THE EFFECT OF HYDROLOGIC RESPONSE UNIT ON CI RASEA WATERSHED STREAMFLOW BASED ON LANDSAT TM

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Abstract. This paper discusses spatial pattern of Hydrologic Response Unit (HRU), which is a unit formed of hydrological analysis, including geology and soil type, elevation and slope, and also land cover in 2009. This paper also discusses the impact of HRU on streamflow of Ci Rasea watershed, West Java. Ci Rasea watershed is located at the upstream part of Ci Tarum watersheds in West Java Province, Indonesia. This research used SWAT (Soil and Water Assessment Tool) model to obtain spatial HRU and river flow. The method used Landsat TM data for land cover and daily rainfall for river flow modeling. The results have shown spatial pattern of HRU which was affected by land cover, soil type and slope. In 2009, accumulated surface runoff and streamflow changes were spatially affected by HRU changes. The large amount accumulation of river flow discharge happened in HRU with landcover paddy field, silty clay soil, and flat slope. While the low discharge of river flow happened in HRU with plantation, clay soil, and slightly steep slopes as HRU dominant. It was found that accumulation of surface runoff in Ci Rasea watershed can be reduced by changing the land cover type in some areas with clay and slightly steep slope to become plantation area and the areas with sandy loam soil and flat slope can be used for paddy fields. Beside affected by HRU, the river flow discharge was also affected by the distance of sub watershed to the outlet. By using NS model and statistical t-student for calibration and validation, it was obtained that the accuracy of river flow models with HRU was 70%. It meant that the model could better simulate water flows of the Ci Rasea watershed.

Keywords: *SWAT, HRU, landcover, watershed, Landsat, Ci Rasea*

1 INTRODUCTION

Land cover changes can increase flood risk (Chubey and Harhout, 2004). The risk is caused by decreasing both ability of land to absorb water and ability of the river to accommodate water flow. Decreasing river water flow could be caused by silting, land conversion in the catchment and excessive groundwater use. Land cover change in the upstream region such as forest change to settlements or open land, also can affect flooding. It will cause increasing runoff due to reducing area of water catchment. The increasing runoff is caused by reducing ability of catchment in holding or permeating the water. The infiltration, surface runoff and évapotranspiration are controlled by the distribution of precipitation, topography, soils, geology and land use within the watershed (Anderson and Burt, 1978; Beven and Kirkby, 1979; Devito *et al.*, 2005).

Issey (2011) stated that flood always happens in South Bandung, Indonesia around Ci Tarum watershed area. Ci Rasea watershed is the branch of Ci Tarum watersheds. According to Yusuf (2010), land cover at Ci Rasea watershed from 1997 to 2007 had changed. According to Balitklimat (2007) and Pawitan (2002; 2006), land cover changes in the watershed could cause hydrology characteristics of watershed changed.

According to Harto (1993), the hydrology characteristic changes could be either behavior or function of surface water. For example the increasing streamflow is caused by infiltration capacity is decreased and causes flooding.

Hydrological characteristic of the watershed was derived by hydrologic response unit (HRU). HRU is hydrological analysis unit which is formed based on soil type, height and slope, structure of geology and landcover. Flugel (1997) stated that HRU can produce both spatial fact and phenomena in watershed relationship, because HRU is characteristic grouping of physical geography related to soil type, slope, structure of geology and land cover of an area.

Soil type, slope, structure of geology and land cover are dynamic variables that can cause changes of HRU temporally. HRU changes usually occur due to the development of an area such as the forest changes become settlement. Fakhrudin (2003) studied the effect of hydrology response caused by landcover changes. Furthermore, the geomorphologic structure could affect the great variety of hydrologic responses that occur in nature (Rodriguez-Iturbed and Valdes, 1979).

A hydrology model which can be used to obtain hydrological characteristics of the watershed is SWAT (Soil and Water Assessment Tool). According Neitsch, et al (2005) SWAT is a model that can be used to predict the effects of land cover related to the water flow, sediment, and other chemical materials which enter the river or water body in watershed. By using SWAT models, which use HRU and rainfall data, can produce flow discharges in watershed or sub-watershed.

Some results of other studies (Hernandez et al. 2000; Suryani, 2005; Briley, 2010; Arnold, 2011 and Adrionita, 2011; Leon and George. 2008; Park *et al.*, 2011) suggested that SWAT could describe the relationship between land cover and watershed hydrology. The previous studied just used SWAT for flow discharge model, but did not study how the HRU effect on the flow on the watershed. Therefor, the objective of this studied ways to get the spatial patterns of the hydrology response units (HRU) and the flow discharge by using model SWAT in Ci Raseawatershed spatially in 2009.

2 MATERIALS AND METHODOLOGY

The research was carried out in Ci Rasea watershed, West Java, Indonesia (Figure 2-1). Ci Rasea is a part of the Ci Tarum watershed, which is located in 7° 2' 17" - 7° 9' 58" S and 107° 37' 37"- 107° 43' 1" E. This area is bordered by Pacet district from the east and the north, Arjasari district from the west and Ciparay, Majalaya and Baleendah district from the south.

This study used tabular and spatial data, such as soil map in a scale of 1: 100,000 containing soil type and texture, obtained from Puslittanak 1993, daily rainfall data obtained from the Ministry of Public Works (PU) for the period of 1997 to 2009, geological data of lithology obtained from the geological map in a scale of 1: 1000.000 which was published by the Ministry of Energy and Mineral Resources. Meanwhile climate data such as temperature, solar radiation and wind speed was obtained from the National Climatic Data Center (NCDC). Furthermore this study used Landsat TM on November 2, 2009 which have spatial resolution of 30 meters and obtained from LAPAN.

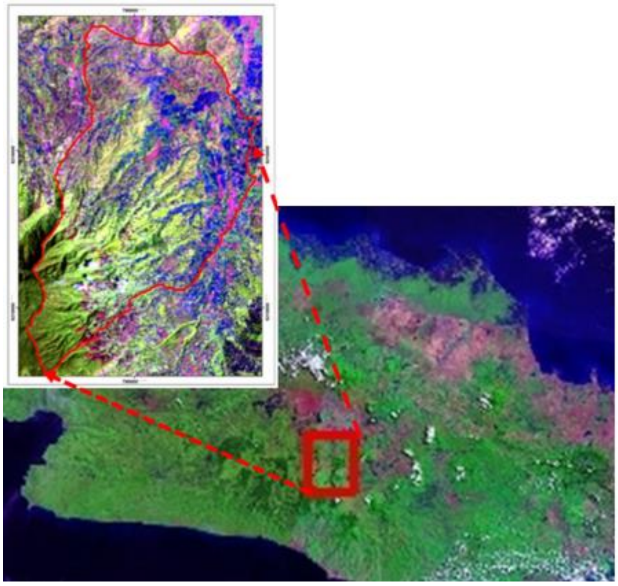


Figure 2-1: Study area, Ci Rasea watershed

The Landsat TM image was used for detection of landcover change in spatially. Digital elevation models (DEM) was genedischarged from the image of Shuttle Radar Topography Mission (SRTM). SRTM image with spatial resolution of 25 meters was obtained from the National Institute of Aeronautics and Space (LAPAN). Daily hydrological data, such as flow discharge in 2009 were obtained from the Ministry of Public Works (PU). The river characteristic was collected from field observation consisted of base and wall roughness of the river. The river characteristic was used to determine the manning's roughness coefficient for river channel. Meanwhile river networks, road networks and administrative boundaries were obtained from RBI maps Indonesia (RBI) issued by BAKOSURTANAL in 2009.

This study used ER-Mapper 7.0 and Global Mapper 11 for remote sensing data processing and Statistic analysis was done using SPSS-17. While for processing and analysis of GIS was used ArcView 3.3 and open source software such as: Mapwindow 4.7.5, MWSWAT, SWAT EDITOR 2005 and SWAT Plot. Accrodin to Briley L (2010) and Leon and George (2008), MWSWAT is an open source tool to provide Geographic Information System (GIS) support and a setup interface for the Soil and Water Assessment Tool (SWAT).

The flow chart of research method is presented briefly in Figure 2-2. Image corrections such as orthorectification, radiometric and terrain correction were done to get the accudischarge image. After that the next step is image processing to produce land cover maps by using maximum likelihood method of supervised classification. This study used six land cover classes, which are forest, scrub, paddy field, plantation, cropland and urban.

Soil type and geological/lithological data used to obtaining soil classification map which related to soil permeability. The soil classification consists of several classes such as clay (C), clayey loam (CL), silt clay (SIC), silt loam (SIL) and sandy loam (LS). SRTM DEM data was used to derive elevation information and then corrected by RBI map to get accudischarge data. The elevation data were used to genedischarge slope information which was classified into flat (0%-8%), slightly tilted (8%-15%), oblique (15%-25%), steep (25%-40%) and very steep (>40%).

The watershed boundary was genedischarged using cluster analysis. A cluster technique used was a non-hierarchical method based on the optimal value. Delineation of watershed boundary was conducted using 5 km optimum values which means the most detailed delineation was up to 5 km. The outlet of watershed which was used is Ci Rasea-Cengkrong point.

The cluster analysis was done by using non-hierarchical threshold with percentage. The threshold which was used is 0% for land cover, soil type 5% and 5% slope. It means that the HRU which have smaller value than the threshold can be ignored by the model and the value can be replaced by its neighbors. The election of the 0 % threshold was done to calculate every existing land cover. Therefore, the changes of HRU caused by land cover changes can be identified in detail. The results of this cluster analysis are HRU Ci Rasea watershed.

The climate data genedischarged by using the SWAT model with input climate data 1997 to 2009 consist of temperature, rainfall, monthly average of solar radiation and wind speed. Temperature data which is used in this study are daily temperature, monthly of maximum and minimum temperature, monthly temperature average, dew point and the standard deviation.

The rainfall data which is used in this study are daily rainfall, the monthly average rainfall intensity, average rain days monthly, a standard deviation monthly, skewness monthly, chances days of rain followed by dry days, the chance of rainy days followed by days of rain and rain extremes half daily monthly. This study used Ciparay station as an outlet which are nearest station at Cirasea watershed.

The SWAT flow model simulated based on HRU and weather data. This process was done in Map Window 4.7.5 software with MWSWAT as an interface. Simulation models to obtain the flow discharge based on rainfall data and daily temperature in January-April 2009. Spatial analysis was carried out by analyzing spatial pattern which are categorized as:

- Random if standard deviation equal to the average.
- Uniform if standard deviation less than the average.
- Cluster if standard deviation more than the average.

Calibration and validation was done by comparing the flow models and field measurements in the same year to see how accudischarge the results. Flows of Cirase-Cengkrong field data in 2009 were used as follows from field measurements, precisely in January-April 2009. It was related to rainfall data which were used. The model of Nash-Sutcliffe efficiency (NS) and models the t (t-student) in SPSS-17 software was used for calibration and validation. According Ahl et al. (2008), the formula of Nash-Sutcliffe efficiency (NS) model as follow:

$$NS = 1 - \left[\frac{\sum \left(y - \hat{y} \right)^2}{\sum \left(y - \bar{y} \right)^2} \right] \quad (2\text{-}1)$$

Where y is flowing at field (mm), ŷ adalah flows model (mm) and ȳ is average flows.

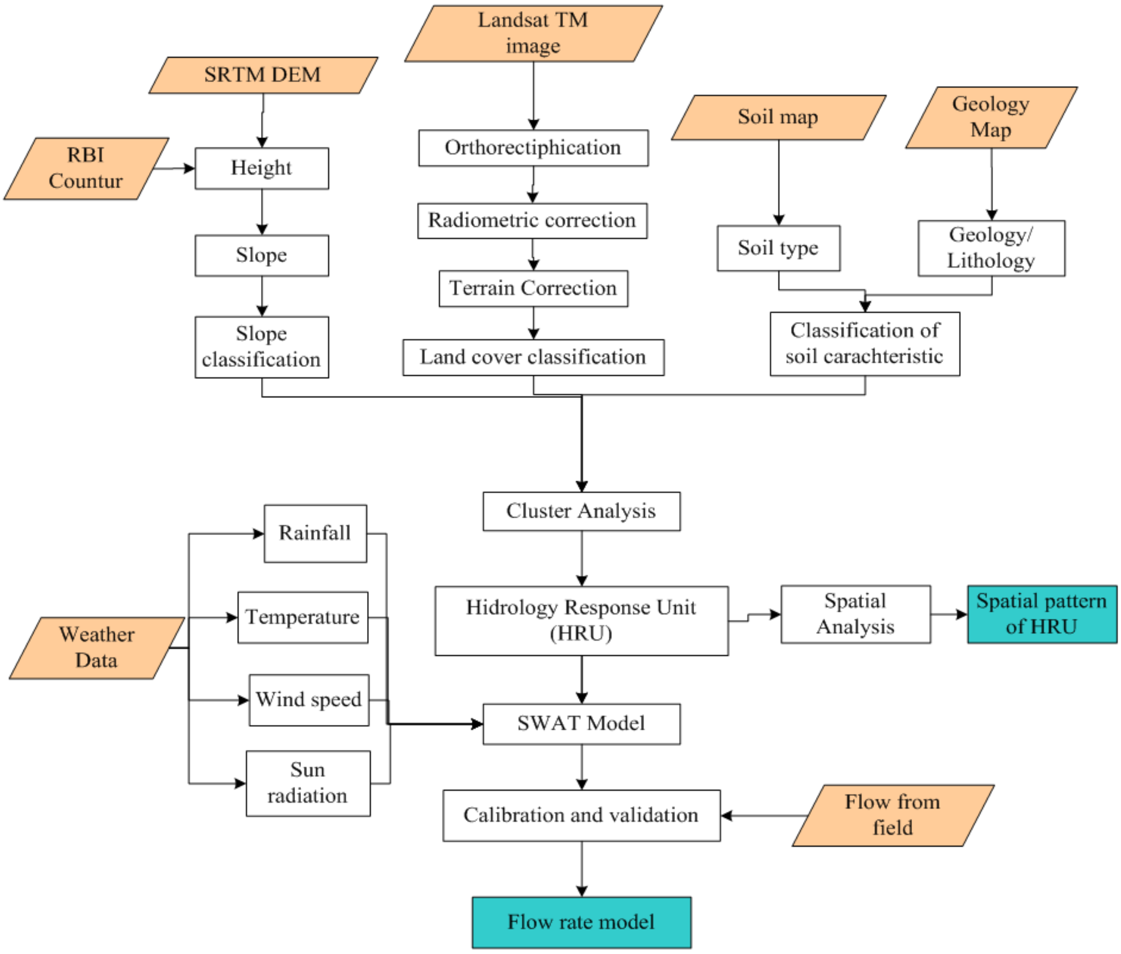


Figure 2-2: Flowchart of research methods

3 RESULTS AND DISCUSSION

Based on National Climate Data Center (NCDC) data from 1997-2009, the average monthly maximum of temperatures at CiRasea watershed are around 26.6° - 29 °C and the minimum are around 18.9°- 20.9 °C. The highest temperature happens in September and the lowest in in December. In 1998-2007 monthly average of wind speed CiRasea is about 0.8-6.3 m/s with solar radiation approximately 14.9-17.6 $MJ/m^2/day$. The average wind speed is highest in May and the lowest in April. While the highest solar radiation occurred in May and lowest in December.

According to DEM SRTM, It was found that around 20% of Ci Rasea watershed are flat, 22.7 % are slightly, 2%4 are oblique, 19.7 % are steep and the rest is very steep. Geology and soil data described that CiRasea watershed mostly formed by *Inceptisols* soil, *Mollisols* soil and *Alfisol* soil. *Inceptisols*soils have textured clay (C), clayey loam (CL), clay dust (SIC), the dusty loam (SIL) and sandy loam (LS). *Mollisols* soil have textured clay (C), clayey loam (CL) and clay dust (SIC). While *Alfisols* have textured clay (C).

Based on field observation, CiRasea have land cover which classes as settlement, forest, paddy field, scrub, plantation and cropland. Settlement including street, houses, schools and buildings. Forest is defined as an area which have dense trees which growth naturally. Scrub is defined as an area which dominated by shrubs, consist of grasses, herbs and geophytes. Paddy field is defined as wet agriculture, which cultivated with rice. Cropland is defined as dry agriculture, which cultivated with seasonal plants at certain slope. Plantation is defined as an area which cultivated with certain plant such tea, vegetable or fruits.

Six landcover classes which obtained from classification, can be as seen in Figure 3-1. Figure 3-1 shows that the settlement and paddy field located at the downstream of the watershed. Croplands, shrubs and plantation were located at downstream, middle and upper watershed. While forest located in the upstream watershed. A dominant area of land cover in 2009 was cropland. In 2009, total area of the forest was 719 ha, the plantation was 1427 ha, the settlement was 343 ha, paddy field was 906 ha, scrub was 1206 ha and cropland was 2010 ha. Land cover is important information which influences the hydrology process. Good landcover will impact the good hydrology condition.

Furthermore, nine sub watersheds, can be seen in Figure 3-3 while the mapping of HRU based on land cover, soil and slope can be seen in Figure 3-3. Figure 3-3 showed that the most of the HRU spatial pattern for cropland was located in the upstream, midstream and downstream watershed. HRU for plantation was located in the midstream and downstream of the watershed. The spatial pattern of forest HRU was located in the upstream watershed. Most of the HRU spatial pattern for paddy field was located at midstream and downstream of the watershed. The spatial pattern HRU for scrub was located widely in midstream and upper stream watershed while the spatial pattern of HRU of settlement were located at the downstream of the watershed.

According to Figure 3-2 and 3-3, plantation with clay soil and slightly tilted slope was dominant HRU in sub watershed one. Cropland with clay soil and slightly tilted slope was dominant HRU in sub watershed two. Cropland with clay soil and oblique slope was dominant HRU in third sub watershed . Scrub with clay soil and oblique slope was dominant HRU in fourth sub watershed. Forest with clay loam soil and steep slope was dominant HRU in fifth sub watershed. Cropland with clay and flat slope was dominant HRU in sixth sub watershed. Plantation with sandy loam soil and flat slope was dominant HRU in seventh sub watershed. While plantation with sandy loam soil and steep slope was dominant HRU in eighth sub watershe. Paddy field with clayey dusty and flat slope was dominant HRU in ninth sub watershed. It is also seen that dominant soil type in the Ci rasea watershed was clay, whereas the dominant slope in the Ci Rasea watershed was flat.

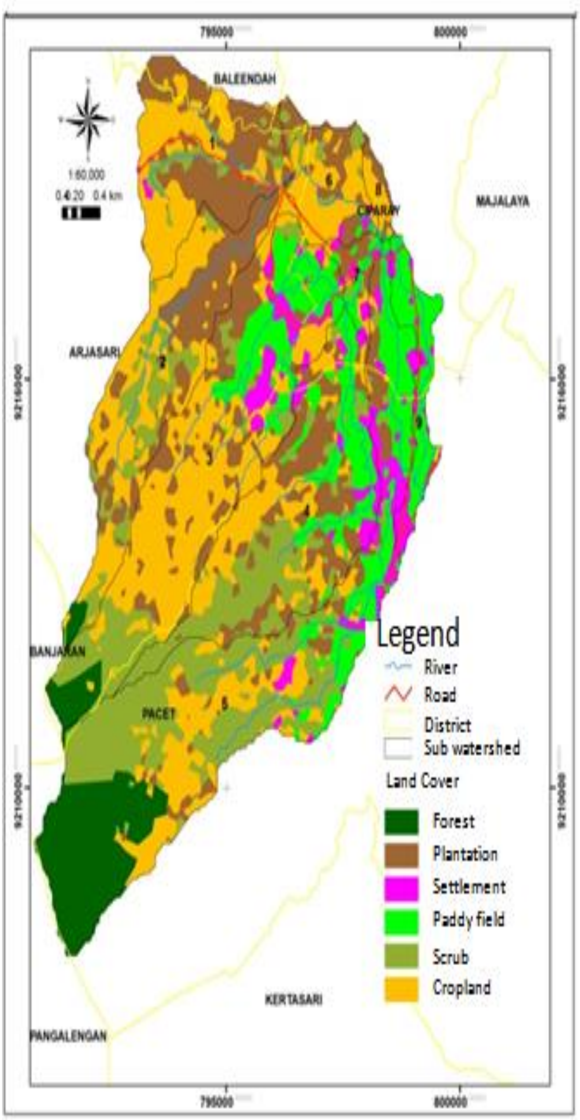


Figure 3-1: Landcover Ci Rasea watershed in 2009 based on Landsat TM data

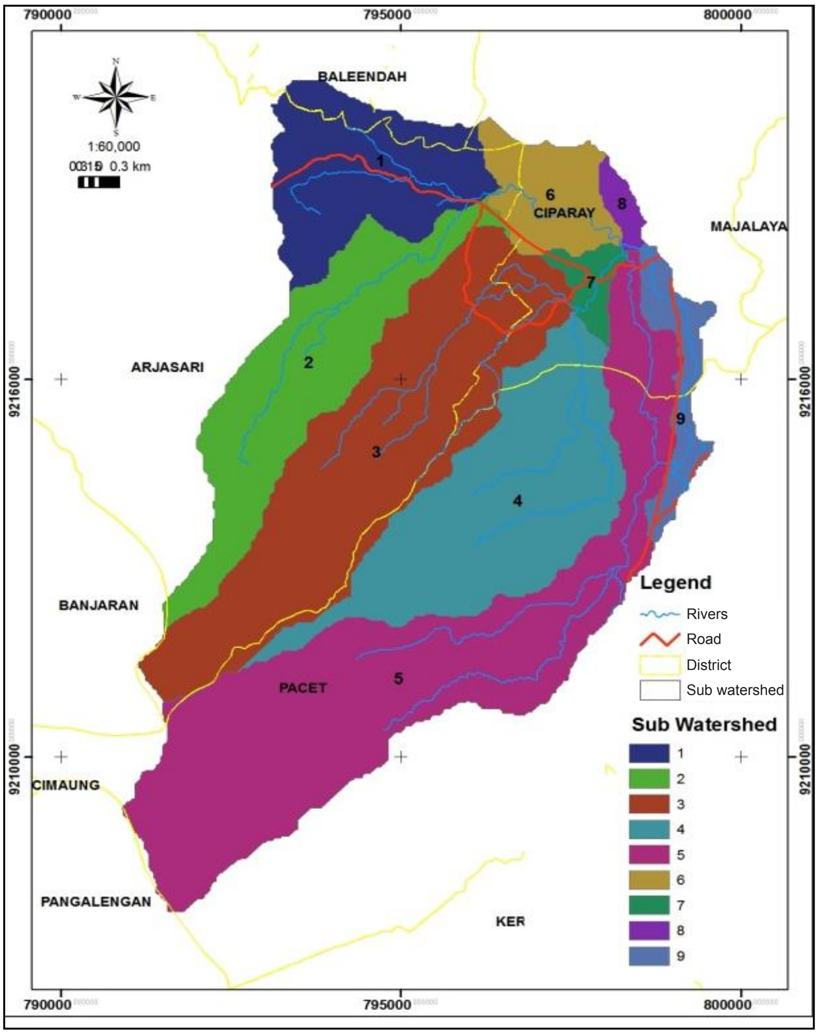


Figure 3-2: Sub region in Ci Rasea watershed based on cluster analysis

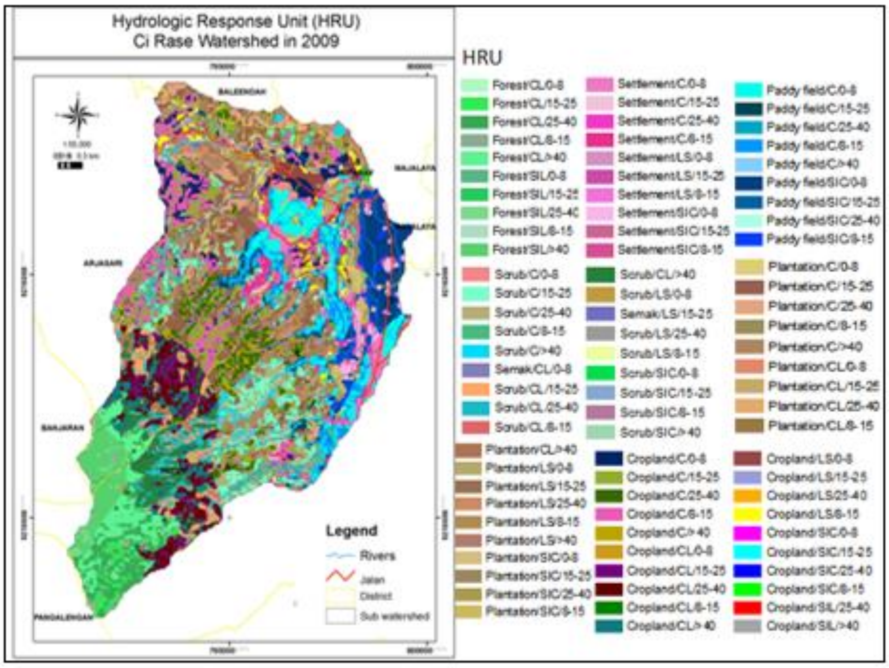


Figure 3-3: HRU spatial pattern Ci Rasea watershed in 2009

Table 3-1: Surface runoff and flow of each sub watershed in CiRasea

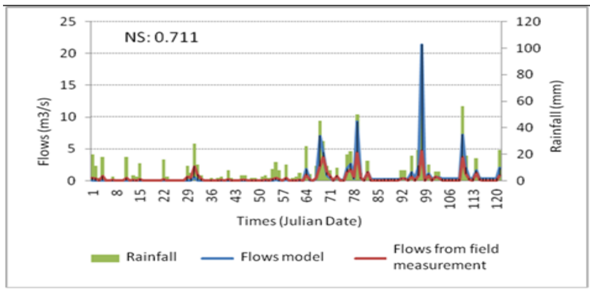
Sub regions	HRU Dominant (Landcover/soil/slope)	Areas of HRU Dominant (Ha)	Spatial Pattern	Surface Run off (mm)	Flows Discharges (m^3/s)
1	Plantation/C/8-15	104.4	Cluster	32.5	2.5
2	Cropland/C/8-15	140.8	Cluster	35.2	3.4
3	Cropland/C/15-25	129.6	Random	33.6	5.8
4	Scrub/C/15-25	91.98	Random	30.3	3.9
5	Forest/CL/>40	171.4	Cluster	29.9	6.8
6	Cropland/C/0-8	53.52	Random	32.6	7.1
7	Plantation/LS/0-8	15.9	Cluster	19.7	10.0
8	Plantation/LS/25-40	7.36	Cluster	25.0	17.2
9	Paddy field/SIC/0-8	117.5	Cluster	29.3	24.7
Number of HRU	288	**Averages**		29.8	9.0

Based on SWAT modeling, surface flow was obtained from any Sub watershed can be seen in Table 3-1. The majority of spatial pattern in the CI Rasea watershed were clustered and dominate with plantation and cropland land cover. The large accumulated of runoff, mostly happen in sub regions of watershed two. As known that sub watershed two has a dominant HRU of cropland/C/8-15 (Figure 3-3). It means the area which have cropland with soil type clay and slope slightly tilted can produce large runoff when the amount of water comes. While sub watershed, which was resulted low accumulation of runoff was sub watershed seventh. This has happened because the landcover sub watershed seventh was a plantation with flat slope and sandy loam soil (Figure 3-3). It seems that plantation with sandy loam soil and flat slope absorb more water.

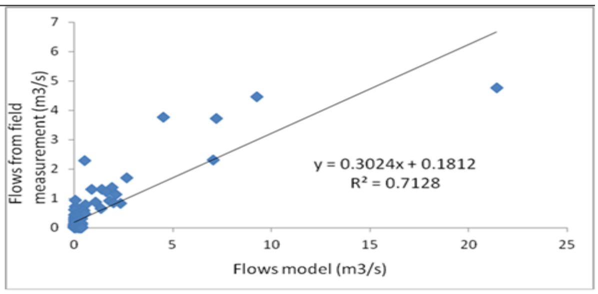
It was also found the way to reduce the accumulation of surface runoff in the Ci Rasea watershed, which have slopes slightly tilted and clay soil can be used for plantations. But the large amount of runoff didn't caused big flow discharge (Table 3-1). It means that the large amount of flow discharge happen in sub watershed nine, which was having HRU dominant of paddy field with clayey dusty and flat slope. While the small number of flows discharge is happening in sub watershed one, which has plantation with clay soil and slightly tilted slopes as HRU dominant.

Table 3-1 shows that the greater distance of sub watershed to outlet resulted a lower flow dischargedischarges. So, based on the length of distance between sub watersheds to an outlet can be found the smallest flow discharge was a sub watershed first. In contrasrt, sub watershed ninth have high flow discharge due to its located near outlate. According to Neistch et al. (2011), flow discharge is a function of surface runoff, area, HRU and and the time. While HRU is defined as fraction of daily rainfall which happen during the time of concentration. Besides that, Rodriguez-Iturbed (1979) also said that HRU related with surface runoff. Therefore, the amount of flow discarges in Ci Rasea watershed was influenced by a distance of sub watershed with the outlet and the HRU.

Based on efficient model of Nash-Sutcliffe (NS), flows discharge model from classification six classes of land cover was 0.7 with accuracy 0.7 (Figures 3-4). It can be defined that the model satisfactory for



a. Flows model, rainfall and flows from field measurement in Ci Rasea watershed. March 2009



b. Correlation between the flows models and flows from field measurement base on HRU in Ci Rasea watershed, 2009

Figure 3-4: Calibration and validation result based on NS model and its correlation

analysis based on grouping criteria of efficiency NS model. Figure 3-4b show that the flow model and flows from field measurement has a fairly high correlation. By using statistical t-student test was obtained p = 0.06 at a significance level of 5%. It was meant the value of p> 0.05. Thus, the null hypothesis (Ho), which means there are not real differences between flows model and flows from field measurement, were received.

The correlation between flow model and flows from field measurement which genedischarged by t-student test was 0. 84. It was using 121 numbers of samples. The accuracy of flow model simulation in the Ci Rasea watershed was 70%. Calculation results of the SWAT model show that flows model of sub watershed, which close to main channel has high accuracy. While the flow model of sub watershed, which was far away from main channel has a low accuracy.

4 CONCLUSIONS

Analysis of Hydrologic Response Unit (HRU) in Ci Rasea watershed shows that the spatial pattern of land cover, soil and slope affects HRU spatially. Then, using more detail of land cover, soil and slope map can produce HRU spatially more detail. Change detection of HRU as spatially affects the accumulation of runoff and flow. Accumulation of surface runoff in Ci Rasea watershed can be reduced by making some area become plantation in clay soil and slightly tilted slope areas and areas which have a sandy loam soil and a flat slope can be used for paddy fields.

The large amount accumulation of flows in Ci Rasea watershed affected by HRU plantation with clay soil and slightly tilted slopes. While the small amount accumulation of flows in Ci Rasea watershed affected by HRUpaddy field with sandy loam soil type and flat slope. Beside that, the amount of flow discharge also influenced by the distance between sub watershed with the outlet. Accuracy of flow models of this HRU was 70%. It means that the model can simulate flows of Ci Rasea watershed wellenaugh.

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