Landscapes Vulnerability on Climate Change in Yogyakarta Province, Indonesia

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Abstract. Whether climate change is real or not, the daily basis phenomena and its evidences should be our concern nowadays. Yogyakarta is one of the provinces that are vulnerable to the impact of climate change in Indonesia. The specific responses to climate change phenomena in Yogyakarta province are indirectly correlated to landscape characteristics. These characteristics are important aspects for the assessment and development of new approaches to address the impacts of climate change. Therefore, this paper presents the status of landscape vulnerability to climate change in Yogyakarta province to consider the issues of mitigation and adaptation to climate change. Analytical hierarchy process (AHP) was applied to determine the objective of the research. The results of previous studies were reviewed in depth and combined with field observations to build a strong argument before evaluating the matrices and weights in the AHP steps. The result analysis showed that the most vulnerable landscape in Yogyakarta province is the anthropogenic landscape, which is located in Yogyakarta city. Furthermore, the combination of population density and poor sanitation management should be considered as a factor in mitigating and adapting to climate change in Yogyakarta city.

1. Introduction
Climate change is a global issue that refers to a changing climate system over a long period of time and over a large geographical area due to natural processes or as a result of human activities [1]. Beyond natural processes contributing to climate change, human influence on climate systems changes is widely recognised [2]. The impacts of climate change are felt all over the world, including Indonesia [3]. In the last 30 years, 80% of natural disasters in Indonesia have been linked to extreme weather events. The World Bank [4] predicts a delay of 30 days in the annual monsoon season, while the dry season will face a 75% decrease in rainfall. In addition, climate change will increase the risks of extreme weather-related disasters throughout Indonesia and increase food insecurity through shifts in agriculture due to changes in rainfall, evaporation, runoff and soil moisture.
The impacts of extreme weather-related disasters will make Indonesia vulnerable. Vulnerability is defined as the global capacity or sensitivity of a given system to respond any stress, such as a natural disaster [5]. It combines the physical, social, economic, environmental and institutional structures and processes that in this context determine capability to react the effects of climate change [6][7]. The IPCC [2] also determine that vulnerability includes exposure, sensitivity and adaptive capacity. One of the regions that are vulnerable to the effects of climate change in Indonesia is Yogyakarta province [1]. Yogyakarta province is located on the Indonesian island of Java between Central Java and the Indonesian ocean in the south. The tropical climate of Yogyakarta is also influenced by monsoonal patterns. However, climate change has been found to have altered these weather patterns affecting agricultural production, water resources, increased natural disasters and widespread social impacts [8].

The province has four regencies and one city (Yogyakarta) located in the centre of the province. Each regency and the city have unique physiographic features. The Sleman regency is a volcanic landscape to the north, while the Bantul regency is a fluvial-marine landscape to the south. Gunungkidul regency is a limestone karst landscape to the east and Kulon Progo regency is an old-structural volcanic hilly landscape in mass movement processes to the west. Yogyakarta city is characterised as an anthropogenic landscape. Based on these conditions, the landscape characteristics of the entire province makes it an ideal location to evaluate the regions vulnerability in climate change issues, which is the focus of this study. The findings presented herein will be useful for climate change vulnerability mitigation and adaptation strategies.

2. Materials and Methods

2.1. Study area and observation locations

The research area is Yogyakarta province (Figure 1). The province consists of four regencies and one city. Yogyakarta city is the administrative centre of province and is located in the middle of the region at about 75 m above sea level. The city of Yogyakarta has the highest population density with around 13,331 people per km² in 2019 [9]. Sleman regency is located to the north of Yogyakarta city. It is a volcanic landscape area where the active Merapi volcano is situated. Population density in Sleman regency is about 2,142 people per km² in 2019. Sleman also acts as a key groundwater recharge area and the volcanic soil provides ideal conditions for agriculture [10]. Bantul regency is a low-lying, alluvial-marine landscape, located to the south of Yogyakarta coast. Population density in Bantul regency is about 2,013 people per km² in 2019. The area is characterised by alluvial and fluvial-marine plains, fertile soil and groundwater discharge area. Wet rice production can be attributed to the well irrigated alluvial volcanic plain and the proximity to the Progo and Opak river [11]. The Progo river enters the Indian ocean in an estuary, forming a sandbank which runs parallel to the shore [12].
Kulon Progo regency is located to the west of Sleman and Bantul regency. Population density in Bantul regency is about 736.9 people per km$^2$ in 2019. Kulon Progo regency includes lowland and hilly areas with the elevation range between 100-1000 meters above sea level. Gunungkidul is the largest regency that cover 46% of Yogyakarta province with population density about 523.4 people per km$^2$ in 2019. Gunungkidul has unique karst topography in the southern part of the regency. The karst system, with deep groundwater caves and rivers create a limited water supply in the region. Therefore, with limited access to water this region is not ideal for vegetable or rice paddy production, however, there has been some success in maize production [15].

2.2. Data collecting and observation

This research combines primary and secondary data to assess the landscape characteristic and its vulnerability potential. Secondary data includes density, hazard occurrence and relevant findings from previous research has been collected and reviewed to construct a strong argument before matrix assembly and weights assessment. Primary data is related to field observation (Table 1). Representative sites, were purposively selected (Figure 1) for identifying processes in every landscape using rapid survey observation approach. This primary data was used to confirm the secondary data.

**Table 1. Field sites observation in 2020**

| No | Site observation                              | Landscape     |
|----|----------------------------------------------|---------------|
| 1  | Merapi volcano barranco                      | Volcanic      |
| 2  | Irrigation paddy field                       | Volcanic      |
| 3  | Coastal and mangroves Baros ecosystem        | Marine        |
| 4  | Waduk Sermo and Menoreh hilly area           | Denudational  |
| 5  | Kali Suci cave and karst area                | Karst         |
| 6  | Underground river outlet of Baron             | Anthropogenic |
| 7  | TPS 3R Brama Muda                            | Anthropogenic |
| 8  | Upper-stream of Code River                   | Volcanic      |
| 9  | Middle-stream Code River                     | Anthropogenic |
| 10 | Down-stream Code River                       | Anthropogenic |
2.3. Data analysis

The AHP technique based on [16] was applied to assess the landscapes weights by defined criteria. In this study, the weights of different landscapes criteria were assigned based on published secondary data and professional judgments during field work observation. The following steps were applied to analyse weights of the landscape criteria using the AHP technique namely: defining goals, defining scaled weights for each criterion based on expert opinion and literature, establishment of pairwise comparison metrics based on scaled weights, calculation of geometric mean, calculation of normalized weights, and calculation of consistency ratio to verify coherence of judgments. The importance of relatively scaled values given by [16] were used to establish the AHP pairwise metric (Table 2).

Table 2. The preference AHP scale for pair wise comparison [16]

| Scores | Importance                        |
|--------|-----------------------------------|
| 1      | Equally important                 |
| 3      | Moderately more important         |
| 5      | Strongly more important           |
| 7      | Very strongly more important      |
| 9      | Extremely more important          |
| 2, 4, 6, 8 | Intermediate values between two levels of importance |

Matrix in the AHP is a positive and inverse type matrix comparison. It means that if the matrix A = (aij) then matrix A is a (n x n) comparison, so, the matrix aji = 1/aij. The relative value of criteria in the matrix can be expressed as normalized relative weights score. This score was obtained from the relative value of each criteria divided by the number of criteria in the matrix. Final result of this calculation is eigenvector and eigenvalues. Then normalized weights were verified based on consistency ratio (CR) calculation, as recommended by [16] in equation 1:

CR = CI/RI

where CI is the consistency index, and RI is the random consistency index. The value for RI is taken from [16] and depends on the number of factors (Table 3). CI was computed using equation 2 [16]:

CI = (λ_{max} - n)/(n - 1)

where, n is the number of criteria or thematic layers, λ_{max} is the eigenvalue of the matrix. Consistency ratios (CR) less than or equal to 0.1 are used in this study as this value is reasonable for consistency requirement by [16].

Table 3. Values for the random consistency index (RI) given by [16]

| n  | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| RI | 0.00| 0.00| 0.58| 0.90| 1.12| 1.24| 1.32| 1.41| 1.45| 1.49|

| n  | 11  | 12  | 13  | 14  | 15  |
|----|-----|-----|-----|-----|-----|
| RI | 1.51| 1.48| 1.56| 1.57| 1.59|
3. Results and Discussion

3.1. Vulnerability of Yogyakarta landscapes
Landscapes in the Yogyakarta province were classified into five types i.e., anthropogenic (A), volcanic (V), marine (M), denudational (D) and karst (K) (Table 1). Every landscape is compared each other using matrix comparison calculation. The order of vulnerability criteria of the landscapes was A>V>M>D>K (Table 4).

| Criteria | A  | V  | M  | D  | K  | Weights | λmax | CI | RI | CR |
|----------|----|----|----|----|----|---------|------|----|----|----|
| A        | 0.56| 0.64| 0.52| 0.43| 0.36| 0.503   | 5.37 | 0.09| 1.12| 0.08|
| V        | 0.19| 0.21| 0.31| 0.31| 0.28| 0.260   |      |    |    |    |
| M        | 0.11| 0.07| 0.10| 0.18| 0.20| 0.134   |      |    |    |    |
| D        | 0.08| 0.04| 0.03| 0.06| 0.12| 0.068   |      |    |    |    |
| K        | 0.06| 0.03| 0.02| 0.02| 0.04| 0.035   |      |    |    |    |
| Total    | 1.00| 1.00| 1.00| 1.00| 1.00| 1.00    |      |    |    |    |

Note: red colour for notice higher weights, blue colour for notice the CR value ≤ 0.1

3.2. Vulnerability of anthropogenic landscape (A) in Yogyakarta city
The most significant criteria of anthropogenic landscape (A) is population density (A-Pd). A-Pd in Yogyakarta city is the result of urbanization, land use change and population increase. This condition leads to increased pressures on the environment to support the demand; the outcome of which is increased impact on other criteria [17]. Sanitation (A-San) is an important criteria due to the urban compactness and dwellings along the Code river. Release of solid waste (A-Sw) and domestic waste through the area and into the Code river has negative impacts on both human and environmental health. A-San includes the impact of A-Sw [18][19]. Table 5 shows the result of matrix comparison in the Anthropogenic landscape of Yogyakarta city. The order of vulnerability criteria of the anthropogenic landscape was San=Pd>Wquan=Wqual>Sw>Uhi.

| Criteria | Uhi | Sw | Wquan | Wqual | San | Pd | Weights | λmax | CI | RI | CR |
|----------|-----|----|-------|-------|-----|----|---------|------|----|----|----|
| Uhi      | 0.03| 0.01| 0.01  | 0.02  | 0.04| 0.04| 0.026   | 6.42 | 0.08| 1.24| 0.07|
| Sw       | 0.09| 0.04| 0.02  | 0.03  | 0.05| 0.05| 0.047   |      |    |    |    |
| Wquan    | 0.15| 0.13| 0.07  | 0.04  | 0.07| 0.07| 0.089   |      |    |    |    |
| Wqual    | 0.21| 0.21| 0.21  | 0.13  | 0.12| 0.12| 0.166   |      |    |    |    |
| San      | 0.26| 0.30| 0.34  | 0.39  | 0.36| 0.36| 0.336   |      |    |    |    |
| Pd       | 0.26| 0.30| 0.34  | 0.39  | 0.36| 0.36| 0.336   |      |    |    |    |
| Total    | 1.00| 1.00| 1.00  | 1.00  | 1.00| 1.00| 1.00    |      |    |    |    |

Note: red colour for notice higher weights, blue colour for notice the CR value ≤ 0.1

Septic waste, runoff from roads and solid waste affect the water quality (A-Wqual) and polluted run off is released to and transported by the Code river. A-Wqual is also polluted by waste, bacteria or chemicals from domestic, industrial or hotel influences. Yogyakarta city relies on piped water and groundwater to meet water quantity demand (Wquan). According to Arijuddin [20], 91.6 % of the area in Yogyakarta city is threatened by limited A-Wquan due to A-Pd. In the other hand, A-Sw is an anthropogenic criteria due to inadequate waste management which has an impact on environmental and social health. The informal dumping of A-Sw across the city leads to contamination of water supply and impacting A-Wqual. In addition, the disposal of organic waste contributes to Green House...
Gas (GHG) emissions. The urban heat island effect (A-Uhi) is an important parameter that results from urbanisation, land cover change and industrialisation.

3.3. Vulnerability of volcanic landscape (V) in Sleman regency
The most prominent criteria for volcanic landscape (V) is volcanic eruption (V-Erup). The impact of volcanic ash (V-Ash) is also important because ash has negative impacts on human health and agricultural productivity. However, V-Ash can positively contribute to agricultural activity due to the addition of nutrients when mixed with the existing soil. Table 6 shows the result of matrix comparison in the volcanic landscape of Sleman regency. The order of vulnerability criteria of the volcanic landscape was Erup>Ash>Hcf>Debris.

Table 6. Synthesized matrix for multi-criteria decision-making of volcanic (V) landscape

| Criteria | Debris | Hcf | Ash | Erup | Weights | λ_{max} | CI | RI | CR |
|----------|--------|-----|-----|------|---------|---------|----|----|----|
| Debris   | 0.06   | 0.04| 0.05| 0.08 | 0.055   | 4.13    | 0.04| 0.90| 0.05|
| Hcf      | 0.19   | 0.11| 0.14| 0.10 | 0.132   |         |     |     |    |
| Ash      | 0.19   | 0.11| 0.14| 0.14 | 0.142   |         |     |     |    |
| Erup     | 0.56   | 0.75| 0.68| 0.69 | 0.671   |         |     |     |    |
| Total    | 1.00   | 1.00| 1.00| 1.00 | 1.00    |         |     |     |    |

Note: red colour for notice higher weights, blue colour for notice the CR value ≤ 0.1

Hyper-concentrated flow (V-Hcf) is a pyroclastic flow mixed with rainwater that flows due to the force of gravity, can exceeded more than 15 km after the 2010 eruption, causing riverbank erosion, riverbed downcutting, and damaging homes, destroying sabo-dams and bridges. V-Hcf also impacts water quantity because of water supply structures buried with V-Hcf material [21]. The distribution of debris (V-Debris) material such as unconsolidated mud, sand, soil, and rock, can impair water quality and quantity in surrounding river systems as well as increase erosion and impact farming practices [22].

3.4. Vulnerability of fluvial-marine landscape (M) in Bantul regency
Water quality (M-Wqual) in coastal area is the most important criteria. It is because riverways transport pollutants from domestic, industrial waste source, sand mining, fisheries, shrimp farming and insufficient of wastewater treatment plant [23]. Wqual is also impacted by more intense rainfall, which increases pollutants and microorganisms in the river system, thereby reducing water quality in marine landscape [24]. Table 7 shows the result of matrix comparison in the fluvio-marine-coastal landscape of Bantul regency. The order of vulnerability criteria of the fluvial-marine landscape was Wqual>Wquan>Sw>Liq=F>Mm=Tsu.

Table 7. Synthesized matrix for multi-criteria decision-making of marine (M) landscape

| Criteria | Tsu | Mm | F | Liq | Sw | Wquan | Wqual | Weights | λ_{max} | CI | RI | CR |
|----------|-----|----|---|-----|----|-------|-------|---------|---------|----|----|----|
| Tsu      | 0.04| 0.04| 0.02| 0.02| 0.02| 0.05  | 0.05  | 0.033   | 7.49    | 0.08| 1.32| 0.06|
| Mm       | 0.04| 0.04| 0.02| 0.02| 0.02| 0.05  | 0.05  | 0.033   |         |     |     |    |
| F        | 0.11| 0.11| 0.06| 0.06| 0.03| 0.07  | 0.07  | 0.074   |         |     |     |    |
| Liq      | 0.11| 0.11| 0.06| 0.06| 0.03| 0.07  | 0.07  | 0.074   |         |     |     |    |
| Sw       | 0.19| 0.19| 0.19| 0.19| 0.10| 0.11  | 0.07  | 0.147   |         |     |     |    |
| Wquan    | 0.26| 0.26| 0.32| 0.32| 0.30| 0.33  | 0.35  | 0.305   |         |     |     |    |
| Wqual    | 0.26| 0.26| 0.32| 0.32| 0.50| 0.33  | 0.35  | 0.333   |         |     |     |    |
| Total    | 1.00| 1.00| 1.00| 1.00| 1.00| 1.00  | 1.00  |         |         |     |     |    |

Note: red colour for notice higher weights, blue colour for notice the CR value ≤ 0.1
High rain intensity related to the Cempaka cyclone in 2017 resulted in overwash and flooding of coastal zone by seawater [25]. However, during the dry season, the seawater level drops and mangroves are not able to survive. Water quantity (M-Wquan) in coastal area must be considered in this landscape as the mangrove plantations are required to be inundated by water for at least 40% of the day [26]. When the mangrove restoration fails, the impact of M-Tsu increases. Solid waste (M-Sw) in coastal area is a parameter that need to be considered. For instance, much of the plastic waste covers the plants or is found attached to the roots of plant structures, acting as marine litter traps [27]. Plastic materials become fragmented generating microplastic due to exposure from solar radiation and wave action, including other factors. Moreover, microplastics can be consumed by many marine organisms, causing mortality [28].

Liquefaction (M-Liq) caused by earthquakes during the rainy seasons is one of the threats in Bantul coastal area [29]. The heavy rain caused by Cyclone Cempaka in November 2017 led to 152 cases of flooding, landslides, and fallen trees around Bantul regency. Tropical cyclones with high intensity of rain are causing increased seawater levels and river systems which lead to flooding in the coastal areas [25]. The cyclone also severely damaged the mangrove area, the community only able to clean and plants hundreds of mangroves in 5 hectares of area due the lack of funding and technology [30]. Marine landscape is also vulnerable to tsunami (M-Tsu) in the event of an earthquake [31]. However, the risk of M-Tsu is low when compared to other parameters. Unfortunately, miss management (M-Mm) of mangroves could impact M-Tsu indeed. If the density and width of the mangrove forest do not meet the ideal conditions, it will not be able to reduce the tsunami waves and speed efficiently [32].

3.5. Vulnerability of denudational landscape (D) in Kulon Progo regency

Mass wasting (D-Mw) occurs naturally in the Kulon Progo regency due to geological characteristics i.e., steep slopes, instable rock layers, frequency of heavy rainfall, earthquakes and high-water content of unconsolidated sediments [33]. The Serang river catchment streams from the hilly landscape and mediates the impact of mass wasting on water quantity (D-Wquan) and groundwater supplies through Kulon Progo [34]. The development of a new International Airport in this area will also increase human traffic and therefore water quantity (D-Wquan) of the landscape [35]. Sedimentation (D-Sed) must be considered as a criteria because it can impact D-Wquan in the river, particularly during the dry season [36]. Table 8 shows the result of matrix comparison in the denudational landscape of Kulon Progo regency. The order of vulnerability criteria of the denudational landscapes was Mw=Wquan=Wquan>Sed.

| Criteria | Sed | Wquan | Wqual | Mw | Weights | \( \lambda_{\text{max}} \) | CI | RI | CR |
|----------|-----|-------|-------|----|---------|-------------|---|----|----|
| Sed      | 0.06| 0.04  | 0.04  | 0.09| 0.057   | 4.18        | 0.06| 0.90| 0.07|
| Wquan    | 0.19| 0.11  | 0.07  | 0.12| 0.122   |             | 0.558|    |    |
| Wqual    | 0.31| 0.32  | 0.22  | 0.20| 0.263   |             | 0.07| 1.00| 1.00|
| Mw       | 0.44| 0.54  | 0.66  | 0.60| 0.558   |             | 1.00| 1.00| 1.00|
| Total    | 1.00| 1.00  | 1.00  | 1.00|         |             | 1.00| 1.00| 1.00|

Note: red colour for notice higher weights, blue colour for notice the CR value ≤ 0.1

3.6. Vulnerability of karst landscape (K) in Gunungkidul regency

The high climate variability in Gunungkidul regency causes wet and dry extremes. When it is wet, the potential for floods and landslides increases. On the other hand, when dry, the potential for prolonged droughts is elevated [37]. Drought (K-Dro) limits the access to save and palatable water supply that impact the overall human capability in the karst area. Table 9 shows the result of matrix comparison in the karst landscape of Gunungkidul regency. The order of vulnerability criteria of the karst landscape was Dro=Wquan=Wqual=Sw.
Karst landscape has unique hydrological systems. It is formed from the dissolution of soluble carbonate rocks such as limestone, dolomite, and gypsum. This condition causes surface water quickly infiltrate and flow away in the karst towards the coast [38]. Unfortunately, the quantity of rain water storage cannot provide water demand during the dry season in Gunungkidul [39]. In addition, access to karst water, typically found in great depth (>100 m), is very limited because it requires high investment and operational cost. Also, many doline ponds dry out after the wet season [40]. Only 30% of all doline ponds in Gunungkidul remain providing water throughout the year. The water storage of doline ponds decreases due to rapid sedimentation and infiltration rate [41].

| Criteria | Sw | Wqual | Wquan | Dro | Weights | λmax | CI | RI | CR |
|----------|----|-------|-------|-----|---------|------|----|----|----|
| Sw       | 0.06 | 0.03  | 0.06  | 0.06 | 0.052   | 4.11 | 0.04 | 0.90 | 0.04 |
| Wqual    | 0.17 | 0.09  | 0.09  | 0.09 | 0.106   |      |     |     |     |
| Wquan    | 0.39 | 0.44  | 0.43  | 0.43 | 0.421   |      |     |     |     |
| Dro      | 0.39 | 0.44  | 0.43  | 0.43 | 0.421   |      |     |     |     |
| Total    | 1.00 | 1.00  | 1.00  | 1.00 | 1.00    |      |     |     |     |

Note: red colour for notice higher weights, blue colour for notice the CR value ≤ 0.1

Water quality (K-Wqual) is a major concern in karst aquifers system. In Gunungkidul, like in many other karst areas, the consumption of untreated water mainly poses severe health risks due to microbiological contamination and calcium carbonate mineralization. Water quality degradation is caused by a variety of activities within the doline ponds, such as bathing (humans and domestic animals) and washing. In addition, the surrounding land use may affect the water quality, particularly in relation to both organic and inorganic fertilizers [41]. Major contaminants of the doline pond are phosphate, COD, nitrate, detergent, E. coli bacteria, and suspended solid [40]. During the observation, solid waste (K-Sw) also has a high potential to directly contaminate doline ponds and underground river intake.

3.7. Hierarchy of landscapes vulnerability to climate change in Yogyakarta province

Climate change is a pressing problem around the world. In Yogyakarta province, Indonesia, the vulnerability of landscapes on climate change is controlled not only by the climate factors but also by the characteristics of this region. In this research, 5 major landscape characteristics have been analysed and weighted to identify and rank the vulnerability probabilities due to climate change. The AHP weighting value of each criterion has been used to classify the priority vulnerability factors of various landscapes (Figure 2). The highest vulnerable landscape is anthropogenic (A) in Yogyakarta city due to population density (A-Pd) and sanitation (A-San) factors.

![Figure 2. Landscape vulnerability hierarchy of weighted values](image)

Eruption (V-Erup) in the volcanic (V) landscape factor in Sleman, is the second most important vulnerability criteria, whereas the marine (M) landscape is the third priority in the climate change...
vulnerability context. The water quality (M-Wqual) criteria is the most important in the coastal area in Bantul regency, while mass wasting (D-Mw) is critical in the Kulon Progo lately. Karst landscape in Gunungkidul regency is the most vulnerable to drought (K-Dro) and water quantity (K-Wquan), but need to be concerned that this landscape can be oppositely most vulnerable due to cyclones combine with heavy rainfall.

4. Conclusions
Yogyakarta province consists of five major types of landscapes, e.g., anthropogenic (A), volcanic (V), coastal (M), denudational (D) and karst (K). The analytical hierarchy process reveals that the landscapes vulnerability is ordered from high to low A>V>M>D>K. The most vulnerable landscape is the anthropogenic landscape in Yogyakarta city. The combination of population density and poor sanitation management should be considered as a factor in climate change mitigation and adaptation in Yogyakarta city. However, this analysis is only based on the previous experience related to evidence of climate change phenomena in Yogyakarta province. Furthermore, a comprehensive analysis with multiple approaches should be applied to accommodate other issues and phenomena in the future.

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