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Potential impact of sub-urban development on the surface runoff estimations (a case study at Upper Ciliwung watershed)

Potential impact of sub-urban development on the surface runoff estimations (a case study at Upper Ciliwung watershed)

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Abstract. Jakarta is a capitol of Indonesia which is located at downstream part of Ciliwung river. Statistic shows that in 2015, there are more than 750,000 people living in Ciliwung watershed which cost the changes in land use and uncontrolled use of river banks for settlement and population activities. Increases of impervious area will be correlated with the surface runoff. The aim of this paper is to analyse the potential impact of land use change on the surface runoff at upper Ciliwung watershed using hydrological model HEC-GeoHMS. Initial condition of this model adopt the SCS-CN model that represent the Upper Ciliwung Watershed characteristic. Rainfall event on 3 February 2007, the highest rainfall in last decade, were analysed at this simulation. This event applied for different land use from 1990 until 2017, with land use change increase by 12% each year, a flood hazard analysis has been carried out and it showed that the area in highly peak flood increased by 30%.

1. Introduction

Soil moisture, land use/land cover (LULC) and topography are the most important parameter that affluence the rainfall runoff processing [1]. The other study notice that soil capacity plays an important role on the surface runoff [2]. However, the influence of land use or land cover change is the key parameter on the hydrological response [3]. The population growth at the region lead the change on land use and land-cover in order to fulfil the human like residential, education and infrastructure facilities. The consequence of that condition, impervious cover developed rapidly, runoff coefficient increases and time concentration become shortly.

Jakarta is the capital of Indonesia, located between 5°19’12’’ to 6°23’54” South latitude and 106°22’42” to 106°58’18” East longitude. As a capital city, centre of administration, economic and government institutions are located at Jakarta. Since the rapid economic growth, population is growing and development at Jakarta is expanding around the city. The greater of metropolitan Jakarta, also referred as Jabodetabek (Jakarta, Bogor, Depok Tangerang, and Bekasi) is living area for more than 22 million people [4]. Combination between the topography and the location of Jakarta, estuary of 13 rivers, caused inundation occure almost each year at Jakarta. The biggest flood in the last three decades in 2007 inundated about 40% of the city and killed 80 people [5].

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Ciliwung is most affected river from 13 rivers that flow into Jakarta. Ciliwung watershed is one of critical watershed in Indonesia [6]. Upper Ciliwung watershed is the important part of Ciliwung. Dendritic shape of Upper Ciliwung Watershed causes the flash flood [7]. The development at Upper Ciliwung Watershed will lead the runoff coefficient and peak discharge. Flood plain condition at Upper Ciliwung Watershed occupied by residential and commercial area. Figure 1. describe the flood plain condition at Upper Ciliwung Watershed.

Figure 1. Flood plain condition at ciliwung watershed

HEC-GeoHMS is the interface of Arc.GIS that developed by Hydrologic Engineering Center based on the geospatial hydrology tools kit for engineer and show a good performance at this watershed. The aim of this paper is to analyze the potential impact of land use development on the peak discharge magnitude at Upper Ciliwung watershed. Simulation will be conducted using rainfall event on 3 February 2007, land use at 1990, 2003 2009 and 2017.

2. Methodology Research

2.1. Study Area and Available Data Set

This study located at upstream part of Ciliwung Watershed. Upper Ciliwung Watershed delineated from Gede Pangrango mountain until Katulampa Weir, with the area about 150 km2 and longest river 25 km. In order to analyse the influence of landuse change at Upper Ciliwung Watershed, this watershed divide into 7 sub watershed. The discretization of Upper Ciliwung Watershed has been done in order to represent the spatial characteristic of its watershed. The spatial distribution of watershed characteristic is important in order to better analyse the hydrological response on hydrological model [8]. The discretization of Upper Ciliwung watershed into 7 sub watershed represents at the Figure 2 below.

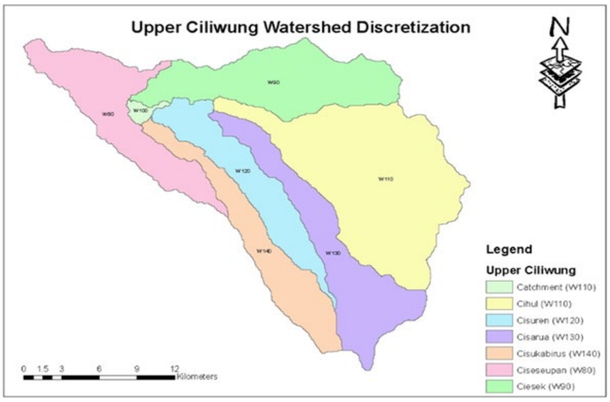

Figure 2. Upper ciliwung watershed discretization based on HEC-GEOHMS

The Land use data in this research used Landsat 8 digitation on 1990, 2003, 2009 and 2017 that organize by Indonesian Geospatial Information Agency.

Rainfall data at Upper Ciliwung Watershed affected by 3 (three) rainfall stations named, Gadog, Cilember and Gunung Mas. The simulation was calculated based on the rainfall event on 3 Feb 2007 that caused worse inundation at Jakarta. Rainfall data provide by Ciliwung Cisadane River Basin Agency. Land use change from the various years can be seen at the Figure 3 – 6.

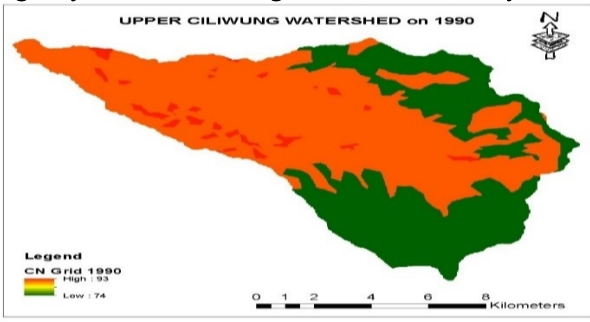

Figure 3. Land use at upper ciliwung watershed on 1990

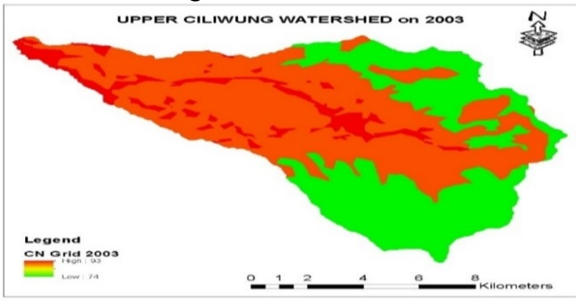

Figure 4. Land use at upper ciliwung watershed on 2003

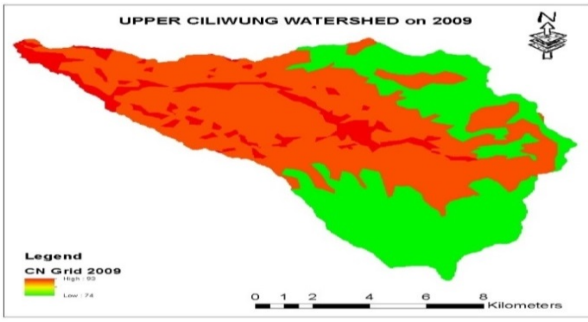

Figure 5. Land use at upper ciliwung watershed on 2009

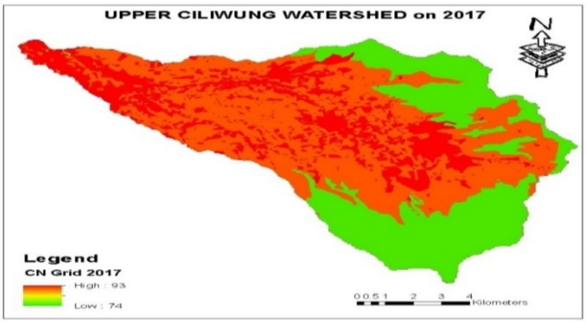

Figure 6. Land use at upper ciliwung watershed on 2017

2.2. *HEC – GeoHMS Spatial Analyse Tools*

HEC-GeoHMS is a public domain tools that developed by Hydrologic Engineering Center's Geospatial Hydrologic Modeling [9]. With the GIS interface, this tools accommodate the hydrologic input for model hydrology HEC-HMS directly. Schematic of the watershed can be built by this program also. Application and calibration HEC-GeoHMS at Upper Ciliwung Watershed for flood event show a good performance [7]. The schematic of Upper Ciliwung Watershed which is generated by HEC-GeoHMS presented at the Figure 7

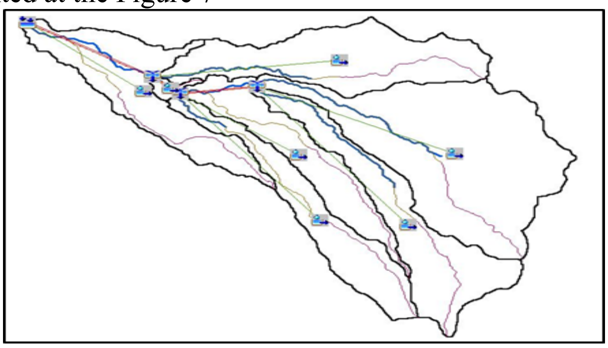

Figure 7. Upper ciliwung watershed schematic

2.3. SCS-CN for Basin Loss Function Method at HEC-HMS

The computation of basin losses (production function) performed for each sub-watershed by Soil Conservation Service - Curve Number (SCS-CN) method. SCS-CN model was developed by USDA (United Stated Department of Agriculture) based on watershed characteristics. The SCS-CN method calculate by the two actual potential quantities as the following equation [10]:

$$\frac{F_a}{S} = \frac{P_e}{P - I_a} \tag{1}$$

From the continuity principle:

$$P = P_e + I_a + F_a \tag{2}$$

an empirical relation of SCS-CN was developed:

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \tag{3}$$

where as $I_a = 0.2S$

$$P_e = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{4}$$

F_a is depth of water in the watershed, P_e is the effective rainfall, I_a is the initial abstraction, S is the soil retention capacity of catchment area in mm and retention capacity value based on runoff coefficient (CN) that depend on land cover, the value of CN is between 0 and 100,

$$\mathrm{S} = 25.4\left(\frac{1000}{\mathrm{CN}} - 10\right) \tag{5}$$

The Custom of CN data used to be standard land cover description using assumptions on detail of land use [11].

3. Result and Discussion

The objective of this step is to analyse the significant implication of land use development on the magnitude of peak surface runoff. Simulation has been done using real rainfall data in February 2007. The hydrological condition of its simulation refers to research before [4] that show a good performance, the simulation take account the initial abstraction, antecedent moisture condition III and percent impervious cover for each sub watershed and each different land use.

Loss method of HMS simulation using SCS-CN Method, and the transfer function using lag time method. Watershed characteristic data, result from HEC-GeoHMS present at Table 1and Table 2.

Table 1. Watershed parameters

Shape Length (m)	HydroID	DrainID	Name	Slope (%)	Area (km^2)	Reach Id
42780	8	8	W80	9.74	20.81	Outlet
38220	9	9	W90	26.90	25.67	R10
7920	10	10	W100	13.20	1.10	R10
45780	11	11	W110	27.27	48.86	R30
38520	12	12	W120	19.24	16.28	R30
45540	13	13	W130	35.58	23.16	R40
41160	14	14	W140	39.64	16.97	R40

Table 2. Reach parameters

Reach	Length (m)	Slope	Tc (minutes)
R10	6075	0.07	44.46
R30	1468	0.03	20.64

Reach	Length (m)	Slope	Tc (minutes)
R40	3224	0.03	37.83

Basin loss method at HEC-HMS using the SCS-CN method, with the transform method at each watershed using SCS Unit hydrograph. However, transfer function or stream routing at this simulation based on the lag time method. Detail information to calculate the basin loss analyzed from the percent impervious area for each sub-watershed. Watershed parameter that use for calculating basin loss method in HMS at Upper Ciliwung Watershed can be seen at the Table 3 below.

Table 3. Basin loss method parameters at upper ciliwung watershed

Name	CN III (1990)	CN III (2003)	CN III (2009)	CN III (2017)	S (2000) mm	S (2003) mm	S (2009) mm	S (2017) mm	Ia (2000) mm	Ia (2003) mm	Ia (2009) mm	Ia (2017) mm
W80	78	80	83	86	2.82	2.50	2.05	1.63	0.56	0.50	0.41	0.33
W90	72	74	77	80	3.89	3.51	2.99	2.50	0.78	0.70	0.60	0.50
W100	76	78	82	86	3.16	2.82	2.20	1.63	0.63	0.56	0.44	0.33
W110	72	74	78	80	3.89	3.51	2.82	2.50	0.78	0.70	0.56	0.50
W120	72	74	78	80	3.89	3.51	2.82	2.50	0.78	0.70	0.56	0.50
W130	74	76	77	78.3	3.51	3.16	2.99	2.77	0.70	0.63	0.60	0.55
W140	75	75	76	77	3.33	3.33	3.16	2.99	0.67	0.67	0.63	0.60

Development at sub-urban has been represent by increases of impervious area on the land use map from 1990 until 2017. Population growth and urbanization cause the land use change from open space area become a residential area or public infrastructure or commercial area. The recapitulation of land use change at Upper Ciliwung Watershed based on land use in 1990 present at the table 4.

Table 4. Percent impervious change

Parameter	Year			
	1990	2003	2009	2017
CN	70.7	72.3	78.7	81.0
% Impervious	5.0	11.0	11.8	42.6
Discharges (m^3/s)	774.1	992.9	1089.8	1421.6

The impervious cover rate reaches up until more than 30 % from 1990 until 2017 (table 4). HEC-GeoHMS simulation used SCS-CN method and time lag method based on the watershed characteristic has been done for different land use (1990, 2003. 2007 and 2017). Hydrograph simulation illustrated the impact of sub- urban development on the surface runoff

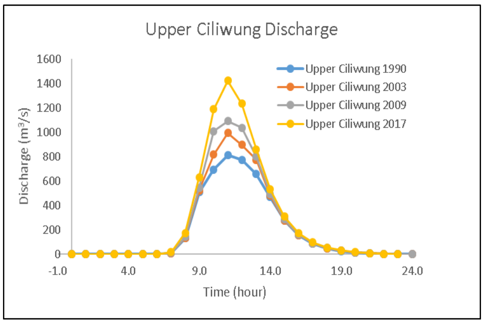

Figure 8. Hydrograph magnitude from 1990 – 2017.

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4. Conclusion

Initial condition of this simulation refers to the research before [4] that shown a good performance of HEC-HMS. Land use development at Upper Ciliwung watershed that become an urban area has significant effect of peak discharge. The amount of rainfall event on 3 February 2007 has been choose in order to analyze the influence of land use change at Upper Ciliwung Watershed. When the impervious area rises up until 40% (2017), the peak discharge will be increased until 30%.

Recently, uncontrollable development will cause bigger inundation than 2007, more victim and economic losses. Furthermore, impact of land use change not only affected the peak flood but also decrease the environmental quality [12].

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