Understanding the Connection between Urbanization and Hydrometeorological Disasters: an Experience from Central Java Province, Indonesia

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Abstract. Climate change is one of the development challenges, both at the global, national, and regional levels. In recent years, the impact of climate change is increasingly affecting the world community. Various studies state that the factor that exacerbates climate change comes from massive human activities, causing the production of increasing greenhouse gases. The growth in population and rapid urbanization causes urban expansion. Land conversion is unavoidable, escalates pressure on the environment, causing hydrometeorological disasters such as floods to occur more frequently. Some of them even claimed many lives and caused material losses. This study aims to investigate the connection between urbanization and hydrometeorological disasters in Central Java Province, as an effort to understand the characteristics of the region in supporting adaptation to climate change. The method used is overlay analysis through GIS by using data on the rural urban status, building density, and disaster events in Central Java Province in 2020. Based on the results of the analysis, it is known that the existence of massive urbanization correlates to the occurrence of disasters, depicted by several spots in Central Java Province.

1. Introduction

Population growth and urbanization from time to time causes urban expansion. This has led to a tendency for massive development and land conversion, from non-built-up to built-up area. The land conversion adds more shock and pressure to the environment. Urbanization in the low-lying areas increase exposure to various types of floods, besides that urbanization also causes changes in river systems and structures that lead to increasing the risk of flooding [1,2,3]. Several cases that occurred in Asian countries, prove that urbanization caused by population growth and land conversion, has an effect on flood events [4,5]. Apart from flooding, several previous studies also have stated that land conversion can trigger disaster events, especially disasters caused by climate change, such as sea level rise, coastal abrasion, landslide, and drought [6,7].

In the case of an archipelagic country such as Indonesia, where most of the territory is on the coast, this condition has a significant impact on human activities [8,9,10]. McGranahan et al. [10] states that high-density areas close to the sea will have a greater risk of being exposed to the impacts of climate change. This statement supported by research conducted by Mansur et al. [11], where urban areas have a high risk of climate change due to the development of human settlements that are concentrated in one area, increasing the vulnerability of the community and infrastructure in that areas to the climate change hazards.
The frequency of disasters in Indonesia, at least in the last three years (2018-2020), has increased by 36.88 percent. Central Java is the province with the highest frequency of disasters in Indonesia with 1,021 disasters occurring in 2020, including landslides with the highest intensity, floods and whirling winds [12]. In addition to coastal areas which are vulnerable to the phenomenon of sea level rise, land subsidence, and the increasing intensity of rain that causes flooding [6], urban and rural areas in the high-lying areas are also vulnerable to shocks and pressures due to the increasing demand for residential land causing land conversion, and then leads to landslides [13].

Urbanization, according to the Badan Pusat Statistik/BPS (Statistics Indonesia) classification, can be traced through the status of the area (i.e., categorized either as rural, urban, or rural-urban area). This status mostly is determined based on the number of populations, availability of urban facilities, and infrastructure provisions. In Central Java Province, there has been a massive transformation of the status of rural to urban areas from 2010 to 2020. It has been indicated by the significance of the high rate of land conversion that placing the Province in high risk of climate hazards.

This study aims to investigate the connection between urbanization and hydrometeorological disasters in Central Java Province, as an effort to understand the characteristics of the region in supporting adaptation to climate change. There are two main research questions used in this study, 1) How is the urbanization dispersed, particularly in Central Java Province? 2) What is the connection between urbanization and hydrometeorological disasters as seen from the case study of Central Java Province? In order to answer those two questions, this paper is divided into three main sections. Section two describes the study area and methods used in this paper; section three discusses the analysis on urbanization in Central Java Province and its connection towards the hydrometeorological disasters; and section 4 is conclusion part.

2. Study Area and Methods

Central Java Province is located in the middle of Java Island, and consists of 35 cities/regencies. In 2020, Central Java Province has 5,326 administrative areas as urban and 3,236 administrative areas categorize as rural [14]. There are several criteria to determine the rural urban status, including population density, percentage of agricultural families, availability of public facilities (such as schools, hospitals, markets, shops, hotels, etc). Related to the rural urban status, the data used is from publication of Master Wilayah Provinsi Jateng 2020 by BPS. There are three terms used in this paper related to the status of specific area given by BPS, namely rural area, potentially urban area, and urban area [1]. Urban area is an area that administratively lies in the city or the capital of regency. Potentially urban area is an area which administratively a village (desa) yet has the character of an urban and located in regency, it is also called as rural-urban (desa-kota) area. Rural area refers to villages in regency.

In this paper, the rural urban status was combined with the building density to formed the urbanization level of Central Java Province. The study area is focused on areas with potentially urban and urban status, as they represent urbanization properly. Building density is obtained through the percentage of built-up area in each kelurahan/villages, based on Landsat 8 OLI Satellite Image for 2020 in 50 x 50 m resolution from the USGS (United States Geological Survey). The formula used to calculate building density is the calculation of built-up area in each kelurahan/villages divided by total area of each kelurahan/villages (1). The results of these calculations showed the density of buildings in each kelurahan/villages.

$$Building\ Density = \frac{\text{Built-up area}}{\text{Total area (kelurahan/villages)}}$$  (1)

After the combined those two provisions, the classification was carried out to determined the level of urbanization using the natural break jenks method. Natural break jenks is a data classification method that is intended to determine the best arrangement of values in different classes, by seeking to minimize average deviation of each class from the class mean and maximizing the deviation of each class from
Based on the result of analysis, three types of classification were obtained. They are low, medium and high.

- Low level of urbanization is composed by the areas with urban and potentially urban status, and have proportion of built-up area between 0.001752 (0.2 percent) until 0.276570 (27.66 percent).
- Medium level consists of areas with urban and potentially urban status, and have proportion of built-up area between 0.276571 (27.66 percent) until 0.624629 (62.46 percent).
- High level consists of areas with urban and potentially urban status, and have proportion of built-up area between 0.624630 (62.46 percent) until 1 (100 percent).

The next step was overlaying urbanization level with hydrometeorological hazards. The hydrometeorological hazards data was obtained from Badan Nasional Penanggulangan Bencana (National Disaster Management Authority) through the inaRISK platform (https://inarisk.bnpb.go.id/). The overlaying process between urbanization and hydrometeorological hazards level established nine typologies of urbanization - hydrometeorological hazard level, namely low-low, low-medium, low-high, medium-low, medium-medium, medium-high, high-low, high-medium, high-high. Due to the availability of data from inaRISK, the type of hydrometeorological disaster used in this paper are floods and landslides. The other reason is these two disasters are the most frequent hydrometeorological disasters occur in the province.

3. **Result and Discussion**

3.1. **Urbanization Level of Central Java Province**

Urbanization is a transformation process of rural population life style to become more “urban”, expansion of the built-up area, and creation a more urban environment [16]. The process is characterized by five aspects, such as economic growth, demographic change, social transformation, reshaped and stretched urban spaces, and shrinking cities [17]. In this study, urbanization that occurred in Central Java Province seen based on demographic change, social transformation and reshaped and stretched urban spaces. The demographic change and social transformation are indicated by the status of rural urban, while the reshaped and stretched urban spaces are indicated by the built-up area. Table 1 shows the distribution area in each level of urbanization in Central Java Province in 2020.

| Urbanization Level | Area (Ha) |
|--------------------|-----------|
| Low                | 1,185,036 |
| Medium             | 398,899.6 |
| High               | 75,558.52 |

Central Java Province are dominated by low level of urbanization. However, every city/regency in that province have at least one area with high level of urbanization. This shows that the process of urbanization in Central Java Province growing sporadically. The process started, generally, from urban expansion-where the urban area spread to its hinterland or suburban area, follow the pattern of transportation infrastructure (such as main road), growing naturally from coastal areas, or in situ urbanization. Urbanization growth in Central Java Province can be seen in Table 2.

The largest number of villages/kelurahan with high level urbanization is Semarang City, considering Semarang City is a metropolitan area and the capital of Central Java Province, where most of facilities and infrastructure, as well as economic activities are concentrated. The second largest number of villages/kelurahan with high level urbanization is Surakarta City. However, Surakarta City has a greater urbanization influence to its hinterlands or suburban area than Semarang City. Figure 1 shows the
distribution of urbanization level in Central Java Province where the medium level of urbanization spread out around the Surakarta City.

As previously explained, in some areas, the distribution of urbanization villages/kelurahan follow the pattern of the main road pattern. This fact shows that infrastructure, particularly transportation, play an important role for urbanization growth. The existence of the main road connecting between cities and regencies has a positive impact on urban expansion [18,19].

Table 2. The Number of High Level of Urbanization Villages/Kelurahan of Central Java Province, in 2020

| No | City/Regency     | Total Sub-district/Kecamatan | Number of Sub-district/Kecamatan experienced a high level of urbanization | Total Villages/Kelurahan | Number of Villages/Kelurahan experienced a high level of urbanization |
|----|------------------|-----------------------------|-------------------------------------------------|--------------------------|-----------------------------------------------|
| 1  | Banjarnegara     | 20                          | 1                                              | 278                      | 1                                             |
| 2  | Banyumas         | 27                          | 7                                              | 331                      | 26                                            |
| 3  | Batang           | 15                          | 2                                              | 248                      | 8                                             |
| 4  | Blora            | 16                          | 2                                              | 295                      | 7                                             |
| 5  | Boyolali         | 22                          | 4                                              | 267                      | 9                                             |
| 6  | Brebes           | 17                          | 4                                              | 297                      | 5                                             |
| 7  | Cilacap          | 24                          | 4                                              | 284                      | 11                                            |
| 8  | Demak            | 14                          | 2                                              | 249                      | 5                                             |
| 9  | Grobogan         | 19                          | 1                                              | 280                      | 1                                             |
| 10 | Jepara           | 16                          | 5                                              | 195                      | 25                                            |
| 11 | Karanganyar      | 17                          | 4                                              | 177                      | 17                                            |
| 12 | Kebumen          | 26                          | 3                                              | 460                      | 7                                             |
| 13 | Kendal           | 20                          | 5                                              | 286                      | 9                                             |
| 14 | Klaten           | 26                          | 8                                              | 401                      | 25                                            |
| 15 | City of Magelang | 3                           | 3                                              | 16                       | 16                                            |
| 16 | City of Pekalong | 4                           | 4                                              | 27                       | 19                                            |
| 17 | City of Salatiga | 4                           | 4                                              | 23                       | 10                                            |
| 18 | City of Semarang | 16                          | 14                                             | 177                      | 120                                           |
| 19 | City of Surakarta| 5                           | 5                                              | 54                       | 51                                            |
| 20 | City of Tegal    | 4                           | 4                                              | 27                       | 20                                            |
| 21 | Kudus            | 9                           | 4                                              | 132                      | 37                                            |
| 22 | Magelang         | 21                          | 1                                              | 372                      | 4                                             |
| 23 | Pati             | 21                          | 4                                              | 406                      | 20                                            |
| 24 | Pekalongan       | 19                          | 7                                              | 285                      | 23                                            |
| 25 | Pemalong         | 14                          | 4                                              | 222                      | 7                                             |
| 26 | Purbalingga      | 18                          | 3                                              | 239                      | 8                                             |
| 27 | Purworejo        | 16                          | 2                                              | 494                      | 4                                             |
| 28 | Rembang          | 14                          | 5                                              | 294                      | 18                                            |
| 29 | Semarang         | 19                          | 4                                              | 235                      | 10                                            |
| 30 | Sragen           | 20                          | 1                                              | 208                      | 3                                             |
| 31 | Sukoharjo        | 12                          | 7                                              | 167                      | 31                                            |
| 32 | Tegal            | 18                          | 7                                              | 287                      | 43                                            |
| 33 | Temanggung       | 20                          | 3                                              | 289                      | 8                                             |
| 34 | Wonogiri         | 25                          | 1                                              | 294                      | 4                                             |
| 35 | Wonosobo         | 15                          | 1                                              | 265                      | 2                                             |
|    | Total            | 576                         | 140                                             | 8,562                    | 614                                           |
3.2. Hydrometeorological Hazard in Central Java Province

The most frequent hydrometeorological disaster in Central Java Province are flood and landslides. From the data of InaRISK, there are three level of hazards, either for flood or landslides, including low, medium, and high. Those classification come from hazard index by InaRISK. Low has a value between 0-0.3, medium has a value between 0.3-0.6, and high has the value between 0.6-1. For the flood hazard, the high level hazard dispersed in the low-lying and coastal area on the north and south, and some of them are located in the center. Meanwhile, the low-level hazard of flood, generally located in the center and high-lying areas. The distribution of flood hazard in Central Java Province in 2020, can be seen in Figure 2. As Handayani et al. [1] stated that flooding is a result of various factors. Related to climate-change effect, the occurrence of floods caused by heavy rainfall and sea-level rise (that leads to tidal flooding) [13].
Figure 2. Distribution of Flood Hazard Level in Central Java Province in 2020

In case of landslide, the distribution of hazard tends to be in the middle of provincial area or in the high-lying areas. The hazard is dominated by the high level and medium level. Meanwhile, for low levels, it is dispersed into a small number of areas (as shown by Figure 3). The characteristic of landslide hazard is the reverse of flood hazard. Because, it is closely related to slope, altitude and geographical conditions of the area. Therefore, the areas with a high level of landslide hazard are in mountains, hills, or high-lying areas, such as in Banjarnegara Regency, Wonosobo Regency, Purbalingga Regency, and others.

Surface conditions and soil types greatly affect the possibility of landslides. In addition, water caused by rain, earthquake or ground shaking, as well as bare surfaces (deforestation) also cause landslides in vulnerable areas. This explains that human activities play role in causing landslides, especially on deforestation due to land conversion.
Figure 3. Distribution of Landslide Hazard Level in Central Java Province in 2020

3.3. Connection Between Urbanization and Hydrometeorological Disasters in Central Java

The connection between urbanization and hydrometeorological disasters, particularly in Central Java Province, can be explained through a typology. As previously explained in Study Area and Methods section, there are nine typological forms to describe the specific connection between two variables, namely low-low, low-medium, low-high, medium-low, medium-medium, medium-high, high-low, high-medium, high-high. The first word describes the level of urbanization, while the second word represents the level of hazard. For example, low-high means the specific area has low level of urbanization, yet high level of hazard.

For the flood events, the dominating typology is low level urbanization and low level of hazard (see Table 3). The influences of high level of urbanization to flood hazard occurs in high-high typology, which located in some municipalities, including Semarang City, Surakarta City, Salatiga City, Pekalongan City, and Tegal City (See Figure 4). This is related to the results of previous studies, which stated that flood events are more common in urban and potentially urban areas [1].

Urban areas have a high level of urbanization because they are centers of growth and services that attract people to come. With the growing rate of urbanization, increasing pressure on the environment, by the changes of land use from non-built-up to built-up area, in order to meet the needs of community. The density and lack of non-built-up area, that initially functions as a catchment area, causing the level of flood hazard in urban and potentially urban areas also increase. That is why the certain area with high level of urbanization also has high level of flood hazard. In addition, people's activities or life style potentially cause a damage for the environment, such as poor waste management system, groundwater extraction, and so on.

For hinterland or suburban areas that have medium level of urbanization, and are directly adjacent to urban areas, also have high level of hazard because they potentially affected by the flood hazard in urban
areas. Meanwhile, for areas with low urbanization level, especially in coastal areas, have a high level of hazard because of tidal flooding.

Table 3. Distribution of Area in Each Typology for Flood Hazard in Central Java Province, in 2020

| Urbanization Level | Hazard Level | Low | Medium | High |
|--------------------|--------------|-----|--------|------|
| Low                | Low          | 386,697.7 | 288,945.6 | 198,248 |
| Medium             | Medium       | 105,119.1 | 111,016.3 | 30,446.94 |
| High               | High         | 17,042.65 | 26,343.94 | 16,454.87 |

Furthermore, Handayani et al. [1] explained that there are some types of flooding in urban area, which are fluvial flooding and pluvial flooding. Fluvial flooding is flood event caused by overflow water from the river. Meanwhile, pluvial flooding is flood event caused by bad performance of drainage systems combined with the lack of catchment area as an effect of land conversion. It gets worse by the change of precipitation. The number of rainy days tend to decreases while the intensity of rain increases, this condition influences the surface water runoff [1]. As for the fluvial flooding, the occurrence of land conversion around the river, both in downstream and upstream, put some pressure in river system and structure.

Figure 4. Flood Typology in Central Java Province, in 2020
For the case of landslides, the affected areas are not as large as the areas affected by flood. Table 4 describes the distribution of area in each typology for landslide in Central Java Province. In 2020 shows that the largest area dominated by low-high typology. It means that in the area with low level of urbanization is likely to experience the high level of hazard. It indicates that urbanization is not significantly affect landslide hazard. Landslide hazard is more influenced by the geographical conditions of certain area, such as topography, soil type, and others. The distribution of landslide typology can be seen in Figure 5.

Table 4. Distribution of Area in Each Typology for Landslide Hazard in Central Java Province, in 2020

| Urbanization Level | Hazard Level | Low  | Medium | High   |
|--------------------|--------------|------|--------|--------|
| Low                |              | 912.4312 | 1,094.391 | 235.0402 |
| Medium             |              |       |        |        |
| High               |              |       |        |        |

Figure 5. Landslide Typology in Central Java Province, in 2020

4. Conclusion

This research shows the connection between urbanization and hydrometeorological disasters caused by climate change, especially for the case of flood. The high level of flood hazard are located in urban area, this is related to land conversion that occur due to urbanization, causing environmental degradation. Human activities contribute a significant role in exacerbate flood events. Meanwhile, for the case of landslide, there is no significant effect from the urbanization growth to landslide hazard. It
may happen because landslide, generally, located in high-lying areas or hills, while urbanization are likely to grow rapidly in the low-lying areas.

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