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Mapping the Epidemic: Did Population Density and Mobility Affect the Number of Covid-19 Cases? Evidence from Yogyakarta City and Its Surrounding Areas

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Abstract

Mobility reduction is believed to effectively reduce the spread of Covid-19 disease by lowering the SARS-COV-2 transmission in the population. A big data platform consists of a big scale of anonymized smartphone location data collected by Citydash.ai and presented as mobility data during the pandemic time to help humanity control the spreading of Covid-19 in Indonesia. This research aims to find the relation between mobility and population density to the spread of Covid-19 in Yogyakarta City and its surrounding areas, Indonesia, by using GIS to visualize the mobility, population density and Covid-19. This research also used a simple correlation method by making a cross-tabulation of the data to verify the relation between variables. This research found that mobility into Yogyakarta City and its surrounding area relates to its Covid-19 spread. At the same time, this research also found that mobility inside the area, mobility out of the area, and population density did not relate to the expansion of Covid-19 in Yogyakarta City and its surrounding areas. This anomaly should be considered in the Covid-19 mitigation or similar diseases to help public health, data-driven decision-making, and improving community response to Covid-19.

Keywords: Big Data; Covid-19; Epidemic Governance; Mobility Mapping; Yogyakarta

1. Introduction

Covid-19 give new challenges to urban health, economic, and social aspect. The covid-19 pandemic is a negative phenomenon and has negatively affected urban living systems (Abbas et al., 2021). Various urban living aspects from people's lifestyle, economy, and mobility patterns received a big impact from that pandemic. Mobility patterns and population density are believed to be some factors that caused the spread of Covid-19 so cities or urban areas that usually had high mobility have become the gateway of SARS-COV-2 viruses (Abdul-Rahman et al., 2020). As a result, governments in various parts of the world are trying to reduce mobility using any means possible to prevent the spread of the Covid-19 virus.

The preventive measures are different in any country such as lockdown (Armillei et al., 2020; Baser, 20201) social distancing (Brauer et al., 2021) mobility reduction (Carteni et al., 2020) etc. but before the preventive measure could be taken, there is a need to understand the cause of Covid-19 spread. Various ways can make Covid-19 spread but the most suspected factor is people's mobility from one place to another (Brauer et al., 2021; Coccia, 2020; Guzman et al., 2021). Other factors suspected to be the cause of Covid-19 vulnerability are population number and density where both allow movement and mobility to occur to, within, and out of any region (Hakim et al., 2021; Jiang et al., 2021).

While there is nothing can be done to reduce population number and density quickly and massively, there is a way to reduce people's mobility. One of the means to reduce people mobility done by governments in various part of the world are through lockdown and other movement restriction policies. Similar policies

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have also been implemented by governments in Asia with China and Indonesia as examples. Indonesian government applied social restrictions from travel bans to community activities restrictions (PPKM) which was done five times from the first time Covid-19 was confirmed in Indonesia (March 2020) to the end of 2020. As a matter of fact, mobility is strongly attached to the cultural system of Indonesian society where Indonesian people have high kinship values so people tend to meet each other either between friends or family.

That cultural value has created an annual phenomenon called mudik which occurs on holidays such as Eid and Christmas where Indonesians return to their hometown to get in touch with their family and friends. The mudik phenomenon will be hard to restrain because of the plentiful mobility actors moving from and to all regions in Indonesia especially within Java. The phenomenon is feared to be a new source of Covid-19 transmission, so the Indonesian government tried various means to prevent the mobility. Nevertheless, the number of Covid-19 cases in Indonesia keeps increasing that in July 2021, Indonesia became the country with the most Covid-19 cases in Southern Asia. The Covid-19 cases in Indonesia peaked in 2021 by July 15th with 56,757 cases confirmed on that day. It is known by the date that it is not the peak yet as on February 16th, 2022 the daily confirmed case for that day was 64,718 cases.

The Indonesian government has tried to control the number through community activities restriction (PPKM). To support the government in restraining the spread of Covid-19, this paper tries to analyze how people respond to the policy. This paper also tries to examine whether variables mentioned by other researchers, such as mobility and population density, contribute to the spread of Covid-19 in Indonesia especially Java with the samples of Yogyakarta city and its surrounding area. This paper hopes to enrich the science of planning and governmental data-driven decision-making about understanding the pandemic with the aim to build a resilient city. This paper also hopes to contribute in enriching the data gathering methods in planning sciences by using anonymized smartphone location big data collected by citydash.ai.

It is known that planners have difficulty acquiring data as it is often unavailable, time-consuming and high-cost surveys are needed to get it, or there is limited access to data. Utilization and testing of the use of big data in planning mean planners can cut the cost and time in the data gathering process so the plan-producing process is more efficient and accurate than using data gathered through statistical and sectoral approaches (Jones et al., 2019). Therefore, this study aims to show and test how mobility patterns and population density relates to the number of Covid-19 case by introducing how we use mobility big data, population data, and the number of Covid-19 data. We also tried to figure the mobility of Yogyakarta and its surroundings resident before and after PPKM was applied.

2. Research Method

2.1. Data Sources

Indonesian community and government have tried to respond to the spread of SARS-COV-2 viruses. The Indonesian government has issued a restriction policy on people's mobility and Indonesia's residents have complied with the approach to a certain degree while also applying health protocols to themselves. But there are geographical dan heterogeneity challenges that tackle the policy to be applied in every region of Indonesia. Therefore, to understand the people's mobility patterns and how far Indonesian residents have complied with the policy, mobility change in the form of mobility percentage in Indonesia's regions needs to be considered which in this paper the regions referred to are Yogyakarta City and its surrounding areas.

The data about mobility was measured by using the average number of individual movements in Yogyakarta City and its surrounding areas recorded on their smartphones. This data was gathered and processed by citydash.ai into a percentage of average mobility. This average mobility data used are in the mids pandemic phase in the middle of 2020 and early 2021. Those data were then mapped and used to show how Yogyakarta City and its surrounding areas residents complied with the PPKM policy by comparing both time frames. The population density data can be accessed from the Statistics Indonesia for Yogyakarta Province portal. That data was also mapped with the year used was 2020. The number of Covid-19 cases data in the study area can be accessed from Yogyakarta Province's, Yogyakarta City's, Bantul Regency's dan Sleman Regency's Health Department portal.

2.2. Number of Covid-19 Cases, Population Density, and Mobility Change

The number of Covid-19 cases is sourced from each Health Department of the regencies in the study area. The number of Covid-19 cases used is in the sub-district level, which is categorized into five levels i.e very low, low, medium, high, and very high. The classification used equal interval method to give equal classes of sub-district within the study area. The classified Covid-19 number of cases was then mapped to figure the Covid-19 expansion in Yogyakarta City and its surrounding areas.

The population density in this paper uses the population density in the sub-district levels. These data were also classified into five levels as proposed by Munawir (Khavarian-Garmsir et al., 2021) which start from very sparse, sparse, medium, dense, and very dense. Population density that has been mapped and has locational meaning is seen as residents crowding location and also reflect their activity.

In this research, mobility change was measured as a percentage of mobility change to the baseline (2020 before the outbreak). We also categorized the percentage of mobility change into five classes: very low, low, medium, high, and very high by using the equal interval method. The measured mobility is in the administrative area unit of sub-district. The mobility used are the average of 2020 May and 2021 January.

The number of Covid-19 cases, population density, and mobility were then integrated into GIS to figure the mobility patterns according to population density and the number of Covid-19 cases. The result of the integration was then visualized as a map to give a general description about the influence of mobility patterns and population density on the Covid-19 number of cases by using descriptive analysis. See Figure 1 for specific research flow.

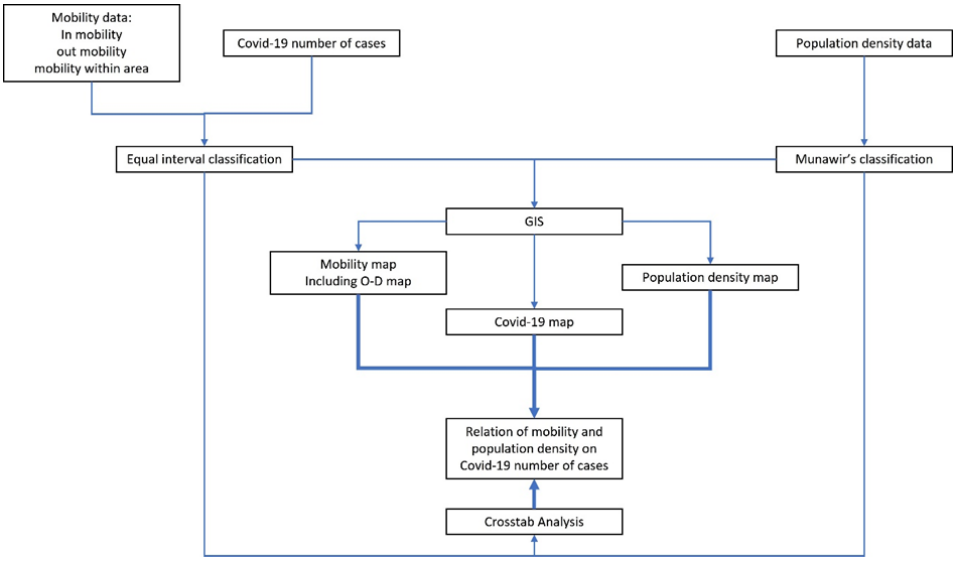


Figure 1. Research Flow

2.3. Correlation Analysis

To give more credibility to the descriptive analysis of the visualization, we then use a simple correlation analysis to see the correlation between population density, mobility, and Covid-19 number of cases. To do that, we did a crosstabulation method using the SPSS application to see the levels spread between variables and then we also used the Sig. The results are variables that correlate to Covid-19 number of cases in Yogyakarta City and its surrounding areas (Figure 1).

2.4. Study Area

This study was conducted at Yogyakarta City and its surrounding area i.e. Bantul and Sleman Regency, Special Region of Yogyakarta located in Indonesia. The area consists of 48 sub-districts which is home to 2,523,629 inhabitants. Figure 2 below is the map of the study area.

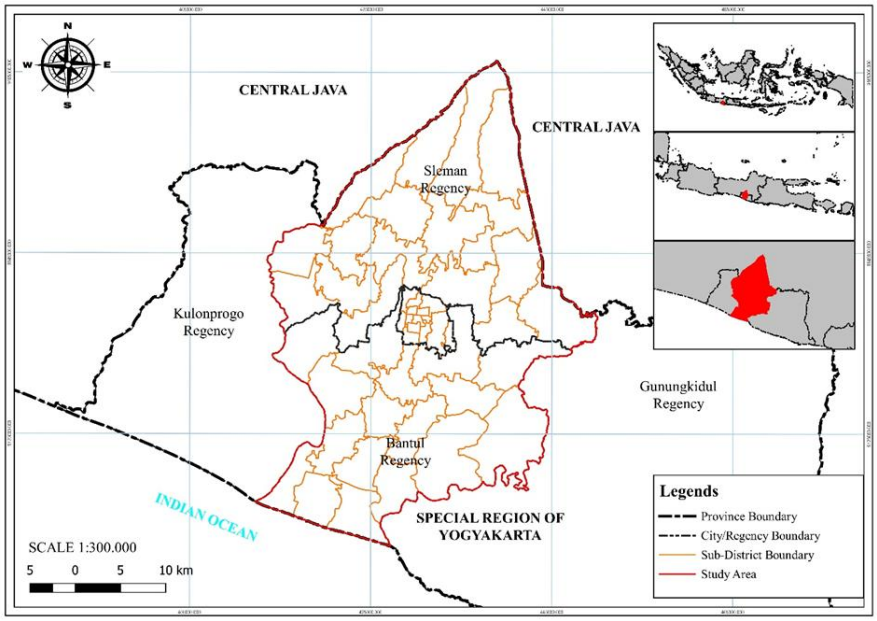


Figure 2. Study Area

3. Result and Discussion

3.1. Covid-19 Number of Case and Mobility Relation Model

We use the origin and destination matrix to model the mobility patterns and changes and then map them to visualize the patterns. Figure 3 shows the origin and destination models of mobility in Yogyakarta City and its surrounding areas in May 2020 (Figure 3a) and January 2021 (Figure 3b) with the thickness of the line showing the percentage of mobility. Figure 3a shows that in May 2020, the highest out-of-sub-district mobility percentage occurred from Turi in Sleman Regency to Gondomanan in Yogyakarta City, about 18.8% to 23.5% from the baseline. The second highest out-of-sub-district mobility occurred from the sub-district around Gondomanan (Danurejan, Mergangsan, Pakualaman, Kraton, and Ngampilan) to Gondomanan and from Gondokusuman to Depok with 14.1% to 18.8% mobility. We also found out that most sub-districts rarely make any movement out of themselves aside from the sub-district mentioned before.

Figure 3 also shows the mobility within the sub-district using its administration area color. Figure 3a shows that in May 2020, the highest mobility within the sub-district occurred in Gondomanan in Yogyakarta City and Srandakan in Bantul Regency which occurred between 26.5% to 31.3% from the baseline. This is followed by Gedongtengen in Yogyakarta City, Depok in Sleman Regency, and Pundong in Bantul Regency with average mobility intensity between 21.8% to 26.5% more than the baseline. Another thing we found was the capital of both regencies: Sleman Sub-district and Bantul Sub-district were included as sub-district with the lowest and low mobility within the sub-district which in fact, both capitals still belong to the Metropolitan Area of Yogyakarta.

Figure 3b shows that there was some increase in the number of mobility especially the out-of-sub-district mobility in January 2021. The quantity of out-of-sub-district mobility was increased as the highest mobility average became 27.4%-34.2% and more sub-districts were included in a higher class than in May 2020 (Figure 3a). The number of sub-districts included as the highest class also increased to 6 (Danurejan, Mergangsan, Pakualaman, Kraton, Ngampilan, and Turi) but with only one destination: Gondomanan. Mobilities between these sub-districts were also followed by an increase in movement from 27 other sub-districts towards Gondomanan. The 27 sub-districts are classified as having a high percentage of mobility by 20.5% and 27.4%. The percentage in this group has also increased from the previous range of 14.1% to 18.8%. The most notable thing in 2021 was more mobility from any sub-district to another sub-district.

In contrast to the increased out-of-sub-district mobility, the mobility within the sub-district decreased if viewed from the movement class. It also has no significant increase in mobility percentage compared to May 2020. Figure 3a shows that in May 2020, there were two sub-districts classified as having the highest mobility within themselves i.e. Gondomanan and Srandakan with 26.5% to 31.3% mobility while there were three sub-districts classified as having high mobility i.e. Gedongtengen, Depok, and Pundong. The decrease can be seen in Figure 3b as there were fewer sub-districts classified as highest and high with almost no differences in the number of mobility percentage classes.

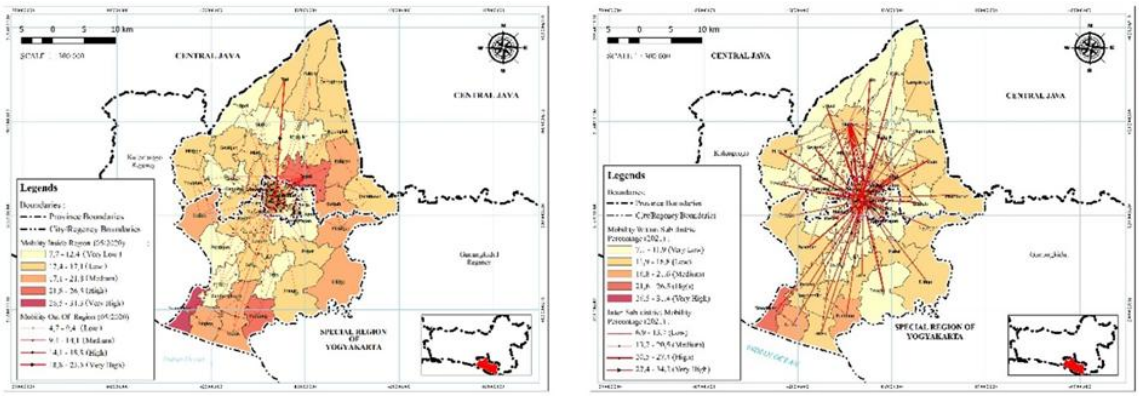


Figure 3. Yogyakarta Mobility Model (a) 2020 and (b) 2021

The results of these models were then used to determine their relation to the number of Covid-19 cases in Yogyakarta City and surrounding areas by using a cross-tabulation method. Table 1. below shows the spread of Covid-19 and the spread of inter-sub-district mobility especially the 'inward mobility'. Sub-districts with the lowest inward mobility tend to have the lowest and low number of Covid-19 cases. The Chi-Square test used to test the relation between the two variables also shows the Chi-Square Asymp. Sig. 0 which means there is a relation between the mobility into a sub-district (inward mobility) with the number of Covid-19 cases in those sub-districts.

Table 1. Cross-Tabulation of In Mobility and Covid-19 Number of Cases in Yogyakarta City and Its Surrounding Area

		Number of Covid-19 Cases					Total
		Lowest	Low	Medium	High	Highest	
In Mobility	Lowest	24	10	1	1	0	36
	Low	1	2	3	2	0	8
	Medium	1	0	0	0	0	1

	High	0	0	0	0	1	1
	Highest	1	1	0	0	0	2
Total		27	13	4	3	1	48

Furthermore, the same method can be used to see the relation between mobility out-of-sub-district and the number of Covid-19 cases. Table 2. below is the cross-tabulation of those variables mentioned before and we can discover that the spread is varied. The Chi-Square Test also shows Chi-Square Asymp. Sig. value is 0.638 which is more than 0.05. That means there is no relation between mobility out-of-sub-district and the number of Covid-19 cases. It is also supported by the fact that the Pearson Chi-Square value is 13.477 which is under the table x2 shows there is no relation between the two.

Table 2. Cross-Tabulation of Out Mobility and Covid-19 Number of Cases in Yogyakarta City and Its Surrounding Area

		Number of Covid-19 Cases					Total
		Lowest	Low	Medium	High	Highest	
Out Mobility	Lowest	6	3	0	0	1	10
	Low	15	5	3	3	0	26
	Medium	2	4	1	0	0	7
	High	2	1	0	0	0	3
	Highest	2	0	0	0	0	2
Total		27	13	4	3	1	48

The relation between the mobility within sub-district and the Covid-19 number of cases were also cross-tabulated. Table 3. shows the cross-tabulation result which consists of a varied spread of variables just as the cross-tabulation in Table 2. The Chi-Square test shows Chi-Square Asymp. Sig. value at 0.542 which means there is no relation between the mobility within sub-district and the number of Covid-19 cases.

Table 3. Cross-Tabulation of Mobility Within Sub-District and Covid-19 Number of Cases in Yogyakarta City and Its Surrounding Area

		Number of Covid-19 Cases					Total
		Lowest	Low	Medium	High	Highest	
Mobility Within Sub-District	Lowest	8	7	4	3	0	22
	Low	14	6	0	0	1	21
	Medium	3	0	0	0	0	3
	High	1	0	0	0	0	1
	Highest	1	0	0	0	0	1
Total		27	13	4	3	1	48

The crosstabulation results showed that not all mobility related to the spread of Covid-19 in Yogyakarta City and its surrounding areas. These findings showed similar results to previous studies that stated that mobility has impact on Covid-19 spread (Abdul-Rahman et al., 2020; Baser, 2021; Guzman et al., 2021). The difference between this study from the other was this study is more specific on what mobility that related to the spread of Covid-19.

3.2. Covid-Number of Cases and Population Density Relation Model

As shown in Figure 4a, the sub-districts in Yogyakarta City are the most densely populated compared to the sub-districts in the regency surrounding it. Yogyakarta City has 14 sub-districts that 12 of them classified as very densely populated with more than 100 person/ha population density while the other two classifies as densely populated with 50-100 person/ha. The regencies surrounding Yogyakarta City (Sleman and Bantul) don't have any sub-district that belong to the very dense class. Only one sub-district (Sewon in Bantul) belongs to the dense class while the other sub-districts are categorized as medium and sparsely populated. The population density map of Yogyakarta can be seen in Figure 4a.

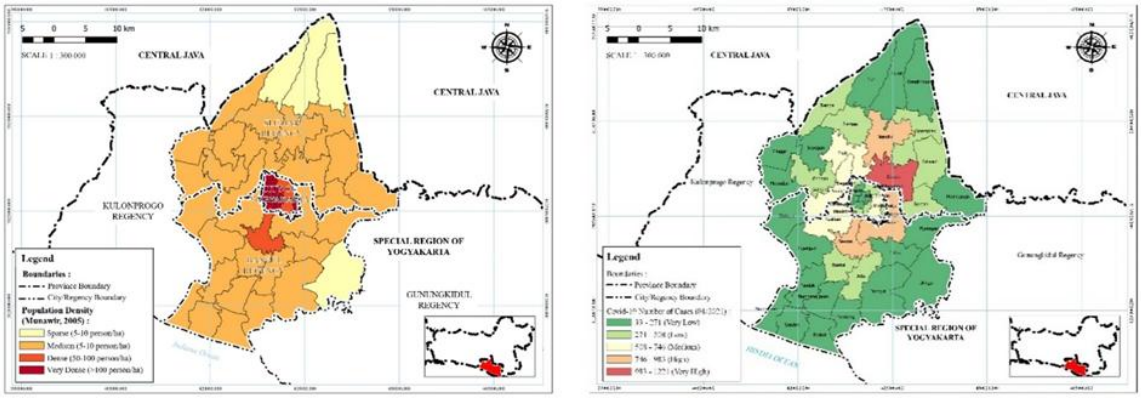
We also test the relation between population density and the number of Covid-19 cases in those sub-districts. The cross-tabulation in Table 4. shows there is no clear spreading pattern. The Chi-Square test also shows the Chi-Square Asymp. Sig. value 0.326 which means there is no relation between the population density and Covid-19 number of cases. This is also supported by the Pearson Chi-Square value 13.608 which is below the table x2. The result was in contrast to previous studies which stated that population density has a relation to the spread of Covid-19 (Hakim et al., 2021; Jiang et al., 2021).

Table 4. Cross-Tabulation of Population Density and Covid-19 Number of Cases in Yogyakarta City and Its Surrounding Area

		Number of Covid-19 Cases					Total
		Very Low	Low	Medium	High	Very High	
Population Density	Sparse	4	0	0	0	0	4
	Medium	15	8	3	2	1	29
	Dense	0	1	1	1	0	3

	Very Dense	8	4	0	0	0	12
Total		27	13	4	3	1	48

The absence of a relation between population density and the Covid-19 number of cases can also be concluded if the population density map (Figure 4a) and the Covid-19 number of case map (Figure 4b) are compared. The sub-districts which have dense or very densely populated in Yogyakarta City have low or very low Covid-19 number of cases. There is only one sub-district that has a dense population and a high Covid-19 number of cases namely Sewon in Bantul. The sub-district that has the highest Covid-19 number of cases in fact did not belong to the dense or very dense class.



(a) *(b)*

Figure 4. (a) Population Density Map; and (b) The Number of Covid-19 Cases Map of Yogyakarta City and Its Surrounding Area

3.3. Public Compliance with Mobility Policies

The Indonesian government has issued several policies about mobility with aims to mitigate or control the expansion of Covid-19. Provincial or regency-level governments then used those policies as a base for issuing mobility policies unique to their territory. In this research, the study areas are Yogyakarta City and its surrounding area thus they obey the policy issued by Sultan Hamengkubuwono X, the head of Yogyakarta Palace and its governor. Therefore, this section of discussion is describing how the residents of Yogyakarta City and its surrounding areas comply with Sultan's policy.

The policy applied in Yogyakarta City and its surrounding areas is those issued by the Indonesian government and Sultan Hamengkubuwono X as Yogyakarta governor which is different from the lockdown and social distancing applied in other regions of the world (Armillei et al., 2021; Braur et al., 2021). In April 2020, the Indonesian government through the Ministry of Transportation issued Permenhub No. 25 Tahun 2020 about transportation control during Idul Fitri 1441 H mudik time. This policy was also continued by the government of Yogyakarta through the Circular Letter of Yogyakarta Governor Number 2/SE/III/2020. The same effort was made by the government below the provincial level, namely the regency and city where in the study area Yogyakarta City and the surrounding areas, the Mayor of Yogyakarta, the Regent of Sleman, and the Regent of Bantul all participated in issuing regulations that complicate travelers to travel to the Yogyakarta City and its surrounding area.

This mobility control policy has a positive impact on controlling the spread of Covid-19 in Yogyakarta City and its surrounding areas where Figure 5 shows that the number of Covid-19 confirmed cases graph was low and has no significant increase. Unfortunately, this did not last long due to the people who started complaining about economic problems caused by the policy that reduce the community's activities [16]. Consequently, the Yogyakarta Province government conducted a trial of a new tourism protocol by allowing tourism destinations to open in late June to early July of 2020 (Mitra et al., 2021). This then led to an increase of Covid-19 confirmed cases in July and August (see Figure 5) as it has been proved that people who are exposed to Covid-19 will only be detected as having Covid-19 three weeks later (Munawir et al., 2005).

The end of 2020 and early 2021 become a disaster for Indonesia, especially Java and Bali which had an explosion of Covid-19 cases. This is caused by year-end holidays carried out by people who are tired or bored of doing anything from home so they do recreation (Noland, 2021). This increase also occurs in Yogyakarta City and its surrounding areas as compared in Figure 3a and Figure 3b where there is an increase in mobility percentage number. This is also supported by the daily and total Covid-19 confirmed cases graph that exponentially rises between 2020 November and 2021 February in Figure 5 and Figure 6.

The Indonesian government has tried to maintain the spread of Covid-19 in those holidays by reducing the number of holidays. Year-end holidays which were usually done for one week before Covid-19 was cut to just three days during the pandemic. This is proven less effective in controlling the spread of Covid-19 as Figure 5 and Figure 6 both show the Covid-19 number of cases rose exponentially in the new year. A small conclusion of this section is residents of Yogyakarta City and its surrounding areas have been complying with the mobility policy in maintaining Covid-19. It's just that the policy which has been strictly enforced in Mudik time got slackened and became the door for Covid-19 to come in. The way the Yogyakarta

government implemented the policy could be seen as an impact of a dilemma by the government because the policy negatively affected people's economies (Oztig & Aksin, 2020; Sigler et al., 2020).

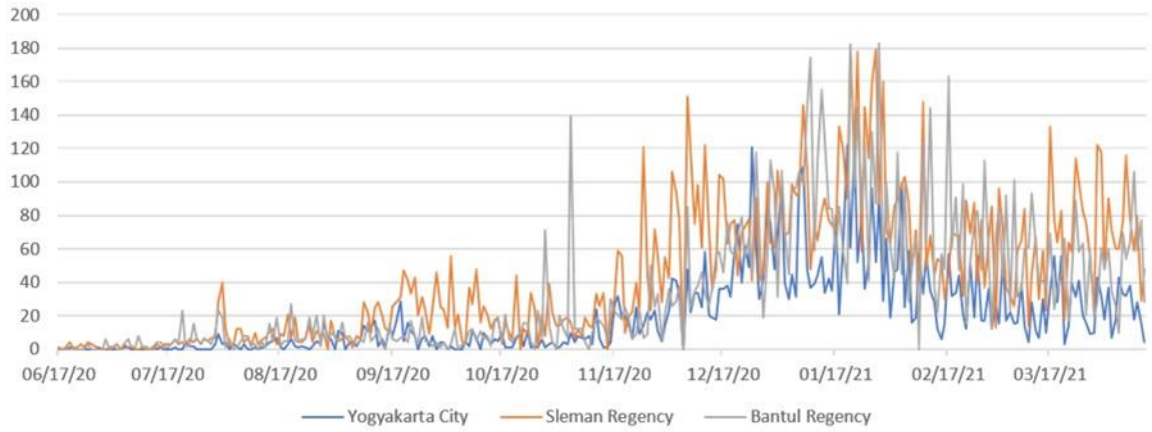


Figure 5. Daily Confirmed Case in Yogyakarta City and Its Surrounding Area (Special Region of Yogyakarta Health Department, 2021)

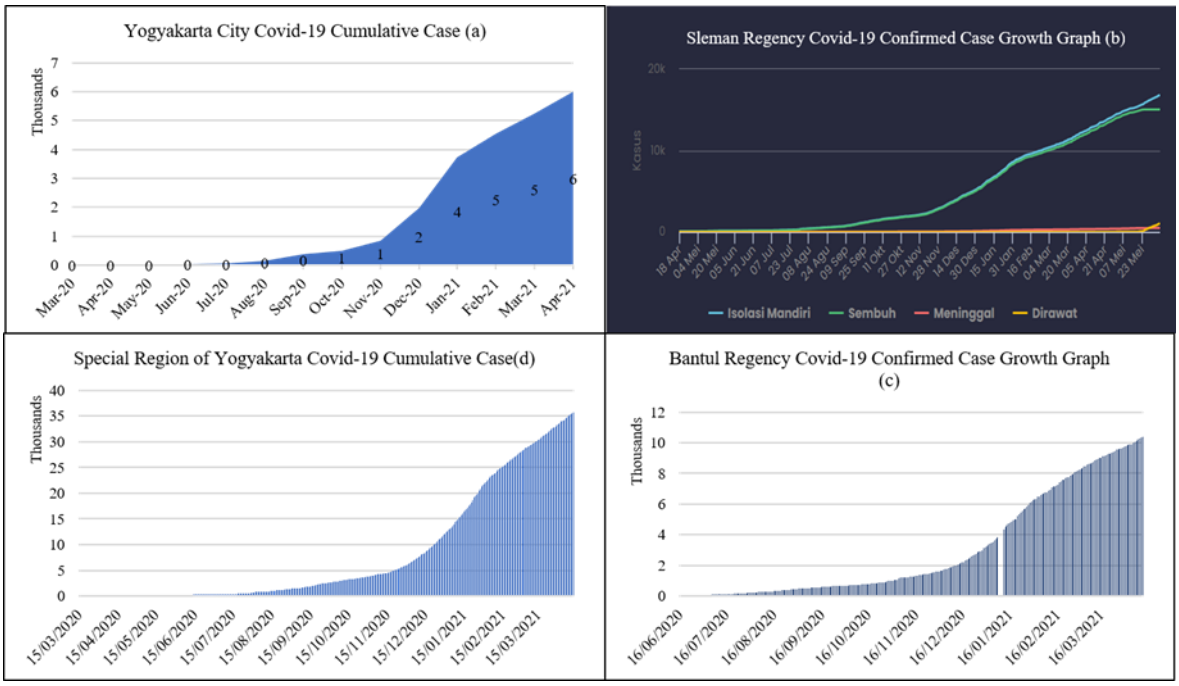


Figure 6. (a) Covid-19 Number of Cases in Yogyakarta City; (b) Sleman Regency; (c) Bantul Regency; dan (d) Yogyakarta Province (Special Region of Yogyakarta Health Department, 2021; and Yogyakarta City Health Department, 2021)

3.4. The Impact of Population Density on Covid-19 Transmission

It is proven elsewhere that population density is one of the Covid-19 determinants (Hakim et al., 2021; Jiang et al., 2021) but this research has proven Yogyakarta and its surrounding areas were different. The result section has pointed out that there is no relation between population density and Covid-19 number of cases in Yogyakarta City and its surrounding areas. It turns out that this anomaly is not the first in the world. The population density needs other variables to become a determinant of Covid-19 [26]. Places with high population density are usually urban areas with residents who are educated and capable of implementing the Covid-19 health protocol and policies that result in the places become less vulnerable to Covid-19 (Venkatesh, 2020).

In addition to compliance and education, another cause of the anomaly is that Sleman and Bantul have more population than Yogyakarta City as they serve to be Yogyakarta City's suburban areas. Most of the residents of these sub-urban areas are active in Yogyakarta City, probably infected in Yogyakarta City, but recorded as having Covid in their living places: Sleman and Bantul. They also have lower economic power which forced them out of their houses in suburban areas to the urban areas in Yogyakarta City to fulfill their needs (Wang et al., 2020). This kind of living those lives in sub-urban but making a living in the urban areas is a real situation in Indonesia [29] as has been done by another research.

The anomaly also was caused by the crowding of people around Yogyakarta City and its surrounding areas. Yogyakarta City, Sleman Regency, and Bantul Regency are tourism and education center which have big potential to be people's crowding places. The people crowding in those regions not only came from those regions but also from other regions who came for tourism. Hamidi & Hamidi (Yang et al., 2020) agree that a place or region becomes the center of Covid-19 spread if it has high crowding and population density is not one the reasons a region became the center of Covid-19 spread.

4. Conclusion

This research has been successful in describing how mobility and population density affected Covid-19 in Yogyakarta and its surrounding areas. The only variable that affected Covid-19 in the study area is mobility into the area. Other variables such as mobility within the area, out of the area, or population density of the area didn't affect Covid-19 in the study area. Therefore, this result should be considered by the Yogyakarta government or another region that has a similar situation as Yogyakarta in making the policy about mobility for controlling Covid-19 or similar diseases.

This research also shows how big data can be used for planning science. Planners should consider the use of big data in the data gathering process of making a plan. The use of big data can significantly reduce the time needed for data-gathering as the data in big data has been gathered automatically and requires some processing to be usable. This is more effective than gathering the data from the scratch and then processing it, especially mobility data in a country where measuring people's mobility is difficult to do accurately.

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