Sensitivity analysis of arc-hydro on the watershed responses in urban and rural area

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Abstract. Program for predicting runoff discharge from rain events is HEC-HMS. The results of the HEC-HMS hydrograph depends on the characteristics of the watershed. Arc-Hydro/HEC-Geo HMS are programs that are usually used in hydrological modelling. The results of the Arc-Hydro analysis depends on the sensitivity of the topographic map. Due to complex surface shapes because the effect of high-level urbanization in urban areas, it will cause error in extracting the pattern of the natural network path due to roads and buildings. This will complicate the Arc-Hydro program in determining watershed boundaries. The objective of this research is to analyse the sensitivity of Arc-Hydro to make watershed delineation and their influence on the watershed responses using HEC Geo-HMS. Based on the result of this study, the resulting catchment area of the Arc-Hydro delineation with manual (based on the field survey) delineation has a significant difference in urban area compared to rural area. These results also have a significant impact on the results of hydrograph simulations of flood runoff in urban areas. So it was concluded that the determination of watershed boundaries in urban areas does not only rely on the Arc-Hydro but also needs to be validated based on the field survey.

1. Introduction

Determination of flow discharge on a watershed is usually predicted through a rain event. A useful program for predicting flow discharge from a rain event is HEC-HMS [1]. HEC-HMS program will produce a hydrograph as an output that represent the characteristics of the watershed. The most important part of the watershed characteristics is the watershed delineation. Tools that are usually used in develop a catchment area is watershed processing using Arc-Hydro program. The analysis of Arc-Hydro for delineating a watershed is based on the sensitivity of a topographical map, usually using DEM (Digital Elevation Model).

Topographic conditions of an area has a greatly effect of the watershed boundary and flow network which will also affect the hydrograph results as well. DEM can be used well to determine watershed boundaries in rural areas because of the dominant level of natural channels compared to artificial channels in rural areas [2]. However, due to complex surface shapes because the effect of high-level urbanization in urban areas, it will cause the modification of the natural network path pattern due to roads and buildings [2]. Those artificial channels will cause errors in extracting networks flow in Arc-Hydro.

The errors on determining the watershed delineation will have an influential result on the characteristics of the watershed. Those results will also have a direct impact on the results of hydrograph simulation output in HEC-HMS. Based on the statement, the objective of this research is to analyse the
performance of Arc-Hydro to make a watershed delineation and their influence on the watershed responses using HEC Geo-HMS. In this paper will compare and analysis the difference shape of watershed by Arc-Hydro using vertices editor by GIS in urban and rural area.

2. Research Methodology and Material

The study began by determining the location of study area based on the characteristics of the watershed using CWP in 2003 for determining urban-rural classification [3]. Based on the ICM chart by CWP, urban watershed can be presented by Universitas Indonesia Watershed that have impervious cover values exceeding 25% and Rural watershed can be presented by Cisukabirus Sub-Watershed that have impervious cover values below 10%. The selection of research site also considered according to the terrain-relief. After that, watershed delineation and properties was carried out using the help of Arc-Hydro and HE-Geo HMS using DEM 1:8000 from DEMNAS and validating the watershed boundaries by field survey and the help of Google Earth 2019 for manually delineation.

Regional rainfall at the study site were conducted using Thiessen Polygon Method [4]. Then Analysis frequency data for design rainfall or return period using rainfall data from 2003-2019 [5] for each study area. The results of analysis frequency data were tested for compatibility using Chi-square test and Smirnov-kolmogrov test [6]. Both of the watershed delineation method (Arc-Hydro and Manual), SCS Unit Hydrograph was used in each study location to produce flow hydrograph [7]. SCS (Soil Conservation Service) developed a classification of soil type into Hydrological Soil Group (HSG). This classification is adjusted based on the consideration of potential surface runoff under the same conditions and land use for determining CN Value [8]. The CN value can be obtained by HEC-Geo HMS by generated CN Grid [9], while for the manual delineation CN valued carried out by the help of GIS open attribute table and excel calculation. For the two methods of delineation, the CN values for each of the land use cover have the same result. The results of weighted CN values can be seen on the table below.

The sensitivity of Arc-Hydro to make watershed delineation can be seen based on the comparison of vertices coordinates of the watershed boundary. Then the influences of the difference in the results of determining watershed boundary on the watershed responses can be seen by the comparison of the flow hydrograph simulations.

2.1. Watershed Delineation

Delineation of a watershed in urban and rural area first obtained from Arc-Hydro program. From Arc-Hydro, for visualizing the characteristics of the watershed, HEC-Geo HMS was used [5].

![Arc-Hydro Delineation](image1.png) ![Manual delineation](image2.png)

**Figure 1.** Universitas Indonesia Watershed (a) Arc-Hydro Delineation (b) Manual delineation
The significant differences in urban area occurred because of the watershed from Arc-Hydro does not define the flow from Danau Kenanga. Danau Kenanga has an upstream flow from Kemiri Residence, and its downstream flows up to Danau Puspa based on the field survey. While for rural area, does not shows too many significant differences in watershed boundary determination. The sub-watershed division in Universitas Indonesia can be seen in Figure 4a. and 4b. From the figure, it can be seen that there are 12 sub-watershed obtained from the manual delineation based on the field survey, whereas only 9 sub-watershed obtained from Arc-hydro delineation.

3. Results and Discussion

3.1. Comparison of Vertices Coordinate of the Watershed Boundary

Based on the comparison of vertices coordinate of watershed boundary from manual and Arc-Hydro delineation can be seen that urban area has a significant difference in determining watershed boundary. Vertices coordinates are coordinates that form a polyline (line) in Arc-Map program [10]. Those coordinates have x and y values based on the location of the topographic surface on earth.
Table 1. Comparison of Catchment Area in Urban and Rural Cisukabirus

|                | Arc-Hydro (Km²) | Manual (Km²) | Arc-Hydro (Km²) | Manual (Km²) |
|----------------|-----------------|--------------|-----------------|--------------|
| Cisukabirus    | 16.642          | 16.79        | 4.88            | 5.78         |
| Universitas Indonesia |

3.2. Comparison of Flow Simulation Hydrograph

Based on the simulation between the Arc-Hydro/HEC-Geo HMS delineation and manual delineation based on the field survey in rural area (Universitas Indonesia) watershed shows a significant difference on the peak discharge of the hydrograph compared to rural area (Cisukabirus watershed). This shows that Cisukabirus that assumes as rural area are showing smallest differences on the peak discharge output comparison between Arc-Hydro and manual delineation. The significant difference of peak discharge in urban area because of the watershed also shows a significant difference on the catchment area between manual and Arc-Hydro delineation.

Figure 4. Flood Hydrograph of Cisukabirus (a) 2-year return period, (b) 10-year return period

Figure 5. Flood Hydrograph of Universitas Indonesia (a) 2-year return period, (b) 10-year return period
Table 2. Percent Ratio of Cisukabirus Sub-Watershed

| Return Period | Peak Discharge (m³/s) | Difference | Percentage |
|---------------|-----------------------|------------|------------|
|               | Manual (16.79 Km²)    | Arc-Hydro (16.64 Km²) |           |
| Q₂            | 81.4                  | 80.2       | 1.2        | 1.47       |
| Q₁₀           | 134.9                 | 133.1      | 1.8        | 1.33       |

Table 3. Percent Ratio of Universitas Indonesia Watershed

| Return Period | Peak Discharge (m³/s) | Difference | Percentage |
|---------------|-----------------------|------------|------------|
|               | Manual (5.78 Km²)     | Arc-Hydro (4.88 Km²) |           |
| Q₂            | 29.5                  | 25.2       | 4.3        | 14.57      |
| Q₁₀           | 46.6                  | 39.7       | 6.9        | 14.08      |

In addition viewed from the comparison of hydrograph using accumulative discharge plotting, the relationship of accumulative discharge of watershed delineation from Arc-Hydro with manual, the line has more slope in urban compared in rural areas. Based on Figure 6 shows that rural areas, the line has an ideal gradient, it shows that the differences of discharge from the two methods of delineation in Cisukabirus has no significant impact. Meanwhile, for urban areas, based on Figure 7, the line has more slope and biased to manual delineation. It can be said that the discharge obtained from the delineation using Arc-Hydro shows significant impact from manual delineation. The significant differences from the discharge obtained in urban area is also supported by relatively large differences in the extent of the catchment area.

![Accumulative Discharge in Cisukabirus (2-year return period)](image1)

(a)

![Accumulative Discharge in Cisukabirus (10-year return period)](image2)

(b)

Figure 6. Accumulative Discharge of Cisukabirus (a) 2-year return period (b) 10-year return period
4. Conclusion

Refers to Figure 2, Universitas Indonesia that assumes urban-watershed has a significant impact of watershed delineation from Arc-Hydro compared to manual delineation based on field survey. Those differences of determining the watershed boundary has also an influence on the output of flood hydrograph. Refers to Table 2, 3 and Figure 6 and 7 the percentage ratio of peak discharge and the accumulative discharge plotting in urban and rural area, shows that Universitas Indonesia watershed has a significant differences output compared to rural watershed (Cisukabirus). This indicates that for a determining watershed boundaries in urban areas that also has a low-terrain relief does not only rely on the Arc-Hydro but also needs to be validated based on the field survey. As for in rural areas with a high-terrain relief, it is more efficient to directly use Arc-Hydro for determining watershed boundary since there are no significant differences obtained on the watershed delineation.

References

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