Criticality Analysis of Recharge Area In Upper Cisadane Watershed

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ABSTRACT--- ***The aims of this research were to (1) identify criticality of recharge area; and (2) analyze water balance of Upper Cisadane Watershed. Identification of recharge area criticality refers to regulation of the Minister of Forestry, Republic of Indonesia Number: P.32/MENHUT-II/2009 by scoring and overlaying of slope, soil type, rainfall, and land use map. SCS-CN (Soil Conservation Service-Curve Number) method was used to analyze runoff and infiltration on each level of recharge area criticality. The criticality of recharge area in the Upper Cisadane Watershed in 2006, 2009, and 2013, are: (1) good: 27.4%, 20.3%, 19.9%; normal: 11.9%, 7.8%, 5.6%; (3) ranging critical: 16.4%, 7.5%, 5.4%; (4) rather critical: 25.3%, 25.6%, 30.6%; (5) critical: 15.3%, 22.2%, 21.6%; and (6) very critical: 3.7%, 16.6%, 17%. We concluded that recharge area with good and normal conditions have an infiltration rate more than surface runoff, while the infiltration rate at recharge area with ranging critical, rather critical, critical and very critical condition less than surface runoff that occured in 2006, 2009 and 2013.***

Keywords ---- Criticality, recharge area, overlay, scoring, surface runoff, infiltration.

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1. INTRODUCTION

Cisadane Watershed is one of the priority watershed in Indonesia which includes to the working area of soil conservation in order to encourage a medium-term development (Minister of Forestry 2009). Determination of priority watershed is based on; (1) critical hydrology area characterized by large ratio between maximum discharge (rainy season) with a minimum flow (drought) as well as the content of the sediment overload, (2) area that has been, is being, or will be built vital installations such as dams, reservoir, and other irrigation building, (3) prone areas to flooding and drought, (4) shifting cultivation areas, (5) area with low awareness in land conservation, and (6) areas with high population density (Arsyad 2006).

The main problem for the Upper Cisadane Watershed is there so many forested area that had been converted for other uses such as farming plantation, settlements, rice field and others. Deforestration that occured in the Upper Cisadane Watershed has caused a degradation of the forest area function, which then increased the number of critical lands. This is happened because the natural infiltration capacity of soil in that area has decreased. The bigger the damage of the forest, the more critical the land. Process of degradation ran slowly and cumulatively, but has long-term adverse effects on the environment. One of the effects that occurred increase in surface runoff and decrease in infiltration rate of rainwater (Muchena 2008). Nilda *et al.* (2015) suggested that there has been an increase in the peak discharge in Upper Cisadane Watershed in 2003 about 81.22 m^3/s and 81.73 m^3/s in 2010. Higher peak discharge is caused by increase of surface runoff, since development of residential in the watershed area. This is shown by the increasing value of average curve number (CN), from 38.5 to 39.4. Value of CN is a factor that affects the magnitude of the surface runoff (Bonta 1997), the large CN value showed high surface runoff and low infiltration rate, while the small CN value showed low surface runoff and high infiltration rate (Zhan and Huang, 2004; Viji *et al.* 2015).

Basically, surface runoff is controlled by the magnitude of the infiltration rate, which has a correlation with vegetation cover, topography, and soil types (Dong *et al.* 2015). According to the Minister of Forestry (2008) the reduction of water recharge areas as the impact of changes in land use that occurred in the Upper Cisadane Watershed can impact on other parts of Sub-Watershed Cisadane either middle or downstream. Further, reduction of green areas as water recharge area will lead to increase of unabsorbable water and flow on the surface. The study was conducted to identify the criticality of recharge areas and analysis of runoff and infiltration in Upper Cisadane Watershed.

2. RESEARCH METHODS

This study was carried out in Upper Cisadane Watershed, West Java Province. The research was conducted from April - July 2015. The tools used in this study are a set of personal computer equipped with MS. Office 2013, the application of program Geographical Information System (ArcGIS10.0) and Corel Draw. Materials used are map of land use (in 2006, 2009 and 2013), slope class, soil type , hydrological soil groups, daily rainfall data (2004 to 2013), coordinate points of Rain Measurement Station, digital elevataion model (DEM), earth map of Indonesia, and map of Upper Cisadane Watershed.

Basic Map Construction of Recharge Area

The basic map of recharge area consists of the land use map, slope map, soil type map, and rainfall map. All four components are classified in advance into the value level of potential infiltration and actual infiltration based on method of Minister of Forestry P.32/MENHUT-II/2009 on Procedures for the Preparation of Technical Plan for Forest and Land Rehabilitation Watershed (Figure 1).

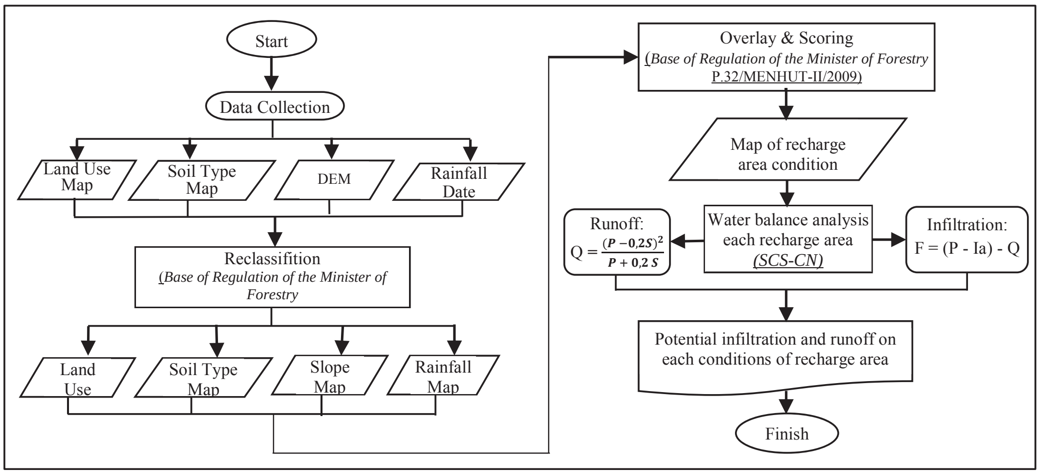

Figure 1. Flow chart of analysis model of recharge area

Classification of Land Use

According to BP-DAS Ciliwung-Citarum 2013, there were 10 forms of land use in Upper Cisadane Watershed in 2006, 2009 and 2013, namely; airport, primary dry land forest, secondary dry land forest, field (horticulture), open land, plantation, settlement, rice field, bush (shrub), and water body. Forms of the land use were classified according to the level of actual infiltration is presented in Table 1.

Table 1. The land use forms base on classes of actual infiltration in Upper Cisadane Watershed

No.	Land use forms	Class of infiltration
1	Dense forests (primary forest and secondary forest)	Very large
2	Plantation	Large
3	Bush and shrub	Moderate
4	Field (horticulture)	Small
5	Settlements, rice field, water bodie, and undeveloped land, open land	Very small

Classification of Slope and Soil Type

Slopes of Upper Cisadane Watershed are classified into 5 classes, namely; flat slope (<8%) or rapid infiltration, gentle slope (8-15%) or infiltration rather fast, undulating slope (15-25%) or moderate infiltration, steep slope (25-40%) or somewhat slow infiltration and very steep slope (>40%) or slow infiltration. Slope of the watershed is one of the factor affecting infiltration of rainwater (Magesh et al. 2012). Steeper the slope, smaller the infiltration and conversely the greater surface runoff (Selvam *et al*. 2015).

Meanwhile, according to the map of soil type in Upper Cisadane Watershed with a scale of 1 : 100000 in the area of research, there are 11 units of soil map (BPDAS Ciliwung-Citarum 2013). In this method soil types are classified into four hydrological soil groups (A, B, C, and D) with increasing potential for generating runoff or infiltration

(Research Center for Soil and Agro-climate Bogor 1992). Potential infiltration rate of the soil was classified based on the hydrological soil groupss, namely; A (high of infiltration level), B (medium of infiltration level), C (low of infiltration level) and D (very low of infiltration level).

Classification of Rainfall

The rainfall on each rain observation stations were developed as a factor of rain infiltration (mm/year) which is the amount of annual rainfall multiplied by the number of rainy days and divided by 100. The classification of rain infiltration are based on the infiltration level, that are the values of rain infiltration; <2500 mm/year (very small infiltration); 2500-3500 mm/year (small infiltration); 3500-4500 mm/year (medium infiltration); 4500-5500 mm/year (large infiltration); and >5500 mm/year (very large infiltration).

Identification of Recharge Area

Identification of recharge area was done by overlaying and scoring using ArcGIS or applications Geographic Information System (GIS). GIS technique can be used to create a hydrological model more accurate through its ability in accommodating various of hydrological parameters (Melesse *et al*. 2003).

The map of slope classes, soil types, and rainfall distribution were overlaid to be a map of potential infiltration. A score were then given according to the level of infiltration, with the score for the notation a = 5, b = 4, c = 3, d = 2 and e = 1. These three aspects provide a natural index of the potential infiltration rate. Forms of land use are aspect under the influence of human activities, have different implications for infiltration (Vink 1975). If a natural aspect reflects the potential conditions, the aspect of land use reflects the actual conditions.

Classification of Recharge Area

After overlaying and scoring of the components mentioned above, then the condition of recharge areas were classified by comparing the value of potential infiltration with the actual infiltration. The method used refers to the Minister of Forestry No. P. 32/MENHUT-II/2009 with the determination of the following criteria:

I. Good conditions, if the value of the actual infiltration is greater than the value of potential infiltration, for example, from (e) to (A), or from (d) to (B) and so on.
II. Conditions of normal natural, if the value of the actual infiltration or remain the same as the value of potential infiltration, if from (b) to (B), or from (c) to (C) and so on.
III. Conditions of ranging critical, if the value of the actual infiltration has dropped one level of infiltration potential value, for example, rom (a) to (B), or from (c) to (D) and so on.
IV. Conditions of rather criticacal, if the value of infiltration actual has dropped two levels of infiltration potential value, for example, from (a) to (C), or from (b) to (D) and so on.
V. Conditions of critical, if the value of the actual infiltration has dropped three levels of infiltration potential value, for example, from (a) to D, or from (b) into (E).
VI. Conditions of very critical, if the value of the actual infiltration has changed from very large to very small, for example, of (a) becoming (E).

How step to identify characteristics and determine the classes of recharge area criticality is shown in Figure 2.

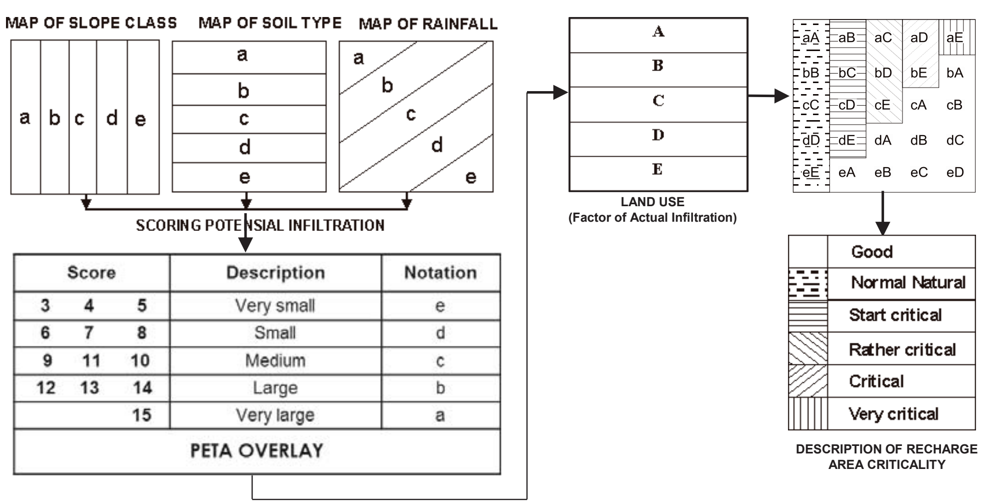

Figure 2. An outline of the approach to modeling study recharge area

Description :

- Score of potential infiltration level (rainfall, soil type, slope class) a = 5; b = 4; c = 3; d= 2; e = 1.
- Score of actual infiltration level (land use): A = very large, B = large, C = medium, D = small and E = very small.

Analysis of Runoff and Infiltration

Surface runoff (Q) and infiltration (F) is calculated by the method Soil Conservation Service-Curve Number (SCS-CN) method with the following equation (USDA 1986).

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad (1)$$

$$S = \frac{25400}{CNp} - 254 \quad (2)$$

$$CN_p = \frac{\sum_i^n CNi \times Ai}{\sum_i^n Ai} \quad (3)$$

$$Ia = 0.2\ S \quad (4)$$

$$F = (P - Ia) - Q \quad (5)$$

In the SCS-CN method, surface runoff (Q) is treated as zero if precipitation (P) = 0.2S. S is the difference in soil conditions and land use on the curve number (CN) or the so-called potential maximum retention. (Ia) is a function of land use, treatment and hydrology, and soil water content beforehand. (F) is the addition of water to the land whose value will always be less than or equal to the potential retention and named as infiltration.

(CNp) is the weigted curve number whose value varies from 0 - 100. If the value of the CN = 100, then the value S = 0 and Q = 0. Values of CNP were calculated from the weighted average of CN values (Fan et al. 2013) and based on hydrological soil groups, land use forms and hydrological conditions are guided by the CN table (Asdak 2002). CNi is the value for land use 1, 2, 3 ....n. Ai is the area of each land use. This method had been used by several researchers (Reshma *et.al* 2010; Luxon and Pius 2013) not only in the USA but also in other countries because the results obtained are valid and consistent (Rishi and Kumar 2013).

3. RESULTS AND DISCUSSION

Level of Recharge Area Criticality

Based on the overlaying and scoring process, data obtained were 6 classes of recharge area criticality in Upper Cisadane Watershed, namely: good condition, normal natural, ranging critical, rather critical, critical and very critical. The level of criticality of recharge area in the Upper Cisadane Watershed can be seen in Table 2.

Table 2. Critical level of recharge area in Upper Cisadane Watershed

No.	Critical level	Area					
		2006		2009		2013	
		Ha	%	Ha	%	Ha	%
1	Good	23370.1	27.4	17283.6	20.3	16975.6	19.9
2	Normal	10119.3	11.9	6669.9	7.8	4738.8	5.6
3	Ranging critical	14003.6	16.4	6367.3	7.5	4635.1	5.4
4	Rather critical	21566.3	25.3	21835.3	25.6	26071.2	30.6
5	Critical	13063.9	15.3	18934.8	22.2	18383.3	21.6
6	Very critical	3133.0	3.7	14165.3	16.6	14452.1	17.0
Total		85256.2	100	85256.2	100	85256.2	100

The data showed that distribution of the recharge area criticality (%) in Upper Cisadane Watershed during 2006, 2009 and 2013, consist of good condition were 27.4%, 20.3%, 19.9%; normal were 11.9%, 7.8%, 5.6%; ranging critical were 16.4%, 7.5%, 5.4%, rather critical were 25.3%, 25.6%, 30.6%; critical were 15.3%, 22.2%, 21.6%; and very critical were 3.7%, 16.6%, 17%, respectively. Based on Table 2, the critical level of recharge area in Upper Cisadane Watershed, the distribution of recharge area criticality can be seen in Figure 3.

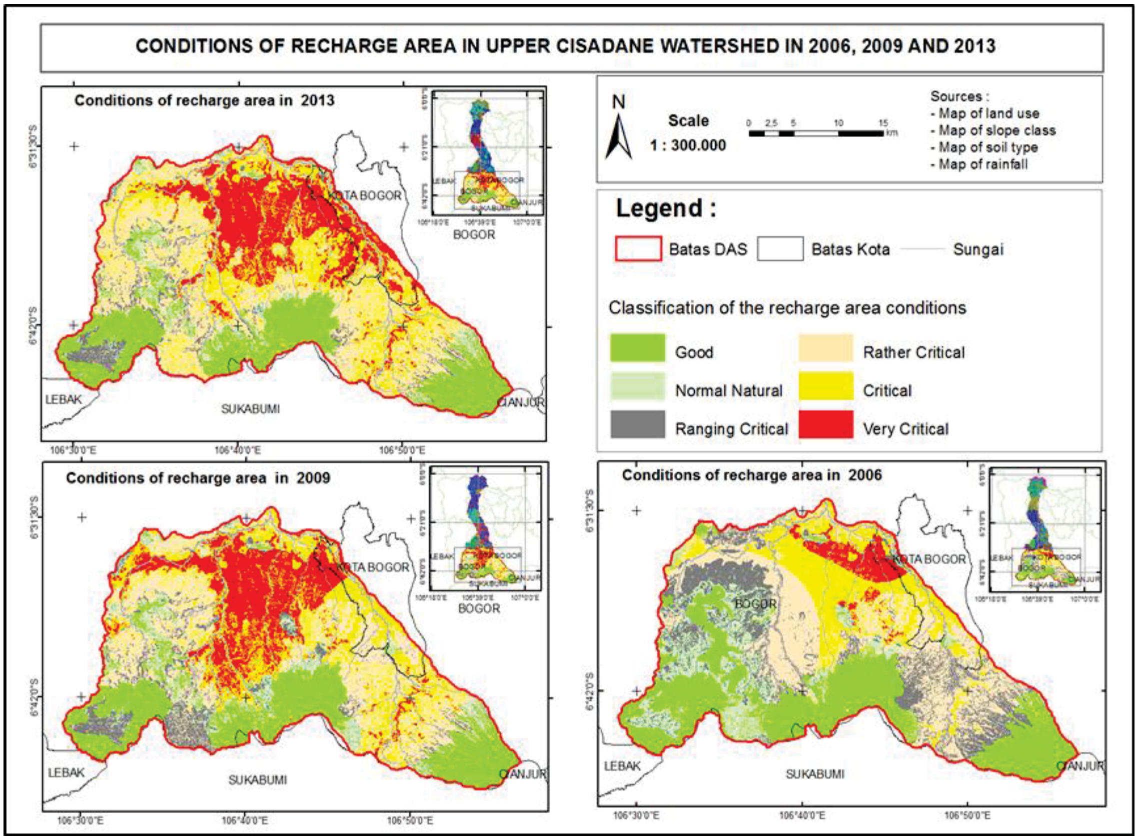

Figure 3. Distribution of recharge area criticality in Upper Cisadane Watershed

Rainfall Region

Distribution of the maximum rainfall in Upper Cisadane Watershed obtained through spatial interpolation process-IDW (inverse distance weighted) of 5 different stations, while high of average maximum rainfall was calculated by technique of thiessen polygon. The results showed maximum rainfall on average increased from 2006-2013 (Table 3).

Tabel 3. High of maximum rainfall in Upper Cisadane Watershed

Year	Maximum Rainfall (mm)					
	Cihideung	Dramaga	Empang	Pasir Jaya	Karacak	$CH_{\text{Maximum area}}$
2006	109 .0	136 .4	104 .0	75 .0	116 .0	100 .85
2009	125 .0	115 .1	112 .0	154 .0	110 .0	127 .81
2013	134 .0	136 .8	145 .0	99 .0	158 .0	133 .12

Curve Number (CN) and Potential Maximum Retention

The table of curve numbers should only be used as guidelines, CN and the empirical relationships that actually should be determined based on data from local and regional at the time of the study (Hawkins 1998 and Canters *et al*. 2006). If the critical level of recharge areas increased, CN value increased. CN value also negatively correlated to the potential maximum retention, a large CN value causes the potential maximum retention will be low and viceversa. This is in agreement with Fan *et al.* (2013) who stated that the sensitivity changes to the CN value on water potential retention is decreasing CN will raise the value of potential maximum retention.

In this study, values of weighted CN are determined based on the integration between the condition of land cover, hydrological soil groups and hydrological condition of recharge areas. Value of weighted curve number (CNp) and the potential maximum retention (S) were calculated using equation 3 and 2 and can be seen in Table 4.

Table 4. Weighted curve number (CN_P) and potential retention (S) based on recharge area in Upper Cisadane Watershed

No	Critical Level	2006		2009		2013	
		CN_P	S (mm)	CN_P	S (mm)	CN_P	S (mm)
1	Good	68.6	116.00	68.7	115.95	68.7	115.66
2	Normal Natural	72.0	98.92	69.1	113.62	69.3	112.56
3	Ranging Critical	74.1	88.65	72.9	94.59	77.4	74.13
4	Rather Critical	76.0	80.24	73.5	91.53	82.2	54.82
5	Critical	80.5	61.66	78.2	70.68	83.4	50.39
6	Very Critical	82.2	54.86	81.0	59.67	83.5	50.16

Surface Runoff and Infiltration

Surface Runoff and Infiltration Surface runoff occured when precipitation is greater than the rate of infiltration (USDA SCS 2005). In this simulation, surface runoff and infiltration were calculated from maximum high rainfall in the recharge areas. At the same recharge area showed always occurs an increasing surface runoff and decreasing infiltration rate every year, this due to changes of CN value in the recharge area. CN value was positively correlated to the amount of surface runoff, but negatively correlated to the infiltration rate (Weng 2001 and Govers et al. 2000) and model of SCS-CN relationship between rainfall and runoff is controlled by the potential maximum retention and (Kumar and Rishi 2013) if the CN value increased, the surface runoff will also increased.

The calculations showed that surface runoff (%) was higher in the recharge area where the condition was worse (critical) and the amount tends to be increased, on the contrary the infiltration rate (%) will be smaller in recharge areas where the condition was worse (critical) and the magnitude were likely decrease from 2006, 2009 and 2013. Results are shown completely in Figure 4a and Figure 4b.

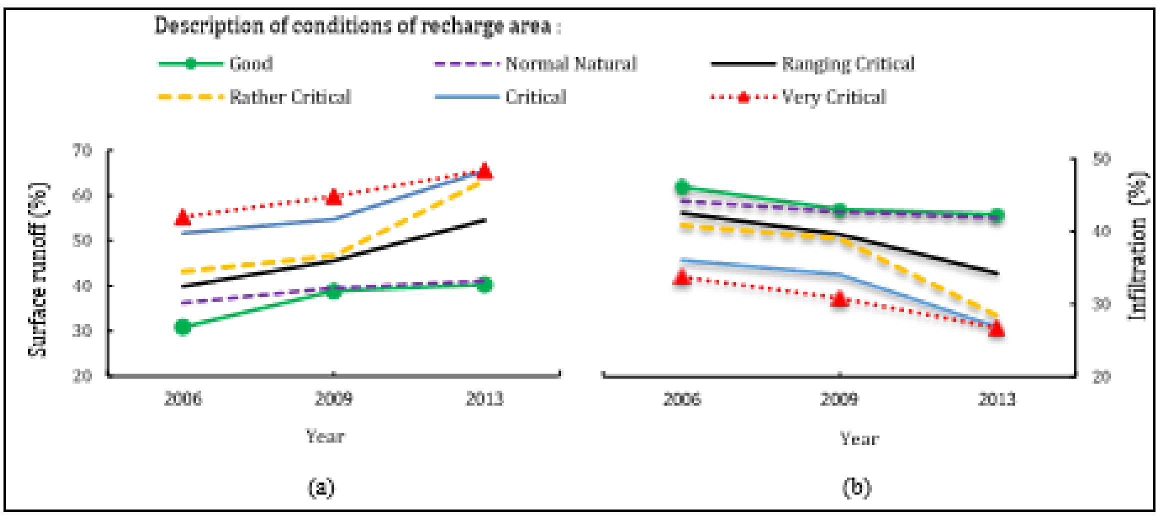

Figure 4. (a) Surface runoff; (b) infiltration in Upper Cisadane Watershed for 2006, 2009 and 2013

4. CONCLUSIONS

Based on the identification results of the recharge area in Upper Cisadane Watershed, obtained distributions of recharge area criticality (%) in 2006, 2009 and 2013 are good (27.4%, 20.3%, 19.9%); normal (11.9%, 7.8%, 5.6%); ranging critical (16.4%, 7.5%, 5.4%), rather critical (25.3%, 25.6%, 30.6%); critical (15.3%, 22.2%, 21.6%); and very critical (3.7%, 16.6%, 17%), respectively.

The simulated of water balance analysis was done on each recharge area by using maximum rainfall of 2006, 2009 and 2013. The simulation results showed that recharge areas with good and normal conditions are able to infiltrate rainwater more than surface runoff, while the amount of rainwater that infiltrate in recharge areas with conditions of ranging critical, rather critical, critical, and very critical condition are smaller than surface runoff.

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