Analysis of Flood Vulnerability Using GIS Method (Case Study : Beringin Watershed, West Semarang)

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Abstract. Land degradation in the Beringin Watershed causes an increase of runoff and have high potential for flood disaster. The fact is proven by the distribution of land use for settlements in 1995 which was 18.45%, increased to 22.65% in 2002, thus enlarging the peak discharge in the Beringin watershed. To overcome this problem, it is necessary to study the effects of land use conversion on flood discharge and formulate the concept of management of Beringin watershed. Maximum annual daily rainfall be calculated with Polygon Thiessen method for 3 rain stations: Mijen, Mangkang Waduk, and Tugu for 20 years data (1998 – 2017). For the land use analysis, we was compared 2015 year Beringin watershed land use data with RTRW Semarang (Spatial Plans) 2011-2031 data and identified by using ArcGIS software. Whereas for the discharge design, the results of the HEC-HMS program modeling with 3 small dam was constructed for 10-years return period is $178.9 \text{ m}^3/\text{dt}$. River normalization is design on the river downstream along ± 3.9 km, from the estuary (STA 0 + 6.2) to the Mangkang (STA 3 + 909.05) and from HEC-RAS simulation results shows that its can discharge safely.

Keywords: Beringin Watershed, ArcGIS, Normalization.

1. Introduction
Flood disaster is the most frequent natural disaster in Indonesia. Data shows that ± 40% of natural disasters are floods [1]. Rapid population growth and development have caused changes in land use in the city of Semarang. Many of the land that was originally open land / forest has turned into residential and industrial areas. This resulted in an increase in runoff and enlarged peak discharge in the Beringin watershed has resulting in an increase in the potential for flood disaster [2]. The Beringin watershed has a flood inundation area in Podorejo Village - 174.00 ha, Mangkang Wetan Village - 323.00 ha, Tambakaji Village - 4.00 ha, Wonosari Village - 28.00 ha, and Mangunharjo Village - 28.80 ha [3]. The distribution of land used for settlements in 1995 was 18.45%, an increase in 2002 to 22.65% of the total area in the Beringin Watershed. Uncontrolled land use has an effect on runoff, thus increasing the peak discharge in the Beringin watershed [4]. The occurrence of these floods, it shows that the quality of the Beringin River Basin (DAS) has a high degradation and needs to be reviewed for watershed management.

2. Methods
The methodology in this research is presented in the flow chart in Figure 1.
3. Results and Discussions

3.1 The Result of Land Use Analysis

Land use analysis with GIS Method has obtained that Beringin watershed is divided into 31 sub-watersheds as Figure 2a and consisting of 3 types of soil, : Alluvial (C), Mediterranean (C), Latosol (D) as Figure 2b.
Figure 2a. 31-Sub Watershed Beringin and Figure 2b. Three types of soil at Beringin Watershed

3.2 The Results of Hydrological Analysis

Hydrological analysis is needed to determine the design flood discharge which will be used to planning reservoir development.

3.2.1 Rainfall Calculation

The rain gauge stations are were used Tugu (Sta. 41), Mijen (Sta. 44), and Mangkang Waduk (Sta. 41c) with rainfall data during 1998-2017 (20 years). Then the Thiessen Method is used to calculate the maximum annual daily rainfall. Table 1. shows the effect of the rain station of the Thiessen coefficient. Table 2. shows the results of the calculation of maximum annual daily rainfall. And Figure 3. shows the location of the rain station and the division of area which is adhered to by Thiessen Polygon.

Table 1. Calculation of The Thiessen coefficient

| No. | Station            | Area (km²) | Thiessen Coeff |
|-----|--------------------|------------|----------------|
| 1.  | Mijen (44)         | 9.57       | 0.28           |
| 2.  | Tugu (41)          | 11.89      | 0.35           |
| 3.  | Mangkang Waduk (41c) | 12.38     | 0.37           |
|     | Total              | 33.84      | 1.00           |

Table 2. Maximum Annual Daily Rainfall (1998-2017)

| No. | Year | Maximum daily rainfall (mm) | No. | Year | Maximum daily rainfall (mm) |
|-----|------|-----------------------------|-----|------|-----------------------------|
| 1.  | 1998 | 72.09                        | 11. | 2008 | 100.21                      |
| 2.  | 1999 | 108.36                       | 12. | 2009 | 170.26                      |
| 3.  | 2000 | 164.09                       | 13. | 2010 | 68.96                       |
| 4.  | 2001 | 82.67                        | 14. | 2011 | 63.43                       |
| 5.  | 2002 | 59.07                        | 15. | 2012 | 96.97                       |
| 6.  | 2003 | 51.40                        | 16. | 2013 | 120.54                      |
| 7.  | 2004 | 104.74                       | 17. | 2014 | 167.33                      |
| 8.  | 2005 | 48.79                        | 18. | 2015 | 111.78                      |
| 9.  | 2006 | 148.11                       | 19. | 2016 | 83.58                       |
| 10. | 2007 | 83.34                        | 20. | 2017 | 127.37                      |
Furthermore, the frequency analysis of rain data is carried out using 4 probability distributions: Gumbel, Normal, Log Normal, and Log Pearson Type III. After processing the data, we obtained values were skewness coefficient (Cs), kurtosis coefficient (Ck), and coefficient of variation (Cv) which are used as variables to select the type of rainfall data distribution.

### Table 3. Result of The Frequency Analysis

| Distribution     | Requisite       | Result | Information |
|------------------|-----------------|--------|-------------|
| Normal           | Cs ≈ 0          | 0.508  | rejected    |
|                  | Ck ≥ 3          | 2.662  |             |
| Log Normal       | Cs ≈ 0.258      | -0.080 | rejected    |
|                  | Cv ≈ 0          | 0.084  |             |
| Gumbel           | Cs < 1.1396     | 0.377  | rejected    |
|                  | Ck < 5.4002     | 2.662  |             |
| Log Pearson III  | Cs ≠ 0          | -0.080 | accepted    |
|                  | Ck ≈ 2.884      | 2.541  |             |

*Source: Triatmodjo, 2008.*

Flood discharge was calculated using the HEC-HMS method. Before calculating the design flood discharge, this research needs to conduct the land use analysis to get the parameters of the HEC-HMS method. The results of the analysis are presented in Table 4.

### Table 4. Ratio of land use RTRW (Spatial Plans) 2011-2031 vs 2015

| No. | Parameter                                | RTRW (Spatial Plans) 2011 - 2031 | 2015 | Increase (+) / decrease (-) |
|-----|------------------------------------------|----------------------------------|------|-----------------------------|
|     | Area (km²) (%)                          | Area (km²) (%)                   |      |                             |
| 1.  | Land Use                                 |                                  |      |                             |
|     | - Forest                                 | 8.552 25.27                      | 7.952 23.50 | -                          |
|     | - City (Industry, Mixed Business, Trade and Services, Education etc.) | 6.933 20.49 | 8.193 24.21 | +                          |
|     | - Settlement                             | 8.994 26.58                      | 11.841 34.99 | +                          |
Flood analysis using the HEC-HMS method with $Q_{10h}$, based on 2015 land use and the RTRW Semarang City (Spatial Plan) 2011-2031 has obtained hydrograph as shown in Figure 5.

From Figure 5, it was concluded that 2015-flood discharge is exceeded than flood as designed 2011-2031 Spatial Plan, so it was necessary to proposed reservoir to reduce the existing flood discharge. Three potential reservoirs proposed in the Beringin watershed with total capacity of $\pm$ 7,504,548 m$^3$.

Flood simulation if 3 (three) new reservoirs in the watershed are constructed, can reduce the existing peak flood discharge from 264.3 m$^3$/sec to 178.9 m$^3$/sec or 32.31% below the peak discharge of the RTRW 2011-2031 for the period 10-years return, as presented in Figure 6.

### 3.3 The Results of Hydraulics Analysis

Hydraulic analysis aims to determine the ability of a river cross section to conduct the design discharge. As explained that one of the causes of flooding is because the river cross section cannot to drain the flood discharge. The HEC RAS simulation concluded that the cross section was unable to accommodate the flood discharge and the cross section needs to be expanded. In river cross-section analysis, the HEC-RAS program modeling method is used.

There are 5 (five) main steps in hydraulic simulation with HEC-RAS model:

1. Start a new project and giving the name of the project
2. Drawing a river flow scheme. The scheme is obtained by exporting data from Auto CAD Civil 3D. Elevations and river cross sections are included in the scheme.
3. Enter the geometry and hydrology data (river scheme, cross section, design discharge data, etc.).
4. Enter the boundary requisites; - Boundary Condition (upstream debit data) - Initial Condition (tidal data)
5. Perform hydraulic calculations. Simulation of river cross section with HEC-RAS is use design discharge i.e. 178.9 m$^3$/sec ($Q_{10}$ years).

### 3.4 Cross Section Normalization Planning

HEC-RAS modeling was running in 2 conditions; 1). Running with the cross section existing, and 2). Running with the river cross section after normalized. Based on running the HEC-RAS modeling
condition 1, it can be concluded that there are still several river cross sections are not able to accommodate flood discharge (see Table 5, part: Cross Section Existing before normalization). Flood is causes runoff of water and inundation in the downstream section of the river. The area of flood inundation can be seen in Figure 7.

![Figure 7. Flood Inundation Area](image)

From Table 5. and Figure 7. it can be concluded that the construction of 3 small dams (embung) in the upstream area is still not enough to reduce the river water level in the downstream. Normalization is needed to accommodate the existing flood discharge. Normalization will be carried out in condition 2 by widening the cross-section of the river to 50 meters wide, with 6 meters height, 1:1 slope ratio and 1:2 slope of embankment.

**Table 5. Comparison of cross sections existing and after normalization (for example)**

| Point       | Cross Section Existing (before normalization) | Cross Section (after normalization) |
|-------------|---------------------------------------------|-------------------------------------|
| STA + 1438.89 | ![Graph](image) | ![Graph](image) |
So that normalization in the downstream Beringin watershed by widening river cross section by 5 to 50 meters is a solution to reduce flood. According to Kodoatie and Sugiyanto (2002) there are several activities to handling floods with non-structural solution, for example:

a. Management of Watersheds
b. Land use arrangements
c. Utilization of the flood area
d. Forecasting and warning of flood hazards
e. Community Extension

4. Conclusion
Based on the land use, hydrology and hydraulic analysis, its can be concluded that:
1. Land Use in 2015 has exceeded the 2011-2031 RTRW, especially forest areas, agriculture, and ponds which have changed into residential and urban areas (industry, mixed business, trade and services, education etc.).
2. Land Use that deviates from the 2011-2020 RTRW causes an increase in peak flood discharge from 232.0 m³/sec to 264.3 m³/sec for Q₁₀.
3. Beringin Management river basin are divided into two parts: upstream and downstream. Upstream is construction of 3 reservoirs which has potential capacity of ± 7,504,548 m$^3$ can reduce peak flood discharge by 32.31% for $Q_{10}$. Downstream is needed by widening the river cross section existing to 50 meters wide to reduce the floods.

4. Increasing the effectiveness of Beringin Watershed management with non-structural solutions such as:
   a. Management of watersheds
   b. Control the development of inundation areas including land use regulations.
   c. Early warning flood system.
   d. Operational flood control.
   e. Society participation.
   f. Law - Enforcement.

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