jeruk, Grogol Petamburan, Pasar Minggu, Pancoran, Jatinegara, Cakung Kampung Makasar, Pasar Rebo, Ciracas, Kramatjati, Cipayung, Pulogadung, Kelapa Gading, Pademangan, Koja, Penjaringan, and Cimanggis
		Low – Low:	Tangerang, Cipondoh, Neglasari, Ciledug, Cibodas, Pinang, Periuk, Jatiuwung, Karawaci, Karang Central, Batuceper, Pondok Aren, Serpong, Pamulang, North Serpong, and Ciputat
4	05/7/21 – 12/7/21	**High - High**:	Tambora, Cengkareng, Kebun Jeruk, Pal Merah, Grogol Petamburan, Kemayoran, Cempaka Putih, Tebet, Mampang Prapatan, Pasar Minggu , Pancoran, Jatinegara, Cakung Kampung Makasar, Pasar Rebo, Duren Sawit, Ciracas, Kramatjati, Pulogadung, Cilingcing, Kelapa Gading, Pademangan, Koja, and Penajringan
		Low – Low:	Tangerang, Neglasari, Ciledug, Cibodas, Pinang, Periuk, Jatiuwung, Karawaci, Karang Tengah, Batuceper, Pondok Aren, Serpong, Pamulang, North Serpong, and Ciputat
5	12/7/21 – 22/7/21	**High – High**:	Cengkareng, Kebun Jeruk, Grogol Petamburan, Cilandak, Pasar Minggu, Pancoran, Jatinegara, Cakung Kampung Makasar, Pasar Rebo, Ciracas, Kramatjati, Pulogadung, Kelapa Gading, and Cimanggis
		Low – Low:	Tangerang, Neglasari, Ciledug, Cibodas, Pinang, Periuk, Jatiuwung, Karawaci, Batuceper, Pondok Aren, Serpong, Pamulang
		Low – High:	Cinere, and Mampang Prapatan
6	22/7/21 – 03/8/21	**High- High**:	Jagakarsa, Pasar Minggu, Jatinegara, Cakung Kampung Makasar, Pasar Rebo, Duren Sawit, Ciracas, Kramatjati, Jatisampurna, West Bekasi, Medan Satria, Cimanggis, Sukmajaya, Beji, Cilodong. East Ciputat, and Ciputat
		Low – Low:	Gambir, Tangerang, Cipondoh, Neglasari, Benda, Cibodas, Pinang, Periuk, Jatiuwung, Karawaci, Center Karang, and Batuceper
		Low – High:	Cinere
7	03/8/21 – 22/8/21	**High - High**:	Pasar Rebo, South Bekasi, Bantar Gebang, Medan Satria, Cimanggis, Sukmajaya, Pancoran Mas, Tapos, Beji, and Cilodong.
		Low – Low:	Tambora, Gambir, Senen, Tangerang, Cipondoh, Neglasari, Ciledug, Cibodas, Pinang, Periuk, Jatiuwung, Karawaci, Center Karang, and Batuceper
		Low – High:	Limo, Rawalumbu, and Jatisampurna.

8	22/8/21 – 30/8/21	**High - High**:	Cipayung, Jatisampurna, West and North Bekasi, Medan SatriaCimanggis, Sukmajaya, Pancoran Mas, Tapos, Beji, and Cilodong
		Low– Low:	Tambora, Gambir, Senen, Matraman, Neglasari, Benda, Cibodas, Periuk, Jatiuwung, and Batuceper,
		Low – High:	Cakung and Limo,
		High – Low:	Setiabudi

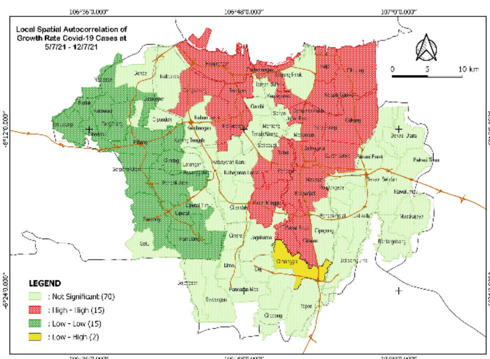
Spatial Grouping Pattern 9/12/20 – 20/6/21



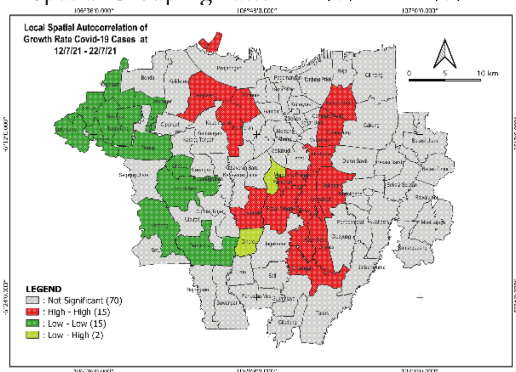
Spatial Grouping Pattern 20/6/21 – 27/6/21



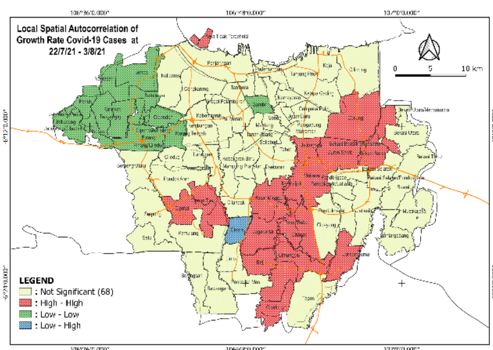
Spatial Grouping Pattern 5/7/21 – 12/7/21



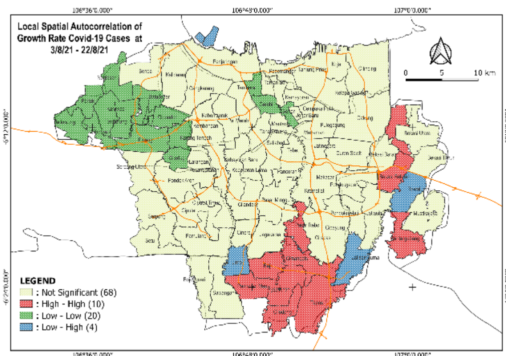
Spatial Grouping Pattern 12/7/21 – 22/7/21



Spatial Grouping Pattern 22/7/21 – 3/8/21



Spatial Grouping Pattern 3/8/2 – 22/8/21



Spatial Grouping Pattern 22/8/21 – 30/8/21

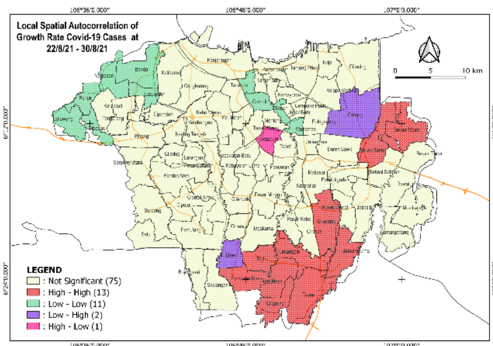


Fig 9. The pattern of Spatial Grouping between Districts

Based on the data presented in Table 5 and Figure 9, it appears that from January to June 2021, two significant groupings emerged at a 5% confidence level. These groupings were found in Quadrants I (High-High) and III (Low-Low). In January 2021, 24 districts in East Jakarta and Bekasi City were included in the Quadrant I group, while 25 districts in Tangerang and South Tangerang cities were included in Quadrant II. During this time, the growth rate of COVID-19 cases in Quadrant I (High-High) ranged from 3.30% to 3.62%, while in the "Low-Low" group, it ranged from 2.19% to 2.98%. As of June 2021, the number of districts in Quadrant I had decreased, with Bekasi no longer significantly included in Quadrant I and an increase in West Jakarta. The specific district names can be found in Table 5. Moving on to the first and second weeks of July 2021, three groupings emerged: Quadrants I, II, and III. The average growth rate of COVID-19 cases in Quadrant I was 13.35%, while in Quadrant III it was 7.45%, and in Quadrant II, Cimanggis Depok had an average growth rate of 4.99%. In week III of July 2021, there was a high growth rate in cities around the province of DKI Jakarta, with an average of 13.31%, while districts had an average growth rate of 12.13%.

In the first and second weeks of July 2021, three groupings occurred, namely Quadrants I, II, and III. The growth rate of COVID-19 cases in Quadrant I averaged 13.35%, and III was 7.45%, while in Quadrant II, Cimanggis Depok had an average of 4.99%. In week III of July 2021, cities around the province of DKI Jakarta showed a high growth rate, with an average of 13.31%, while districts had an average growth rate of 12.13%.

Based on the results, from the fourth week of July to the end of August, there was a decreasing rate of COVID-19 cases in the research area. Generally, the grouping pattern was divided into three groups, namely High-High, Low-Low, and Low-High. The grouping distribution in Quadrant I (High-High) was concentrated in Depok and Bekasi, while the Quadrant III group occurred in Tangerang city. The Quadrant II group occurred in the districts of Limo, Depok, and Cakung East Jakarta. By the end of August, only Setiabudi was included in group IV (High-Low)

Spatial regression model

The significance of the spatial regression model in reflecting field conditions is determined by the P-value, with a smaller value indicating greater significance (0.05 being the standard). The best spatial regression model is identified by considering three indicators - AIC, R2, and Adjusted R2. The model with the smallest AIC, highest R2, and highest Adjusted R2 values is the best. The pattern of the spread of COVID-19 in the study area, as shown in Table 7, has two characteristics. When there is a spike in the increase of COVID-19 cases, the SAR regression model is suitable. Conversely, when the rate of spread of COVID-19 shows a pattern of decline or stable growth, the SEM regression model is applied. The results from the LM test indicate significant autocorrelation (Moran's Index P-value < 0.05) - see Table 6.

Table 6. Lagrange Multiplier test results

No	Dd/mm/yy	Moran's Index (error)		Lagrange Multiplier (lag)		Lagrange Multiplier (error)	
		Statistic	P-Value	Statistic	P-Value	Statistic	P-Value
1	9/12/20 – 20/6/21	9.9212	0.00000	84.2748	0.00000	80.5882	0.00000
2	20/6/21 - 27/6/21	5.8660	0.00000	47.7076	0.00000	26.3981	0.00000
3	27/6/21 – 5/7/21	1.0320	0.30207	0.8647	0.35243	0.3153	0.57446
4	05/7/21 – 12/7/21	4.3685	0.00001	34.9762	0.00000	13.8401	0.00020
5	12/7/21 – 22/7/21	3.7653	0.00017	11.9114	0.00056	9.9172	0.00164
6	22/7/21 – 03/8/21	8.4476	0.00000	53.6189	0.00000	57.4865	0.00000
7	03/8/21 – 22/8/21	10.2264	0.00000	85.3481	0.00000	85.8590	0.00000
8	22/8/21 – 30/8/21	8.9039	0.00000	65.6759	0.00000	64.2236	0.00000

Table 7. Comparison of Model Goodness Measure Values

No	Dd/mm/yy	AIC		R^2		Adjusted R2	
		LM (Lag)	*LM* (error)	*LM* (Lag)	*LM* (error)	*LM* (Lag)	*LM* (error)
1	9/12/20 – 20/6/21	1819.91	1818.97	0.802507	0.811965	0.705695	0.00000
2	20/6/21 - 27/6/21	1410.63	1424.28	0.807204	0.787184	26.3981	0.00000
3	27/6/21 – 5/7/21	1790.93	1789.57	0.188815	0.181485	0.3153	0.57446
4	05/7/21 – 12/7/21	1510.91	1525.40	0.836125	0.818435	13.8401	0.00020
5	12/7/21 – 22/7/21	1547.97	1546.66	0.669859	0.674896	9.9172	0.00164
6	22/7/21 – 03/8/21	1464.63	1456.73	0.600655	0.638413	57.4865	0.00000
7	03/8/21 – 22/8/21	1458.34	1451.94	0.603319	0.628067	85.8590	0.00000
8	22/8/21 – 30/8/21	1165.18	1164.03	0.460727	0.457407	64.2236	0.00000

The growth rate of COVID-19 cases was affected by certain spatial variables, which were analyzed using two models. The SAR model examined the impact of the number of health centers and road connectivity. On the other hand, the SEM model analyzed the influence of the number of health centers, buildings, and population densities.

The SAR that was formed is expressed below:

Y = -18,8899 + 177,858 (number of health centers) – 86969,6 (road connectivity) + 0.524039Wy

The SEM regression model is:

Y = -596.655 + 87.1975 (number of health centers) – 68186.6 (road connectivity) - 0.00938007 (population density) + 4.73125(building density) + 0.699409

where:

Y : The rate of COVID-19 cases increases

The spatial regression models show that the coefficient of spatial variables is negative, which means that an increase in these variables is likely to decrease the number of COVID-19 cases and vice versa. The SAR and SEM models were significantly used in DKI Jakarta Province, Bekasi Regency, Tanggerang City, Tangsel, and Depok City at a real level of 10%. The spatial regression model indicates that areas with higher building density and a greater number of health centers tend to have a higher number and rate of COVID-19 cases. Conversely, areas with lower road connectivity and population density tend to have fewer cases, and the number of additional COVID-19 cases is lower. According to the SAR and SEM regression models, spatial variables such as the number of health centers, road connectivity, building density, and population density significantly influence the growth rate of COVID-19 cases. The SAR model suggests that the rate of COVID-19 cases increases as the number of community health centers increases but decreases as road connectivity increases. On the other hand, the SEM models show that increasing the number of health centers and building density reduces COVID-19 cases, while higher population density and lower road connectivity lead to more cases.

4. Conclusion

A study conducted on COVID-19 cases in DKI Jakarta and surrounding areas found that the density of buildings and the number of health centers in an area were directly proportional to the number and rate of cases. Conversely, areas with low road connectivity and population density had fewer cases. The rate of COVID-19 cases in DKI Jakarta changed in four phases, with the pandemic peaking from mid-June to early August 2021. The district was the epicenter of COVID-19 cases in neighboring areas such as Bekasi, Depok, South Tangerang, and Tangerang. The study also revealed that the number and rate of cases per district were influenced by neighboring cities or spatial autocorrelation between districts, as demonstrated by the significant global and local Moran's Index values. Spatial factors such as the number of health centers, road connectivity, building density, and population density had a significant impact on the distribution pattern of COVID-19 cases in DKI Jakarta and surrounding areas. The study found that the more the number of health centers and the denser the building, the higher the number and rate of cases in the district. In contrast, as the connectivity and accessibility of roads decreased, the number and rate of cases also declined alongside the reduction in population density.

The government policy of implementing LSSR and CARE from July 3, 2021, positively impacted the rate of COVID-19 cases in DKI Jakarta and surrounding areas. The findings of the study can be used to formulate integrated policies to combat COVID-19 cases in DKI Jakarta, Tangerang, South Tangerang, Depok, Bekasi (JABEDETA), and other cities in Indonesia.

Acknowledgement

This research was conducted with supervision, technical and substantial assistance from Cluster Research of Quality Environmental and Risk Management, School of Environmental Science, Universitas Indonesia.

References

Anderson, O. 2021. “Estimasi Tingkat Kerentanan Permukiman Terhadap COVID-19 Berbasis Informasi Geografis (Studi Kasus: Kota Jakarta Utara).” Doctoral dissertation, Institut Teknologi Sepuluh Nopember.

Anselin, Luc. 2009. “Spatial Regression.” *The SAGE Handbook of Spatial Analysis* 1: 255–76.

Bekti, Rokhana Dwi. 2012. “Autokorelasi Spasial Untuk Identifikasi Pola Hubungan Kemiskinan Di Jawa Timur.” *ComTech: Computer, Mathematics and Engineering Applications* 3 (1): 217–27.

Bivand, Roger, Giovanni Millo, and Gianfranco Piras. 2021. “A review of software for spatial econometrics in R. ” *Mathematics*, 9(11), 1276.

Cholidah, Lilih, Djamuludin Ancok, and Haryanto Haryanto. 1996. “Hubungan Kepadatan Dan Kesesakan Dengan Stres Dan Intensi Proposal Pada Remaja Di Pemukiman Padat.” *Psikologika: Jurnal Pemikiran Dan Penelitian Psikologi* 1 (1): 56–64.

Cordes, Jack, and Marcia C Castro. 2020. “Spatial Analysis of COVID-19 Clusters and Contextual Factors in New York City.” *Spatial and Spatio-Temporal Epidemiology* 34: 100355.

Covid-19 Emergency Service DKI Jakarta. 2021. “Covid-19 Emergency Service DKI Jakarta 2020-2021.” 2021.

Depok City Covid-19 Information and Coordination Center. 2021. “Data Covid-19 on 2020-2021.” 2021. https://ccc-19.depok.go.id/index.php/Data/index.

DKI Jakarta Provincial Statistics Agency. 2021. “Covid-19 2020 and 2021 on DKI Jakarta.” 2021. https://jakarta.bps.go.id/subject/30/kesehatan.html#subjekViewTab3.

Fotheringham, A Stewart. 2009. “‘The Problem of Spatial Autocorrelation’ and Local Spatial Statistics.” *Geographical Analysis* 41 (4): 398–403. https://doi.org/10.1111/j.1538-4632.2009.00767.x.

Franch-Pardo, Ivan, Brian M Napoletano, Fernando Rosete-Verges, and Lawal Billa. 2020. “Spatial Analysis and GIS in the Study of COVID-19. A Review.” *Science of The Total Environment* 739: 140033.

Gross, Bnaya, Zhiguo Zheng, Shiyan Liu, Xiaoqi Chen, Alon Sela, Jianxin Li, Daqing Li, and Shlomo Havlin. 2020. “Spatio-Temporal Propagation of COVID-19 Pandemics.” *Europhysics Letters* 131 (5): 58003.

Guliyev, Hasraddin. 2020. “Determining the Spatial Effects of COVID-19 Using the Spatial Panel Data Model.” *Spatial Statistics* 38 (August): 100443. https://doi.org/10.1016/j.spasta.2020.100443.

Hardianto, Jonathan. 2020. “Korelasi Kepadatan Penduduk Dan Penyebaran COVID19.” 2020.

Junaedi, Dedi, Muhammad Rizal Arsyad, Faisal Salistia, and Moh Romli. 2022. “Menguji Efektivitas Vaksinasi Covid-19 Di Indonesia.” *Reslaj: Religion Education Social Laa Roiba Journal* 4 (1): 120–43.

Kissling, W Daniel, and Gudrun Carl. 2008. “Spatial Autocorrelation and the Selection of Simultaneous Autoregressive Models.”

Global Ecology and Biogeography 17 (1): 59–71. https://doi.org/https://doi.org/10.1111/j.1466-8238.2007.00334.x.

Kucharski, Adam J, Timothy W Russell, Charlie Diamond, Yang Liu, John Edmunds, Sebastian Funk, Rosalind M Eggo, et al. 2020. "Early Dynamics of Transmission and Control of COVID-19: A Mathematical Modelling Study." *The Lancet Infectious Diseases* 20 (5): 553–58. https://doi.org/https://doi.org/10.1016/S1473-3099(20)30144-4.

Lee, Jay, and David W S Wong. 2001. *Statistical Analysis with ArcView GIS*. New York: John Wiley & Sons.

Official Information Portal of Covid-19 Tangerang City. 2021. "Covid 19 2020 – 2021 Tangerang City." 2021. https://covid19.tangerangkota.go.id/.

Perobelli, Fernando Salgueiro, and Eduardo Amaral Haddad. 2003. "An Exploratory Spatial Data Analysis of Brazilian Interregional Trade." *São Paulo: Nereus*.

Revildy, Windy David, Siti Sarah Sobariah Lestari, and Yollanda Nalita. 2020. "Pemodelan Spatial Error Model (Sem) Angka Prevalensi Balita Pendek (Stunting) Di Indonesia Tahun 2018." In *Seminar Nasional Official Statistics*, 2020:1224–31.

Samadi, Hari, and Yudiantri Asdi. 2017. "Penerapan Model Regresi Spasial Dalam Menentukan Faktor-Faktor Yang Mempengaruhi Indeks Pembangunan Manusia Di Kabupaten/Kota Provinsi Sumatera Barat." *Jurnal Matematika UNAND* 6 (4): 80–89.

Solakha, Zahrotul Amalia. 2020. "Analisis Multilevel Terhadap Kasus Covid-19 Di Provinsi Banten, Dki Jakarta Dan Jawa Barat." In *Seminar Nasional Official Statistics*, 2020:171–81.

South Tangerang City COVID-19 task force. 2021. "Covid-19 Task Force South Tangerang City." 2021. https://lawancovid19.tangerangselatankota.go.id/.

Statistics Agency of Bekasi City. 2021. "Covid-19 on 2020-2021 Bekasi City." 2021. https://bekasikota.bps.go.id/subject/30/kesehatan.html#subjekViewTab3.

Statistics Agency of Depok City. 2021. "Covid 19 on 2020-2021 Depok City." 2021. https://depokkota.bps.go.id/subject/30/kesehatan.html#subjekViewTab3.

Statistics Agency of South Tangerang City. 2021. "Covid 19 on 2020-2021 South Tangerang City." 2021. https://tangselkota.bps.go.id/indicator/30/33/1/jumlah-puskesmas-balai-pengobatan-dan-rumah-bersalin-menurut-kecamatan.html.

Sukarna, S, and W Sanusi. 2019. "Analisis Autokorelasi Moran's I, Geary's C, Getis-Ord G, Dan LISA Serta Penerapannya Pada Penderita Kusta Di Kabupaten Gowa." Doctoral dissertation, Universitas Negeri Makasar.

Tobler, W R. 1970. "A Computer Movie Simulating Urban Growth in the Detroit Region." *Economic Geography* 46 (sup1): 234–40. https://doi.org/10.2307/143141.

Weku, Winsy Christo Deilan. 2020. "Eksplorasi Efektifitas Model Spasial Untuk Menjelaskan Hubungan Antara Penduduk Dan Infrastruktur Terhadap Kesejahteraan Masyarakat Kota Manado." *AITI* 17 (2): 130–42.

Xiong, Yongzhu, Yunpeng Wang, Feng Chen, and Mingyong Zhu. 2020. "Spatial Statistics and Influencing Factors of the Novel Coronavirus Pneumonia 2019 Epidemic in Hubei Province, China." *Spatial Statistics* 38 (100443). https://doi.org/10.21203/rs.3.rs-16858/v2.

Yanuari, A. 2013. "Perbandingan Pengujian Efek Spasial Dengan Lagrange Multiplier Dan Robust Lagrangemultiplier Pada Pemilihan Model Regresi Dependensi Spasial." Doctoral dissertation, Universitas Brawijaya.