The vulnerability of COVID-19 pandemic based on urban density (a case study of the core urban area in Cirebon City, West Java)

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Abstract. COVID-19 has become a global concern due to its outbreak in early 2020. Not much is known yet about this disease so the only viable acts against it is prevention. City, specifically dense and large ones, has been the center of the pandemic, leading researchers to believe that there is a need to be concerned regarding COVID-19 prevention in particularly high-density areas. This research aims to measure the level of COVID-19 spread susceptibility based on the urban density variables. There are four urban density variables used in this research namely density, intensity, built-up area, and mass activity or public facilities. Data was collected through primary observation and secondary data collection. Five types of analysis were employed to answer the research objective namely density analysis, intensity analysis, built-up area analysis, mass attraction or public facilities analysis and COVID-19 spread susceptibility analysis. Each analysis shows the level of susceptibility in every variable. The results show that activity centers or agglomeration of public facilities have the highest level of vulnerability. The vulnerability can be compounded by the small road geometry and the informality around it. There are several ways that can be done to decrease the vulnerability based on urban dense area variables.

1. Introduction
By the end of December 2019, the World Health Organization (WHO) officially notifies the first cluster cases of pneumonia in Wuhan City, China. It turned out that the cause of the severe acute respiratory syndrome known as COVID-19 is a novel coronavirus, SARS-CoV-2. They explained that most people who were infected by the virus would experience mild to moderate respiratory and could recover without receiving any special treatment. Current evidence found that COVID-19 spreads between people through direct and indirect contact with infected people via mouth or nose, which includes saliva, respiratory or droplets secretion. It has spread rapidly evolving into the global pandemic. As of 26 July 2020, there were 16,018,105 cases of COVID-19 worldwide reported, including 644,832 deaths [1]. On 11 March 2020, WHO declared that COVID-19 is a pandemic. More aggressive steps need to be taken around the world to prevent and treat COVID-19 because until now, there are no vaccine or special treatments available.

Since not much is known yet about the disease and how to cure it, the most advisable act is prevention. Lall and Wahba (2020) [2] exclaimed that prevention acts need to be done to slow the transmission and avoid the use of any limited health resources. The principal act of prevention is through containment
and social distancing along with recurring handwashing. The disease spread prevention can also be done by limiting mass activities and congested use of public spaces. Distancing acts and mass activities are closely linked to the internal condition of a city.

City becomes the main target of this pandemic outbreak. Ample numbers of activities and facilities that are used on a large scale and collectively is the primary reason on how city became the main target. For instance, what transpires in Wuhan, New York, Lombardy and Sao Paolo. Furthermore, the population crowding in city based on density, population, intensity and built-up areas which are called as urban density, serving as the main problems in doing proper distancing, hence making cities and urban areas more susceptible to the COVID-19 contagion. Further observations on urban density conditions become significant since COVID-19 is mainly transmitted through extended close contact, particularly in enclosed spaces. This situation is closely related to the internal density of an area on a close scope [3]. An urban density observation can help the local government determine the focused priority areas based on the highest exposure and contagion risk, along with what actions are taken (Lall & Wahba, 2020).

Accordingly, this research aims to measure the level of COVID-19 spread susceptibility based on the urban density variable. Three steps have been taken to achieve this objective, namely: (i) formulating variables and criteria of a urban density; (ii) measuring the level of COVID-19 spread susceptibility based on the criterion in every variable; and (iii) measuring the level of COVID-19 spread susceptibility in an urban area. The outcome of this research are recommendations to decrease the susceptibility level of COVID-19 based on urban density. Furthermore, it can help the local government undertake preventive actions against the COVID-19 spread through the physical context of urban density.

2. Case Study
Cirebon City is one of the National Activity Centers (locally known as PKN) which is stated in the National Government Regulation No. 26/2008 on The National Spatial Plan [4]. It is also the core city of Ciayumajakuning developmental area, which includes Cirebon City, Cirebon Regency, Indramayu Regency, Majalengka Regency, Kuningan Regency and parts of Sumedang Regency, as stated in The Provincial Spatial Plan of West Java 2009-2029 [5]. Therefore, Cirebon City become activities and services center for PKN Cirebon Raya Metropolitan Area and Ciayumajakuning developmental area. Therefore, Cirebon City has a vital role in the development of its surrounding, such as but not limited to the development of trade and services, cultural and religious tourism, and integrated facilities.

As written in the Cirebon City Spatial Plan 2011-2031 [6], this city is divided into four sub-districts (locally known as SWK), where SWK II is defined as the main urban area in Cirebon. This main urban area has the role of Urban Services Core (locally called PPK) with the primary function of trade and services that caters to a city-wide scale. Aside from being a PPK of Cirebon City, SWK II represents Cirebon in portraying its role as the core of WP Ciayumajakuning. This role as the core urban area is supported by having various regional scale primary infrastructures, such as Type-B Hospitals, Type-A Train Stations, Type-A Terminals, and major road networks that connect Cirebon City and its region. Furthermore, SWK II becomes the foremost destination for citizens, specifically WP Ciayumajakuning citizens, in having economic activities.

SWK II of Cirebon City consists of five county districts, namely: Harjamukti, Kejaksan, Kesambi, Lemahwungkuk, and Pekalipan. In addition, SWK II consists of 18 village districts.
Table 1. County and Village Districts in SWK II of Cirebon City. (Source: Cirebon City Central Bureau of Statistics (BPS), 2020)

| Variables     | Criteria                          |
|---------------|-----------------------------------|
| Harjamukti    | Kecapi                            |
|               | Larangan                          |
|               | Sukapura                          |
| Kejaksan      | Kejaksan                          |
|               | Kebonbaru                         |
|               | Kesenden                          |
|               | Pekiringan                        |
| Kesambi       | Drajat                            |
|               | Kesambi                           |
|               | Sunyaragi                         |
|               | Lemahwungkuk                      |
|               | Pegambiran                        |
| Lemahwungkuk  | Kasepuhan                         |
|               | Panjunan                          |
|               | Pulasaren                         |
| Pekalipan     | Pekalipan                         |
|               | Jagasatri                         |
|               | Pekalangan                        |
Based on the Bureau of Population and Statistics (2018) of Cirebon City [7], SWK II of Cirebon City has an area of 1,632 Ha with a population of 154,512 people. This number of populations is 48% of the total population in Cirebon City, with a relatively high density of 95 people per hectare. Regarding land use, SWK II of Cirebon City can be considered a high density and dynamic city, as seen in Figure 2. The land use is dominated by residential, with 34.9% for high-density residential and 16.26% for middle-density residential. Furthermore, in line with its function as the core of city-scale trade and services, the trade and services land use also takes a considerable part of SWK II, with the percentage of 15.12% for direct trade and services and 4.96% for singular trade and services.

In the case of COVID-19 spread in Indonesia, specifically in West Java Province, the number of cases in Cirebon City is generally low compared to cases in other cities and regencies in West Java. However, until recently, the number of COVID-19 cases in Cirebon City is still on the rise. Moreover, Gunung Jati General Hospital, located in SWK II, is set to be the referenced hospital regarding handling of COVID-19 for WP Ciayumajakuning since the early spread of the virus. In consideration of the relatively high urban density of SWK II, this could affect the rapidness of COVID-19 spread. Therefore, anticipation and preventive measures need to be taken to suppress the spread of the virus so that it would not disrupt the significant role and function of SWK II, both for Cirebon City and its surrounding area.
3. Methodology

3.1. Research Method
This research used SWK II of Cirebon City, which has the role of being an Urban Core Area in Cirebon City, as the study location. It used explorative approach with mixed method approach. The quantitative method scores of each variable were used for the analysis, and the qualitative method illustrated the analysis spatially. The data collection method in this research consisted of primary and secondary surveys. The primary survey was done by observing every block in SWK II to gather data about the existing location. Primary data used in this research included existing land use, building intensity, location of public facilities and activities center, and road geometry. Meanwhile, the secondary survey was done by collecting secondary data, such as: relevant documents, statistical data, and maps.

3.2. Analysis Method
The primary analysis method of this research is spatial analysis. The smallest data scale for this spatial analysis is information regarding blocks. Each block (i) is confined within the village district boundaries; (ii) is confined by physical borders such as roads, bridges, or bodies of water; and (iii) represents a typical condition or land use. Based on these conditions, 304 blocks were determined in SWK II for research analysis. Those data were then degenerated as village district data.

This research used four variables: density, intensity, built-up area, and mass activity/facilities, which illustrated the dense area.

- Density: illustrating the density level of an area. In this variable, an area density is depicted based on population density and building density.
- Intensity: relating to building height and the intensity of a site.
- Built up Area: relating to enclosed spaces and opportunity to do social distancing. The fewer open space available and the less distance between people, the higher potential of virus spreading.
- Mass Activity or Public Facilities: regarding high-risk places that are used publicly and in conjunction that becomes the core/central activity area for citizens.

The following table shows the criteria and variables used for this research.

| Variables       | Criteria                            |
|-----------------|-------------------------------------|
| Density         | • Building density                  |
|                 | • Population density                |
| Intensity       | • Floor Area Ratio                  |
|                 | • Building height                   |
|                 | • Number of stories                 |
| Built-up Area   | • Built-up area percentage          |
| Mass Activity/  | • Distribution area for facilities  |
| Facilities      | • Road geometry                     |

Each criterion represented their corresponding variables. All of them were measured in accordance with the existing conditions within every block. These existing conditions were then divided into levels based on each criterion. The table below shows the stipulation representing each criterion.
Table 3. Level of Susceptibility Stipulation based on Variables. (Source: Lall & Wahba, 2020; Pafka, 2020)

| Variables             | Criteria                  | Stipulation                                                                 |
|-----------------------|---------------------------|----------------------------------------------------------------------------|
| Density               | Building density          | The denser the area, the more susceptible it is to COVID-19                  |
|                       | Population density        |                                                                            |
| Intensity             | Floor Area Ratio (FAR)    | The higher intensity that the area has, the more susceptible it is to COVID-19 |
|                       | Building height           |                                                                            |
|                       | Number of storeys         |                                                                            |
| Built up Area         | Built-area percentage     | The higher built-area percentage and smaller the roads are, the more susceptible it is to COVID-19 |
|                       | Road geometry             |                                                                            |
| Mass Activity/        | Distribution of core areas| The more core areas and facilities are distributed in the location, the more susceptible it is to COVID-19 |
| Public Facilities     | Distribution of facilities|                                                                            |

After measuring every variable distinctively, comprehensive measurements were needed to determine the susceptibility level of each area. The more criteria show susceptibility, the more susceptible the area is to COVID-19 spread.

The spatial data collected for this research was processed by overlays using the correct scale of maps, which is 1:5,000. Spatial data related to each variable was used in accordance with their criteria in the analysis. The data processing method was mainly conducted using a GIS software. The outputs of every spatial analysis are maps regarding the susceptibility of each variable. On those maps, green areas represent a low level of susceptibility. The level of susceptibility is shown through various gradation of red colors with the understanding that the stronger the red color, the higher level of susceptibility that area has.

4. Analysis

4.1. Density Analysis
The COVID-19 susceptibility density analysis was measured based on the population density and building density inside the boundaries of this research location.
The result of density analysis map shows that generally SWK II has low COVID-19 spread susceptibility. Based on the analysis, there are only several areas with high-level susceptibility, including most Pulasaren Village and expands to parts of Jagasatru and Kesepuhan Village, also at Sukapura Village. These locations are more susceptibility than other locations since they have a denser population density compared to other locations in SWK II. Moreover, slums can be found in these locations, which has the characteristic of high-density residential with the occupancy rate of more than one household inside a single house, which increases the chance of COVID-19 contagion on those locations.

4.2. **Intensity Analysis**

The COVID-19 susceptibility intensity analysis was measured based on the Floor-Area Ratio (FAR), the number of stories, and the height of buildings located inside the research boundaries.
Figure 4. Intensity Analysis Map.

The analysis result on building intensity map shows that the level of COVID-19 spread susceptibility in SWK II of Cirebon City is considered low. Only a few locations have a high level of susceptibility, namely: Sukapura Village, Pekalangan Village, Pekalipan Village, Pulasaren Village, and parts of Kejaksan Village. The superior level of susceptibility on these locations is due to the high building intensity located around the city core and main roads of SWK II.

4.3. Built-up Area Analysis
The COVID-19 susceptibility built-area analysis was measured based on the built-up area percentage and road geometry inside the research location boundaries.
From the map, the level of COVID-19 spread susceptibility in SWK II of Cirebon City is relatively low. Only several locations are indicated with high susceptibility levels compared to other locations in the area, namely: Drajet Village, Kesambi Village, Pekiringan Village, and Kepalangan Village. These high levels of susceptibility are caused by the high percentage of built-area with unsupportive and limited road networks (in this case defined by small and narrow roads), resulting in a higher level of susceptibility for citizens that are active in these locations. This increased level of susceptibility comes from the difficulties for such citizens to do social and physical distancing in the limited space. Some locations with mid-to-high levels of susceptibility are situated in slum areas at Pekalipan Village, Jagasatru Village, and Kesepuhan Village. These locations also contain a high percentage of built-up area and narrow roads, supporting the earlier characteristics.

4.4. Mass Activities and Facilities Analysis
The COVID-19 susceptibility mass activities and facilities analysis were measured based on the distribution of the activity hubs and public facilities.
Based on the analysis, the level of COVID-19 spread susceptibility based on mass activities and public facilities in SWK II of Cirebon City is considered mid-to-high level. As seen on the map, locations that are deemed to have a mid-to-high level of susceptibility clusters and connected as if agglomerated. This agglomeration happens due to these locations are considered urban hubs with urban facilities located close to each other. These locations are also directly connected to major trade and services activities. Some areas with high-level susceptibilities are Panjunan Village, Pekalangan Village, Pekalipan Village, Pulasaren Village, and Jagasatru Village. High-level susceptibility can also be found in parts of Sukapura Village and Pekiringan Village.

High susceptibility levels towards COVID-19 spread can be found in Panjunan Village, Pekalangan Village, Pekalipan Village, Pulasaren Village, and Jagasatru Village because these areas contain the core activity area for SWK II as well as contain social facilities agglomeration. Some areas, such as Kejaksan Village, Panjunan Village, and Pekalangan Village, are also considered highly susceptible to COVID-19 because they are developed as Urban Service Cores (PPK), which provides services for Cirebon City as a whole. These services include modern shopping facilities (supermarkets), shopping complexes, government facilities, educational facilities, offices, and other services. Meanwhile, the high susceptibility level in Pekiringan Village is because it is developed as a Sub-Urban Service Core (SPPK) Gunung Sari Cipto. This SPPK has a function to be a trade and service center. There is an agglomeration of department stores that facilitates not only SWK II and Cirebon City, but also their surrounding regions, leading to an increased level of susceptibility.

The Kanoman area, which covers Kanoman Market and Kanoman Palace, is a significant attraction in Cirebon City. The Kanoman Market, which is the top market of Cirebon City, is located at Pulasaren Village District. The location of Kanoman Market is directly adjacent to the Kanoman Palace, which is a key cultural tourism destination of Cirebon City. Furthermore, shopping districts and informal vendors surround the market area. The considerable amount of activities in the Kanoman Area results in a high level of COVID-19 spread susceptibility.

**Figure 6.** Mass Activities and Public Facilities Analysis Map.
Specific locations, like Drajat Village and Larangan Village, have a homogenous type of land use and activities, usually mid-to-high density settlements, making it more susceptible to COVID-19. These locations are one level below the previously mentioned areas in terms of COVID-19 spread susceptibility. This condition is also applicable to green colored areas with homogenous activities but does not have a high population and building density, making it less susceptible to other regions.

4.5. **COVID-19 Spread Susceptibility Analysis based on Urban Area Density**

The COVID-19 susceptibility level map shown above is an overlay of the four previous urban dense area variable maps—high level of susceptibility results when every variable shows a high level of susceptibility.

![Figure 7. Urban Density Analysis Map.](image)

The table below shows categories of urban dense area susceptibility based on the number of high-level susceptibilities from the previous analysis.

| Susceptibility Category | Number of High Susceptibility Level from Previous Analysis |
|-------------------------|-----------------------------------------------------------|
| Very High               | 4 high susceptibility from 4 analysis                      |
| High                    | 3 high susceptibility from 4 analysis                      |
| Mid                     | 2 high susceptibility from 4 analysis                      |
| Low                     | 1 high susceptibility from 4 analysis or 0 high susceptibility from 4 analysis |
After overlaying and classifying the previous analysis, the results show that generally the Core Urban Area of Cirebon is highly susceptible to COVID-19 spread. Areas with very high susceptibility rate are Pekulangan Village, Panjunan Village, Pekalipan Village, Pulasaren Village, Jagasatri Village, and Kesepuhan Village when compared to other areas surrounding them. Those areas are included to the ‘Very High’ category because they have high density, high intensity, large built-area percentage, and many activities and facilities resulting in a very high level of susceptibility to the spread. Areas, such as Sukapura Village, Kesenden Village, Kebonbaru Village, Drajat Village, and Larangan Village, are identified as high susceptibility areas. These areas are categorized as ‘High’ because three analyses shows that they are highly susceptible to the COVID-19 spread.

As observed on the Urban Dense Area map, areas with a high level of susceptibility of the COVID-19 spread agglomerates. Currently, that area is where the core activity of Cirebon City happens, centered in Pulasaren Village and linked to surrounding villages. Kanoman Market, which is the primary market of Cirebon City, is also located in Pulasaren Village. Apart from a location where locals buy daily needs, Kanoman Market also serves as a regional market that receives and supplies comestibles for Cirebon City and beyond. Moreover, located close to the Kanoman Palace which is the main tourism destination of Cirebon City, this market also acts as a key souvenir hub of Cirebon City. The amount of activities happening in the Kanoman Area is not supported with decent road infrastructures, resulting in passersby needs to jostle and to have difficulty in maintaining a safe distance. This situation makes the area highly susceptible to the COVID-19 spread.

Aside from having Kanoman Palace and Kanoman Market, the agglomerated high susceptibility area also has slums within its boundaries. As previously explained in the density analysis section, slums in SWK II of Cirebon City have high density, both building density and population density. The roads here are narrow, and there are many community activities and facilities here, making these slums highly susceptible to the COVID-19 spread. Another area identified as highly susceptible is trade and service center that acts as activity hubs for Cirebon City.

Other areas have mid-to-low susceptibility level because these areas are identified as high susceptible for only once or twice in the previous four analysis. Areas with mid-to-low susceptibility level are Pegambiran Village, Larangan Village, Kecapi Village, Surnyaragi Village, Kesambi Village, and parts of Pekiringan Village. These villages generally consists of low-density residential, not urban hubs, and equipped with adequate infrastructures, making these locations relatively less susceptible to COVID-19 spread compared to other regions in SWK II of Cirebon City.

5. Findings and Discussion
Analysis of each urban dense area variables and urban dense area as a whole show that generally Cirebon City core urban area has mid-to-high susceptibility to COVID-19 spread. Locations with high susceptibility are locations that act as Cirebon City central hub, to cater both Cirebon City internally and its hinterland. This condition is in line with the role of Cirebon City as the center of WP Clayumajakuning and the primary city of PKN Cirebon Raya. At the same time, locations surrounding that core area may also have a high susceptibility to COVID-19 due to being close to the core area and affected by the multiplier effect from the core area.

The high susceptibility on the activity hubs of Cirebon City is not only caused by high activity traffic and density there, but also caused by the inadequate quality of supporting infrastructures, such as roads, pedestrian access, and open spaces making it difficult for people to maintain an appropriate distance for physical distancing. The absence of pedestrian walks and decent-sized roads also affects the difficulty to do physical distancing. Another matter that affects leads to this difficulty is the presence of informal traders throughout the area.

On the other hand, building density and population density indirectly affect the activities and facilities condition in areas with high susceptibility because the variety of public facilities provided in an area is based on the number of activities. This research shows that the denser an area is, both built-up area and population, the more activities occur, and the more facilities are provided to support it in return. Some
activities taken to account on this research are education, health, worship, economic, offices, and others. Facilities analysed in this research relates to the activities previously mentioned, such as schools, mosques, markets, offices, and many more.

The research shows that density not only directly affects the COVID-19 spread susceptibility but also affects building intensity, such as building heights, and the kind of activities happening there. Both densities, built-up area and population, affect the susceptibility rate because some locations show that they have high susceptibility while not having a high percentage of built-up area. It is also important to remember that this condition also depends on the quality of supporting infrastructures, such as accessibility and infrastructure existence. Based on these facts, density serves as a principal variable in determining COVID-19 spread. However, density cannot be seen on its own, but as how it is linked and affects other determining variables.

Based on the arguments above, every urban dense area variable directly affects each other; they cannot be seen partially. Accordingly, to formulate regulations and policies regarding preventive actions against the spread of COVID-19, these variables need to be considered comprehensively. Nevertheless, priorities can still be ranked from every variable of the urban dense area.

Lastly, the existence of slums increases the COVID-19 spread susceptibility of areas. Slums that are known for having high density, both population and built-area; irregular building layout; sparse open spaces, resulting in poor air circulation and light exposure; inaccessible road infrastructure and narrower than 3 meters, adding difficulties to physical distancing; and having most facilities used together by the community, such as public bathrooms; make slums a typical location with high susceptibility, other than urban hubs. This phenomenon relates to urban informality problems, which does not only relate to urban aesthetics but also local public health. Within the context of COVID-19 contagion, these characteristics make slums one of the higher susceptible land use to the COVID-19 spread.

6. Recommendation

Based on the findings and discussion gained from the analysis of the case study in this research, some actions need to be taken, and policies need to be implemented to decrease the susceptibility rate of the COVID-19 spread linked with urban dense areas as a preventive measure. Those recommendations are:

- Quality and comprehensiveness increase essential services and public facilities that serve locally or on a neighborhood level. This upgrade is vital so that fewer people depend on larger scale facilities, for example, increasing the quality of local/neighborhood trade facilities. Therefore, people do not have to shop at larger trade facilities that are possibly located far away and potentially have more people in them.

- Supporting infrastructures of urban hubs need to adjust more to the COVID-19 conditions to facilitate physical distancing and other preventive actions. This adjustment can be done by widening pedestrian access and improving the air circulation on highly susceptible areas.

- Distributing urban hubs and service facilities more evenly to avoid agglomerations. The closer urban hubs and service facilities are with each other, the more people will congregate on those locations, and with this gathering, close contact will happen easier, and physical distancing will be more difficult.

- Increasing order and surveillance of supporting infrastructures, especially in high-density areas, to avoid overuse and close contact. For example, implementing rules and limits on public bathrooms or community clean water facilities. Furthermore, necessary upgrades on street size are essential so people can do proper distancing.

- Better handling of slums and squatter issues from the city government to decrease the susceptibility level of COVID-19. As previously mentioned, slums are COVID-19 contagion hotspots because of its high density. With better slums and squatter regulation, the area will be less susceptible to COVID-19. Moreover, slums and squatter issues handling as a preventive
action against COVID-19 is also in line with several urban slums handling concepts, such as restoration, resettlement, and rejuvenation.

7. References

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