Performance of SCS unit hydrograph and kinematic wave methods application on rural and urbanized watershed

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Abstract. Flood routing in the catchment area can be simulated by transform method. Based on the complexity of data requirement, there are two significant differences of the transform method in watershed routing, namely the SCS Unit Hydrograph and Kinematic Wave. The purpose of this study is to analyze the effectiveness of those two methods by comparing two hydrographs using HEC-Geo HMS on Urban and Rural Watersheds. Comparison has been simulated by calculating the ratio of peak hydrograph discharge to each calculation condition and the level of hydrograph compatibility. Another possibility to analyze the effectiveness of two methods by plotting accumulative discharge values from the two hydrographs produced by the SCS Unit Hydrograph method using the Kinematic Wave method. The results of the hydrograph comparison indicate that Kinematic wave method which requires more detailed data more suitable for Urban Watershed than SCS Unit Hydrograph. However, for the Rural watershed, SCS Unit Hydrograph shows satisfactory result.

1. Introduction
A procedure for determining or predicting the time and magnitude of flood flow at a point on a river based on data that is known or assumed in the upstream part is called Flood Routing [1]. Analysis of flood routing can be reviewed at two locations, namely in the river channel section and in the catchment area of the watershed. Flood Routing in the channel is an analysis of water flow on the connecting channel of each Sub-DAS or reach in the watershed [2]. Whereas flood routing in the catchment area is an analysis of water flow at each channel level in the Sub-watershed (catchment area).

Flood routing conducted in the catchment area can use the transform method component in the additional ArcGIS Geo HMS software tools and HEC HMS software. Based on the level of data needed, there are two significant differences in the Transform Method, namely the SCS Unit Hydrograph and Kinematic Wave. SCS Unit Hydrograph method is a flood routing method in the Lump Sum watershed. While the Kinematic-wave method estimates, the need for more complex data such as taking into account every dimension of the channel found in the watershed [3].

The use of these two methods has advantages and disadvantages of each in conducting flood searches. Kinematic Wave Method requires more data than the SCS Unit Hydrograph method. With more data requirements in the kinematic wave method, there is an assumption that the level of accuracy will be greater than the SCS Unit Hydrograph Unit method of conducting flood routing. However, with many data requirements, data search time will be longer and can require greater costs, and vice versa with fewer data requirements, costs will be lower. This causes more choices of faster and cheaper methods,
the SCS Unit Hydrograph. Based on the characteristics of urban (urban) and rural (village) watersheds, each trait has a level of complexity. Urban properties are more suitable to use kinematic wave methods because there will be more components that must be more detailed than rural (village) properties. Whereas rural property can be more representative using a lump sum method such as the SCS Unit Hydrograph.

Based on the consideration of the use of the method, there are questions whether the consequences are if the nature of the Urban Watershed uses a lump sum method such as the SCS Unit Hydrograph and vice versa as well as how efficient the use of both methods are tested on urban and rural properties. The efficiency of the use of the methods are seen by comparing the results of the flow hydrograph due to the use of methods on flood routing in the catchment area (Transform method) which are tested on both the nature of the watershed, Urban and Rural. So, based on the results of the comparison, it can be seen the level of suitability of the method used in the Transform Method component on the nature of the watershed reviewed.

2. Research methodology and material

The study began by determining the location of the study based on the characteristics of a sub-watershed in the Upper Ciliwung watershed, namely sub-watersheds dominated by rural, urban and existing conditions (rural-urban). The characteristics of a sub-watershed are determined based on the impervious cover level of each sub-watershed. In this study, determining the characteristics of the sub-watershed using impervious cover charts adapted by CWP in 1998 [4]. After determining the location of the study, the properties of the sub-watershed were carried out using the help of HEC-Geo HMS software on ArcGIS. The results of modelling in this application will be input into the HEC-HMS application.

In the flood routing process, rainfall data that affect the location of the research have needed. Regional rainfall at the study site was influenced by three rain stations including Gunung Mas Station, Cilember Station, and Gadog Station, which were conducted using the Thiessen polygon method. Then Analysis Frequency Data as design rainfall or return period using rainfall data 2008-2017 [5]. The results of the frequency data analysis were tested for compatibility using the Chi square test and the Smirnov test [6]. The flow hydrograph has generated with the help of HEC-HMS software by inputting the data properties and design rainfall of the research location. Then the running process has carried out using the SCS Hydrograph and Kinematic Wave method in each study location to produce flow hydrograph.

In achieving the research objectives, it is to review the efficiency of the use of the SCS Unit Hydrograph and Kinematic Wave method on the nature of Urban and Rural Watersheds. The efficiency of using the method will be seen based on the comparison of the results of the hydrograph of the four calculation conditions. Comparison is done from two ways, namely calculating the ratio of peak hydrograph discharge to each calculation condition and the level of hydrograph compatibility. The hydrograph suitability level has seen by plotting accumulative discharge values from the two hydrographs produced by the SCS Unit Hydrograph method using the Kinematic Wave method.

2.1. Rural and urban classifications in each Sub-DAS in the Ciliwung Hulu watershed

Based on the impervious value of the Upper Ciliwung Sub-watersheds, the characteristics of watershed can classified using Impervious cover model chart that was adapted from CWP in 1998[4]. The nature of Urban Watershed can be represented in the Crises cover values exceeding 25% and Rural Properties can be represented by Cisukabirus Sub watershed, which has impervious cover values below 10%. In addition, the study has a location that has both urban and rural characteristics by taking sub-watersheds that have impervious cover values between 10% - 25% (Figure 1 and Table 1).
2.2. Rural and urban classifications in each Sub-DAS in the upper Ciliwung watershed Determination of CN value in the Ciliwung Hulu watershed

Based on the 2014 Technical Guidelines for National Soil Classification [7], it can be seen that both types of soil are included in the type of andosol where Hapludands is a type of andosol soil Umbrik and Udivitrands are types of andosol vitric soil. Based on HSG, the two types of soil can be classified sequentially into soil types B and C and presented in Table 2.

| Sub Watershed                  | HSG     |
|-------------------------------|---------|
| Ciliwung Hulu Sub Watershed   | B & C   |
| Cisarua Sub Watershed         | B & C   |
| Cisuren Sub Watershed         | B & C   |
| Cisukabirus Sub Watershed     | B & C   |
| Ciesek Sub Watershed          | B       |
| Ciseseupan Sub Watershed      | B       |
| Cibalok Sub Watershed         | B       |

Referring to the value of the CN by the USDA [1] and Classification of soil types according to the type of HSG, then the resulting value of the CN composite in their respective Regional Sub-Ciliwung Upper shown in Table 3.

Table 1. Impervious Cover for each Ciliwung Hulu Sub-watershed

| Sub Watershed                  | Impervious Cover (%) |
|-------------------------------|----------------------|
| Ciliwung Hulu Sub Watershed   | 20.80                |
| Cisarua Sub Watershed         | 15.73                |
| Cisuren Sub Watershed         | 11.45                |
| Cisukabirus Sub Watershed     | 7.67                 |
| Ciesek Sub Watershed          | 18.25                |
| Ciseseupan Sub Watershed      | 34.36                |
| Cibalok Sub Watershed         | 23.65                |

Figure 1. Map Ciliwung Hulu Watershed

Figure 2. Map land use of upper Ciliwung watershed

Table 2. Classification of Soil Type Types According to HSG
Table 3. The composite CN value in the territory of each of the Upper Ciliwung sub-watersheds

| Sub Watershed                  | CN composite |
|--------------------------------|--------------|
| Ciliwung Hulu Sub Watershed    | 73           |
| Cisarua Sub Watershed          | 81           |
| Cisuren Sub Watershed          | 71           |
| Cisukabirus Sub Watershed      | 77           |
| Ciesek Sub Watershed           | 69           |
| Ciseseupan Sub Watershed       | 77           |
| Cibalok Sub Watershed          | 79           |

2.3. Hydrological parameters in 3 Sub-watershed-study sites

Delineation of the Research Sites directly uses tools at HEC-Geo HMS to estimate hydrological parameters to provide sub basin properties [8]. The processed products in HEC-Geo HMS are general data on the completeness of a watershed such as river length, river slope, longest river flow, CN value, loss rate of various types of land and land use of a watershed and can estimate the time lag in Sub-watershed. Property of the research sites presented in Table 4.

Table 4. Property of the Cisukabirus Sub-watershed, Ciseseupan Sub-Watershed and Cisarua Sub-Watershed

| Properties Sub Watershed          | Cisukabirus Sub Watershed | Ciseseupan Sub Watershed | Cisarua Sub Watershed |
|-----------------------------------|---------------------------|--------------------------|-----------------------|
| Area Sub Watershed (km²)          | 16.743                    | 12.448                   | 4.988                 |
| Slope Sub Watershed               | 0.41                      | 0.095                    | 0.17                  |
| CN Sub Watershed                  | 76.696                    | 77.23                    | 82.76                 |
| River Length (m)                  | 3099.721                  | 2752.23                  | 6217.856              |
| River Slope                       | 0.040                     | 0.027                    | 0.04194               |
| TimeLag (min)                     | 81.68                     | 135.04                   | 53.4                  |

2.4. Design rainfall

This study uses rainfall data from 3 observation stations which are considered to represent 3 sub-watersheds (Cisukabirus, Ciseseupan and Cisarua watersheds), namely Gadog Station, Cilember Station, and Gunung Mas Station. Analysis of the frequency of rainfall data has done to get the planned rainfall. Determination of regional rainfall has determined by the Thiessen Polygon method [2], which takes into account the broad percentage of influence of each station on the total watershed area.

The design rainfall with a return period of 5, 10 and 25 years shown in Table 6. However, in this research the results of the hydrograph compared to the rain load are only using a 10-year return period for all methods in the flow simulation because it only calculates the suitability of the hydrograph at a certain time. Calculations using frequency analysis with the length of the 10-years rainfall data (2008-2017) then performed the Chi-square test and Smirnov test [6].

Table 5. The design rainfall for each of the research sites

| Return Period (year) | Cisukabirus Sub Watershed | Ciseseupan Sub Watershed | Cisarua Sub Watershed |
|----------------------|---------------------------|--------------------------|-----------------------|
| 5                    | 122.526                   | 139.592                  | 124.854               |
| 10                   | 131.957                   | 155.035                  | 134.391               |
| 25                   | 142.817                   | 172.516                  | 144.031               |
3. Results and discussion
3.1. Simulation flow hydrograph
The results of the simulation flow that occurred at the research sites (Cisukabirus Sub-watershed, Ciseseupan Sub-watershed, Cisarua Sub-watershed) using the SCS Unit method Hydrograph and Kinematic wave can be seen from the peak discharge (Qp), Time of peak (Tp), and rain duration values summarized in Table 6, 7 and 8. The results of the hydrograph for each method are given in Figure 3, Figure 4 and Figure 5.

| Parameter          | SCS Unit Hydrograph | Kinematic Wave |
|--------------------|---------------------|----------------|
| Q Peak (Qp) (m3/s) | 8.1                 | 8.2            |
| Time of Peak (Tp)  | 00:00               | 23:00          |
| Duration (hour)    | 31                  | 30             |

Figure 3. Flood Hydrograph of Cisukabirus Sub –watershed

| Parameter          | SCS Unit Hydrograph | Kinematic Wave |
|--------------------|---------------------|----------------|
| Q Peak (Qp) (m3/s) | 7.7                 | 7.8            |
| Time of Peak (Tp)  | 00:00               | 23:00          |
| Duration (hour)    | 34                  | 29             |

Figure 4. Flood Hydrograph of Ciseseupan Sub –watershed

Figure 5. Flood Hydrograph of Cisarua 1 Sub –watershed (a) Flood Hydrograph of Cisarua 2 Sub –watershed (b)
Table 8. Results of simulation flow in the Ciseseupan sub-watershed

| Parameter                  | Existing condition | SCS unit hydrograph | Kinematic wave |
|---------------------------|--------------------|---------------------|----------------|
| Q Peak (Qp) (m³/s)        | 13.3               | 13.4                | 13.2           |
| Time of Peak (Tp)         | 00:00              | 00:00               | 23:00          |
| Duration (hour)           | 32                 | 32                  | 33             |

3.2. Comparison results of flow simulation hydrographs

Based on the comparison between the use of the SCS UH method and the kinematic wave in the Cisukabirus sub-watershed, it appears that the smallest percentage is when using the SCS UH method (Table 9). This shows that the Cisukabirus sub-watershed, which is assumed rural, is entirely more suitable using the SCS UH method on the Transform Method. In addition, viewed from the results of the graph of the accumulative debit relationship between the SCS UH method and the Kinematic wave, it can be seen that the direction of the slope line is not biased towards the Kinematic wave method (Figure 7a). With the two balanced results, it can be said that the Cisukabirus sub-watershed does not have a significant effect when using the SCS UH and Kinematic Wave methods.

Table 9. Percentage Suitability of SCS UH and Kinematic wave methods

| Research Sub Watershed | Transform Method | Percentate (%) | Suitability Method |
|------------------------|-----------------|----------------|-------------------|
| Cisukabirus Sub Watershed | SCS UH         | 1.2            | SCS UH            |
|                        | KW              | 4.8            |                   |
| Ciseseupan Sub Watershed | SCS UH         | 1.3            | Kinematic         |
|                        | KW              | 1.2            | wave              |
| Cisarua Sub Watershed  | SCS UH          | 0.75           | Neutral           |
|                        | KW              | 0.75           |                   |

Based on the comparison between the use of the SCS UH method and kinematic wave in the Ciseseupan Sub-watershed, it appears that the smallest percentage value is when using the kinematic wave method (Table 9). In addition, viewed from the results of the graph (Figure 7b), the relationship of accumulative debit of the SCS UH method with the kinematic wave shows that the line has more slope towards the kinematic wave method. This shows that the Ciseseupan Sub-watershed, which is assumed urban, is entirely more suitable using the kinematic wave method in the transform method model.

From the results of the two comparisons, it can be said that Urban Sub-watersheds are very influential if the method of flood routing in the catchment area uses a method that is lump sum due to the significant difference in results.

Figure 6. Accumulative discharge in the Cisukabirus Sub-watershed (a) Accumulative discharge in the Ciseseupan Sub-watershed (b)
Figure 7. Accumulative discharge in the Cisarua Sub-watershed 1 (a) Accumulative discharge in the Cisarua Sub-watershed 2 (b)

Based on the comparison between the use of the SCS UH method and kinematic wave in the Cisarua sub-watershed, it can be seen that the percentage of existing conditions with the use of the kinematic wave and SCS UH methods did not differ (Table 9). Moreover, in terms of the results of the accumulative discharge graph SCS UH method with the condition of the existing seen that the direction of the line slightly inclined towards the SCS UH method (Figure 7a). As for the use of the kinematic method wave direction graph lines are neutral (Figure 7b).

4. Conclusion

Refers to figure 7a, Cisukabirus sub-watershed with Rural sub-watersheds will be more efficient when using the SCS unit hydrograph method because of the suitability of the results of the percentage ratio of peak discharge and accumulative discharge direction of the two methods that indicate compatibility with the SCS unit hydrograph method. In addition, with the SCS UH method, the use of methods is easier, faster and cheaper without reducing the level of accuracy of the results of the hydrological analysis of a watershed.

Refers to figure 7b, Ciseseupan sub-watershed with urban sub-watersheds can use both methods (SCS UH and kinematic wave) but it will be more efficient to use the Kinematic Wave method to weigh the level of accuracy of the results obtained because the already complex nature of the watershed requires more detailed data analysis. So as to get the results of a more optimal hydrological analysis even though it requires more time and money when analysing the hydrology of a watershed.

Refers to the figure 8 a and b, Cisarua sub-watershed with existing conditions (both urban and rural) will have an effect if using the SCS UH method on the transform method component. So if the sub-watershed, which is dominated by rural characteristics, it is more efficient to directly use the SCS UH because the results of the flow hydrograph are not very different when using the kinematic wave method. So as to maximize the time and costs needed to analyze the hydrology of a watershed.

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