Mapping flood risk zone (a case study: Gajah Wong Sub Watershed, Special Region of Yogyakarta)

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Abstract. Gajah Wong Sub Watershed often experiences a flood incidence that has potentials to destroy and cause material loss so that needed an examination on a flood risk. This study’s objective is to map the level of a flood disaster risk zone and its spread in Gajah Wong Sub Watershed, Province of Special Region of Yogyakarta. The study’s method used weighing and scoring method with overlay analysis technique of flood risk parameter attribute data consisting of flood hazard, vulnerability and capacity using Geographic Information System (GIS). It complies with Disaster Prevention-National Agency Head’s Decree No. 02/2012 with modification. Each parameter is modified, weighing and scoring are used to gain values of attribute data. The results of study indicate that flood risk in Sub Watershed Gajah Wong consisted of 3 levels, namely, low level of flood risk having 440.86 ha (89.22%), medium level of flood risk having 157.81 ha (3.20%) and high level of flood risk having 374.25 ha (7.59%). Low level of flood risk widely dominated distribution to upstream zone covering sub-district of Pakem, sub-district of Ngemplak and sub-district of Ngaglik. Medium level of flood risk was distributed to some middle areas and downstream zone covering some sub-districts, such as part of Umbulharjo, part of Kota Gede and part of Banguntapan. While, high level of flood risk was spread in south part of Depok sub-district and north part of Pleret sub-district.

1. Introduction
Global warming causes sufficiently significant climate anomaly. Change in global climate makes hydrologic cycle abnormal, which will affect extreme conditions such as flood [1]. Flood disaster is generally very associated with climatic condition [2]. Flood causes some sufficiently serious impacts on human life. Flood disaster is considered as one natural disaster most frequently contributing to great disaster, loss, damaged infrastructures and ecology [3], as and give a negative influence on the social economy, obligations and property, problems related to health, and ecosystem functions [4].

Gajah Wong Sub Watershed is a part of Opak Watershed covering 3 areas of district/city, namely, district of Sleman, Yogyakarta City and district of Bantul. Gajah Wong Sub Watershed has river known as Sungai Gajah Wong, being one biggest river frequently facing flood events [5]. Flood potential dominated Gajah Wong Sub Watershed. Flood inundated houses and resulted in loss; on April 22 of 2015, flood inundated 95 people’ houses and and damaged their houses. Event of cempaka hurricane cycle on November 29 of 2017 caused flood resulting in damaged dam and people’ houses in some locations [6]. Resulting effects would increase every year so that it is necessary to map flood risk zones using Geographic Information System (GIS) facilities to minimize flood disaster risks.
Knowledge on disaster is necessary to understand and minimize the resulting effects in order that life is safe and peaceful [7].

A flood is an unpreventable natural phenomenon. Flooding occurs due to the effects of heavy rain and natural waterways that do not have the capacity to accommodate excess water [8]. Flood disaster has negative impacts for humans both in long-term as well as long-term, so that needed to determine areas that have a flood risk as an initial step to the necessity of a flood disaster management.

Each area has disaster risk potentials. Disaster risk is loss potential caused by a disaster such as death and loss of materials occurring in a community and the people in specific period [9].

Disaster risk occurs in zones having high hazard and vulnerability rates with lower capacity. Disaster risk is gained using simple formulations consisting of hazard, vulnerability and capacity parameters [10].

Attribute analysis with scoring method aims at giving specific values of spatial data phenomena. It aims at understanding effects of components on flood risk in Gajah Wong Sub Watershed. Parameters used to make flood risk map consist of flood, vulnerability (classified into aspects of physical, economic, social and environmental susceptibilities) and capacity parameters.

Geographic Information System (GIS) is an integrated software, designed specially to be used with geographic data to perform tasks of data processing comprehensively consisting of input, storage, retrieving and output of data with various analytical and descriptive types [11]. Use of GIS with remote sensing combination can widely be used and applied to analyze disaster with provision of spatial data networks nationally and entirely [12]. GIS can be a very important tool in decision making of sustainable development, because GIS gives information to decision making for spatial database and analysis [13].

2. Area of Study and Data

Gajah Wong Sub Watershed is a part of Opak Watershed located in the Province of Special Region of Yogyakarta. Administratively using 3 areas of district/city consisting of upstream parts, Sleman district covers sub-districts of Pakem, Ngemplak, Ngaglik, and Depok. The middle part is Yogyakarta City covering sub-districts of Umbulharjo, Kota Gede and Gondokusuman. Downstream part is district of Bantul covering sub-districts of Banguntapan and Pleret [14].

![Figure 1. Location of study area](image)
Most of these study data were collected from secondary data deriving from governmental institutions such as Development Planning Agency at Sub-National Level (BAPPEDA), Central Agency on Statistics (BPS), Center for Water Resources Management (BPSDA), Mlati Climatology Station (BMKG) and primary data, namely, the results of observation and interview. The data are used to make maps of flood risk consisting of maps of flood, vulnerability parameter data and capacity parameter data.

Secondary data are used to comply with area of Gajah Wong Sub Watershed, then these are classified again to make scoring and weighing based on magnitude of effect on flood event. Here is a list of data used in this research:

| Datasets                                      | Source                                           | Date or Year | Resolution |
|-----------------------------------------------|--------------------------------------------------|--------------|------------|
| Flood Hazard Map                              | Development Planning Agency at Sub-National Level (BAPPEDA) | 2015         | Vector     |
| Environmental Vulnerability                   | Development Planning Agency at Sub-National Level (BAPPEDA) | 2015         | Vector     |
| • Land use                                    |                                                  |              |            |
| • Inclination of slope                        |                                                  |              |            |
| • Land type                                   |                                                  |              |            |
| • Geology                                     |                                                  |              |            |
| Contour                                       | Development Planning Agency at Sub-National Level (BAPPEDA) | 2015         | Vector     |
| Data of average annual rainfall of 4 observation points for 14 years | Mlati Climatology Station (BMKG) | 2003-2017    | Vector     |
| Map of Gajah Wong Sub Watershed               | Center for Water Resources Management (BPSDA)    | 2017         | Vector     |
| Physical vulnerability                        | Central Agency on Statistics (BPS)               | 2016/2017    | Vector     |
| • Total public facilities                     |                                                  |              |            |
| • Total critical facilities                   |                                                  |              |            |
| Social vulnerability                          |                                                  |              |            |
| • Population density                          |                                                  |              |            |
| • Ratio of female population                  |                                                  |              |            |
| • Ratio of poverty                            |                                                  |              |            |
| • Ratio of disable persons                    |                                                  |              |            |
| • Vulnerable age group                        |                                                  |              |            |
| Economic vulnerability                        |                                                  |              |            |
| • Productive land                             |                                                  |              |            |
| • GRDP                                        |                                                  |              |            |
| Google Earth Image to calculate total house buildings. | Google Earth | 12/11/2017 | Raster (8 meters) |
| Flood capacity                                | Observation & Interview | 15/03/2018-01/04/2018 | - |
3. Methodology
This study is descriptive-quantitative, leading to expression of facts followed by interpretation and analysis [15]. This study used weighing and scoring method based on magnitude of effects of arrangement parameters on flood risk with overlay technique. Norm of flood risk map arrangement complies with Disaster Prevention-National Agency Head’s Decree No. 02/2012 with modification.

Analysis by weighing, scoring and overlay are more popular used today, especially related to the use of a Geographical Information System (SIG). Some governmental institutions such as Regional Development Planning Board, Public Work Office, BMKG and others often use this method in performing a spatial analysis, especially related to natural disaster study. The methods used are easier and are able to use a varied parameter attributal data/variable that will be overlaid. However, this analysis has also a weakness because it greatly depends on availability, data update and parameter data generalization process to be used so that it can decrease the accuracy of a flood risk data output yielded.

3.1. Parameters of Flood Risk

3.1.1. Flood Hazard
Flood Hazard is an event having potential to cause damage, human death or ecologic damage. Map of Flood Hazard is gained from Development Planning Agency at Sub-National Level (BAPPEDA) used as reference to arrangement of Disaster Prevention Plan (RPB) at provincial level. This map was made by Cropping according to area of Gajah Wong Sub Watershed and re-scored by highest score of 25, medium score of 15, and lowest score of 5.

3.1.2. Flood Vulnerability
Physical vulnerability consists of total houses/sub-district, total public facilities and total critical facilities. Social vulnerability consists of population density, ratio of female population, ratio of poverty, ratio of disabled persons, ratio of vulnerable age group (0 – 14 years and > 65 years old). Economic vulnerability consists of area of productive land and gross domestic regional product (GRDP). Ecologic vulnerability consists of land use, slope inclination, rainfall, land type, geology, height of location and river buffer.

Each of parameters is given weighing according to magnitude of effect on Flood Vulnerability. Each of vulnerability variables gives highest and lowest scores, then the scores are quantification to gain vulnerability score interval.

| No. | Variable              | Highest Score | Lowest Score |
|-----|-----------------------|---------------|--------------|
| 1   | Physical Vulnerability | 50            | 10           |
| 2   | Social Vulnerability  | 65            | 13           |
| 3   | Economic Vulnerability| 35            | 7            |
| 4   | Ecologic Vulnerability| 130           | 26           |
|     | Total                 | **280**       | **56**       |

Equation to make interval class follows simple equation by Dibyosaputro in Hermon (2015) minimizing total highest and lowest scores, then divided by total desirable classes [16].
\[ I = \text{class interval distance}, \ b = \text{total lowest scores} \text{ and } k = \text{desirable class}. \]

This study used three desirable vulnerability classes. The obtained intervals are classified into high vulnerability criteria > 206 – 280, medium vulnerability interval > 131 – 206, and low vulnerability interval 56 – 131.

All vulnerability parameters consist of physical vulnerability, social vulnerability, economic vulnerability and ecologic vulnerability conducted by overlay technique to make Flood Vulnerability Map of Gajah Wong Sub Watershed. Overlay is conducted by quantifying end scores of each vulnerability parameter and classified based on made intervals.

### 3.1.3. Flood Capacity

Capacity is people’ ability consisting of attribute, force, and resources to take action to minimize hazard threat rate, vulnerability and loss as result of a disaster of an area.

Capacity parameter is classified into 5, each of them are scored based on magnitude of effect. Capacity consists of rules and institutionalization of disaster prevention, early warning and review of flood risk, education of disaster, minimization of basic risk factor, and readiness development in all lines. Similar to Flood Vulnerability, we find highest and lowest scores to make Flood Capacity interval.

| No. | Variable                                      | Highest Score | Lowest Score |
|-----|----------------------------------------------|---------------|--------------|
| 1   | Rule and Institutionalization of Disaster Prevention | 15            | 3            |
| 2   | Early Warning and Review of Disaster Risk     | 25            | 5            |
| 3   | Education of Disaster Issues                  | 20            | 4            |
| 4   | Minimization of Basic Risk Factor             | 20            | 4            |
| 5   | Readiness Development in all Lines            | 20            | 4            |
|     | **Total**                                    | **100**       | **20**       |

Classification of Flood Capacity level consists of three classes, namely, high interval criteria > 74 – 100, medium interval criteria > 47 – 74, and low interval criteria = 20 – 47.

### 3.2. Flood Risk

Maps of flood disaster risk in Gajah Wong Sub Watershed were obtained by overlay parameter of flood risk, namely, maps of hazard, vulnerability and capacity. Overlay was conducted using simple equation principle for end scores of flood risk parameters based on simple formula based on Disaster Prevention-National Agency Head’s Decree No. 02/2012.

\[ R = \frac{(H \times V)}{c} \]

Where:
- \( R \) = risk
- \( H \) = hazard
- \( V \) = vulnerability
- \( c \) = capacity

flood risk level intervals are found by using principle similar to vulnerability and capacity using simple equation for highest and lowest scores of flood risk parameters.
Table 4. Highest and Lowest Scores of Flood risk

| No. | Variable              | Highest Score | Lowest Score |
|-----|-----------------------|---------------|--------------|
| 1   | Hazard                | 25            | 5            |
| 2   | Total Vulnerability   | 280           | 56           |
| 3   | Capacity              | 100           | 20           |
|     | Risk=(Hazard x Vulnerability/Capacity) | 70            | 14           |

Based on the table, classification of flood risk level is classified into 3 interval classes. High flood risk interval > 52, medium flood risk interval > 33 – 52, and low flood risk interval < 33. Arrangement of flood risk map may be seen in flowchart of study shown in the Figure 2:

Figure 2. Flowchart of Study (research)
4. Result and Discussions

4.1. Parameters of Flood Risk

4.1.1. Flood Hazard

Based on the results of classification analysis, Flood Hazard level is classified into three levels, namely, low Flood Hazard level having 3113.77 ha reached 63.11% of total area of Sub Watershed, medium hazard level having area of 1662.34 ha reached 33.69%, high flood disaster level having area of 157.81 ha reached 3.20%. The medium hazard level was distributed unevenly starting from sub-district of Depok to sub-district of Pleret. High flood disaster level was distributed to south area of Kota Gede sub-district, Umbulharjo sub-district, and middle area of Banguntaman sub-district. The low flood disaster level was distributed to all of Pakem sub-district, Ngemplak sub-district, and Ngaglik sub-district. The following flood disaster map of Gajah Wong Sub Watershed can be seen below.

![Figure 3. Map of Flood Hazard](image)

4.1.2. Flood Vulnerability

Based on the results of overlay analysis of vulnerability level of Gajah Wong Sub Watershed, it consists of two vulnerability intervals, namely, medium and high Flood Susceptibilities. Medium Flood Vulnerability widely dominated Gajah Wong Sub Watershed having area of 4933.92 ha, nearly reaching 100% of total area in Sub Watershed. The high vulnerability interval has area of 8.78 ha only reaching 0.18%.
Based on the Figure 4, distribution of medium Flood Vulnerability interval was distributed to nearly all areas of Sub Watershed Gajah Wong. The high Flood Vulnerability interval was distributed to only downstream segment of Gajah Wong Sub Watershed, exactly located in Pleret sub-district. The high vulnerability interval has area following flow pattern of river buffer analysis in distance from 0-25 m² Gajah Wong.

![Figure 4. Map of Flood Vulnerability](image)

4.1.3. Flood Capacity

The high Flood Capacity interval widely dominated the Gajah Wong Sub Watershed. The high Flood Capacity interval has area of 2148.79 ha reaching 43%. The medium Flood Capacity interval has area of 1648.47 ha reaching 33.41%. The low Flood Capacity interval has area of 1136.66 ha reaching 23.04%.

The high Flood Capacity interval dominated five sub-districts, namely, sub-district of Ngemplak, sub-district of Umbulharjo, sub-district of Kota Gede, sub-district of Gondokuman and sub-district of Banguntapan. The medium Flood Capacity interval covered sub-district of Pakem, sub-district of Ngaglik, and sub-district of Pleret. The low Flood Capacity interval faced alone only sub-district, namely, sub-district of Depok. So, the Flood Capacity interval would tend to be high, leading to central city.
4.2. Flood Risk

Based on the results of analysis, flood risk interval in Gajah Wong Sub Watershed consists of three intervals, namely, low flood risk interval, medium flood risk interval and high flood risk interval. The low flood risk interval was distributed to various zones of Sub Watershed and had wider area, namely, 4401.86 ha reaching 89.22% of total area. The remaining, approximately 10% consists of medium flood risk interval having area of 157.81 ha reaching 3.20% and the high flood risk interval has area of 374.25 ha reaching 7.59%.

| No | Flood risk Interval | Area (Ha) | Percentage of Total Area (%) |
|----|---------------------|-----------|-----------------------------|
| 1  | Low                 | 4401.86   | 89.22                       |
| 2  | Medium              | 157.81    | 3.20                        |
| 3  | High                | 374.25    | 7.59                        |

Distribution of flood risk interval in Gajah Wong Sub Watershed covered upstream, middle-stream, and downstream zone segments. Flood risk interval with low criteria was nearly distributed to all parts of Sub Watershed consisting on all areas of Pakem sub-district, Ngemplak sub-district, and Ngaglik sub-district. The medium flood risk interval was distributed to some parts of middle and downstream zones only covering few administrative Umbulharjo sub-district, some of Kota Gede and
Banguntapan sub-districts. Zones with high flood risk intervals consisted of two sub-districts, namely, southern part of Depok sub-district and northern part of Pleret sub-district with upstream and downstream zone segment divisions.

The results of observation and interview indicate that the sub-district of Depok and sub-district of Pleret have higher flood disaster risks than other sub-district areas. The areas have lower Flood Capacity interval and have other problems such as overflow from Gajah Wong River. The condition was proven by some details and documentations of KPGW leader suggesting that the areas frequently faced floods and the floods inundated zone of confluence between Gajah Wong River and Opak River also frequently facing floods in height reaching one-half meters. It was proven by mud being the remaining materials of floods frequently occurring in rainy season.

People’ care for river is found lower. Activities of household waste and garbage throwing are still sufficiently intense in zone of Gajah Wong River. In addition, there are activities of sand mining conducted by people surrounding, which would certainly affect the damaged river dam. The following is a map of flood disaster risk distribution to Gajah Wong Sub Watershed.
Figure 8. Map of Flood risk

5. Conclusion and Recommendation
Flood risk intervals in Gajah Wong Sub watershed were dominated by low risk, having area of 4401.86 ha reaching 89.22% of total area. Medium risk interval with area of 157.81 reached 3.20% and high risk interval with area of 374.25 ha reached 7.59%. Low flood risk interval was distributed to most of upstream zone covering sub-district of Pakem, sub-district of Ngemplak, and sub-district of Ngaglik as well as higher proportion of Depok sub-district. Medium flood risk interval was distributed to some parts of middle and downstream segment zones covering few of administrative sub-district of Umbulharjo, some of Kota Gede sub-district, and Banguntapan sub-district. High flood risk interval was distributed to some sub-districts of Depok and Pleret.

This study has some disadvantages and weaknesses so that needed to add and update data. Such as data of rainfall that only consisting of rain average during 14 years, at least 20 to 30 years. Other disadvantages such as land use, slope of mountain, land type geology and height of location are data from 2016 so that it should be updated at least last year. DEM data used to make a map of location height is only sourced from contour interpolation, this data should be obtained through interpolation of height point based on results of a direct field survey. There is a strong generalization towards some parameters such as flood capacity parameter and some flood vulnerability parameters. This more directs to data limitedness problems.

Flood frequently facing Gajah Wong Sub watershed would continuously affect people’ loss. Damages consisted of damages of building infrastructures, dam dike and other facilities, so that it is necessary to make efforts to prevent further damages. In analysis of disaster review, such as, hazard,
vulnerability, risk capacity and mitigation direction mapping is an initial step to minimize resulting disaster effects. The government should take some actions of flood resistance construction improvement. Some of the constructions are dike, barbed, and dam facing damages to minimize further damages in Gajah Wong Sub watershed. The government should optimize independent cooperation in finishing sectors such as river base dredging to minimize river shallowness caused by sedimentation and erosion.

Part of upstream segment is provided with forest conservation aiming at establishing absorption zones. It is conducted to minimize rain water overflow deriving from upstream, because upstream zone tends to have averagely high rainfall so that effect of flood disaster may be minimized.

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