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Tank Model Application for Runoff and Infiltration Analysis on Sub-Watersheds in Lalindu, Southeast Sulawesi Province

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Abstract
Improper land management often cause flooding, this is due to uncontrolled runoff. The runoff is influenced by the management of land cover. This study aims to analyze the flow rate by using a tank model, which can describe the magnitude of hydrologic runoff and infiltration capacity on some land use and evaluated in the study area, which is located in the watershed Lalindu, Southeast Sulawesi. The results showed that the runoff in the forest at 2,639.21 mm/yr, reeds at 2,517.05 mm/yr, palm with slopes of more than 45% at 2,715.36 mm/yr and oil with slopes of less than 45% at 2,709.59 mm/yr. Infiltration in the forest value of 30.70 mm/yr, reeds at 7:51 mm/yr, palm with slopes of more than 45% of 24.13 mm / yr and oil with slopes of less than 45% of 29.67 mm/yr. Contribute to streamflow runoff for water availability.
Keywords: runoff, infilrasi, land management, models of tanks, DAS Lalindu

Introduction

Changes in land use in the watersheds (DAS) provide a dominant influence on flood discharge (Jayadi 2008). The greatest influence changes in land use on the sustainability of water resources is the changes from forest land to other uses such as agriculture, farming, residence or industry. If these activities are not well-managed, it will result in water excess (flood) during the rainy season, and drought during the dry season. Unwisely changes in land use and is not accompanied by conservation measures will largely become runoff.

The expansion of oil palm plantations keeps going in Indonesia, including in Southeast Sulawesi, which is spread almost all over North Konawe Regency, including in Wiwirano District. The changes of land cover grow rapidly and it is one of areas used as a priority area of oil palm development. It can be viewed from the increasingly growing oil palm plantation during the last five years, both operated by the community and by private plantations. Such changes will certainly have an impact on the ecological condition of the watershed area, but on the other hand, the demand for land needs is unpreventable upon consideration of human needs fulfillment.

The land use ignoring sustainability aspect, such as deforestation will put impact on the reduced water discharge in Lalindu watersheds. The deforestation is a consequence of the land function transfer. Land use transfer has resulted in changes of land structure. During dry season, the soil becomes hard and barren due to absorption strength of the sun, penetrating into the soil. If various trees still exist, the sun heat will be muffled in the foliage and the soil will stay fertile for the stable humidity. In addition, travel time of the water is relatively short, thus the rate of water infiltration by land is slower than the runoff rate. It is influenced by a number factors, among others; by concave topography of Mount Wiwirano (although the nature of the soil supports the absorption of water into the soil) resulting in most rainwater that will be lost through runoff and later run towards the river and eventually into the sea, before the rain water fills the underground water through infiltration and percolation process. A settlement is located surrounding this valley, thus during heavy rains, floods will occur.

Tank model or lump model is the method that is based on the hypothesis that the runoff flow and infiltration is a function of the water amount presents in the soil). The tank model can be constructed in such a way, thus representing the function of sub- watersheds area, or represents the difference in the structure/ type of land in each layer. Besides explaining the lost of initial rainfall and the dependence on prior rain, the tank model can also present some of the components forming the runoff flow, which have specific period and time lag. The tank model structure is the closest model to each watershed (Sugawara, 1961 in Bangun 2010.)

A tank with wasting channel on its side represents runoff, lower wasting channel represents infiltration, and saving component represents the runoff processes in one watershed or in watershed partly. Several parallel similar tanks can represent a large watershed (Mulyana, et al., 2011), thereby, this study is aimed to analyze the flow rate by using a model consisted of runoff parameter, infiltration capacity and ground water content.

LITERATURE REVIEW

Changes of land-use are changes of use from one side use to any other use followed by the reduction of land use type, from time to time. Changes or development of land use is influenced by two factors: natural factors and human factors (Worosuprojo, 2007).

Changes in land use of an area can put positive and negative impacts on the availability and quality of the resources. It is hard to make a universal statement on the impact of land use on water resources for several reasons. Effects of land use on water resources depend on biophysical factors of the land (climate, topography, and land) and socio-economic factors, including the awareness and economic ability of the farmers, management practices, and build infrastructure, such as roads. Furthermore, the agricultural impact and land use may be difficult to predict, whether due to natural factors or human influences, such as land degradation, affecting water resources (surface water and groundwater).

Water is a resource that is highly vital for the human survival and life. With the increasing number of population, then maybe one day the water may not be able to meet human needs, in case the method to preserve it is not sought. Experts predict that as of 2025, about two-thirds of the world's population will face water shortage. there will be a very tight competition among users in the utilization of water resources (Sutawan, 2001).

According to the Law No.7 of 2004, Water Resources is the water, water resources, and water energy contained in it. Water is the entire water contained in, above, or below the soil surface, including surface water in this definition is ground water, rain water, sea water and land. The water source is a natural container of water and/ or artificial contained in, above, or below the soil surface. Water resources management is an effort to plan, implement, monitor, and evaluate the implementation of water resources conservation, utilization, and the control of water damage force.

In the Indonesian context nowadays, the problems related to water resources can be identified, among others: the symptoms of the water crisis; degradation of water resources; conflicts due to competition among water users; shrinking of irrigated land for conversion; lack of clarity in the provisions of the water rights; lack of coordination between agencies in dealing with water resources; and the weakness of the water resource policy (Sutawan, 2001). These problems require the presence of an appropriate policy option, thus the utilization of water resources can be sustained.

Watersheds can be viewed as a hydrological system in which precipitation is the input from streams, and evapotranspiration is the system output. Furthermore, it is said that the watershed is the place where the simultaneous processes happen and become a part of the hydrological cycle (Sulityowati, 2010).

According to Seyhan (1990), as referred to in Nurhayati (2008), the main factors in the watershed greatly affecting the availability of water resources are:

(i) Vegetation; Vegetation is a protector of the earth's surface from the pounding rain, gusts of wind and sunlight heat. The main function of vegetation is to protect the soil from vegetation. This protection is conducted by means of: (a) protection of the soil against the destructive power of the rainfalls, (b) the protection of the soil from damaging power flow of water on the soil surface, and (c) improvement of soil structure, infiltration capacity and absorption force or water capacity force.

(ii) Land; besides being a vegetation growth medium, land also serves as a water system regulatory. The role of soil in regulating the water system depends on the level of the land ability to absorb water which is affected by infiltration capacity and land permeability.

Changes in the hydrological condition as a result of uncontrolled expansion without regard to the principles of conservation of soil and water often leads to unwanted conditions, namely the increased erosion and sedimentation, reduced land productivity, and the acceleration of land degradation (Directorate General of RLPS, 2009).

2.RESEARCH METHODOLOGY

2.1 The Location and Time of the Research

The research was conducted on sub watersheds in Lalindu, North Konawe, one of the districts in Southeast Sulawesi and was conducted from January and December 2011. Observations made on hydrological conditions on 4 sub-watersheds which were parts of the Lalindu Sub-watershed. The placement of 4 sample plots in each sub-watershed represented the three types of vegetation or land cover in the sub-watershed. The vegetations were the forest, reeds and palm oil. Palm oil itself was divided into two by the steepness, i.e. palm with steepness > 15% and palm oil with steepness <15%. The observation plots schemes and sub-watersheds samples are presented in Figure 1.

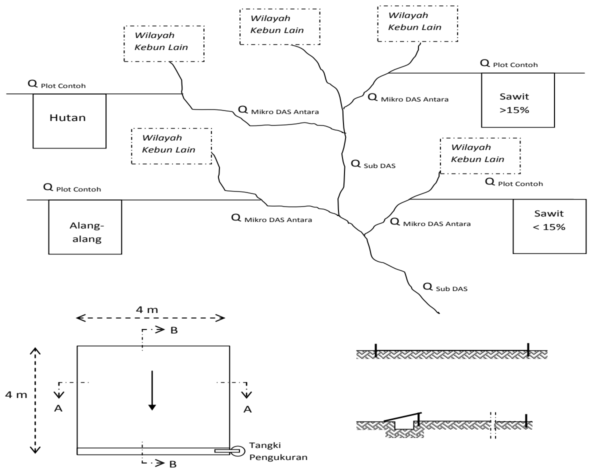


Figure 1. Schematic of observation plots and sub-sub DAS instance

2.2 The Type and Source of the Data

The data used in this research were primary data and secondary data. The primary data included water discharge data on sample plots, sub- watersheds and sub-watershed from January to December 2011. Secondary data was the climate data, soil-type data and biophysical conditions. The data analysis was performed on the amount of rainfall, infiltration, evapotranspiration and runoff. Furthermore, tank model creation was made to describe runoff processes occurring in the watershed. The model was verified by observing the sample plots to obtain parameter value of the first tank (Figure 2)

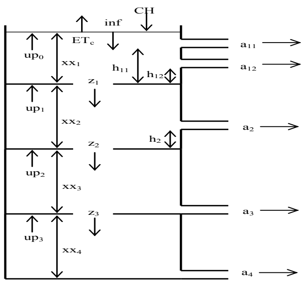


Figure 2. The Tank Model Tank Used in the Research

Where;
xx: ground water content (mm)
h: height of tank outlet hole (mm)
a: the coefficient tank outlet hole
z: coefficient of tank hole downwards
t: time (days)
Q: river discharge
The runoff can be formulated as follows:

1. The basic equation for the first tank is as follows:

$$xx_1(t) = xx_1(t-1) + CH - ET_c - z_1.xx_1(t-1) - [(xx_1(t) - h_{11})a_{11} + (xx_1(t) - h_{12})a_{12}]$$

2. The equation for the second tank is as follows:

$$xx_2(t) = xx_2(t-1) - z_2.xx_2(t-1) + z_1.xx_1(t-1) - [(xx_2(t) - h_2)a_2]$$

3. The equation for the third tank is as follows:

$$xx_3 = xx_3(t-1) - z_3.xx_3(t-1) + z_2.xx_2(t-1) - xx_3(t).a_3$$

4. The equation for the fourth tank is as follows:

$$xx_4(t) = xx_4(t-1) + z_3.xx_3(t-1) - xx_4(t).a_4$$

The runoff discharge from river (Q) is calculated by the following equation:

$$Q(t) = [(xx_1(t) - h_{11})a_{11} + (xx_1(t) - h_{12})a_{12}] + [(xx_2(t) - h_2)a_2] + xx_3(t).a_3 + xx_4(t).a_4$$

Where:
Xt : height of ground water content (KAT)
H_a : height of stored water (outlet hole level)
Z : infiltration coefficient
a, b : outlet hole coefficient
CH: rainfall depth
Etc: actual evapotranspiration
t : time (days)
i :1….4

Tank model validation process was done by using daily rainfall data and daily actual discharge in 2011 from the results of direct measurements in the field. The actual discharge data used in this validation process was the actual discharge data in the sub watersheds of gardens and other lands located in the surrounding garden location of the research.

3. FINDINGS AND DISCUSSION

3.1 Calibration and Validation of Tank Model

Daily rainfall data and evapotranspiration of ETo value from the calculation result of climate data in the garden in 2012 are presented in Figure 3. The rainfall and evapotranspiration data is used as an input value in the analysis of the tank model.

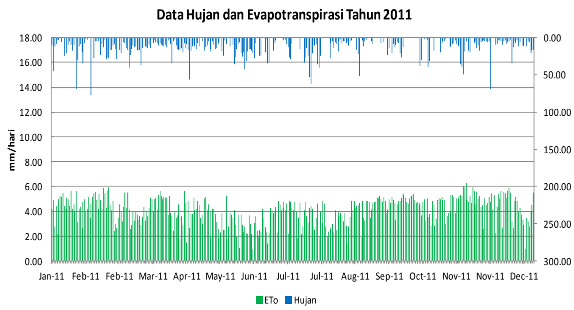


Figure 3 daily rainfall and evapotranspiration data of ETo value in the garden of 2011

The discharge measurement of sample plots on four types of land cover is forest,reeds, and palm oil land, with a steepness > 15% and <15%. The discharge data on the measurement results with sample plots of the size 16 m^2 is presented in Figure 4.

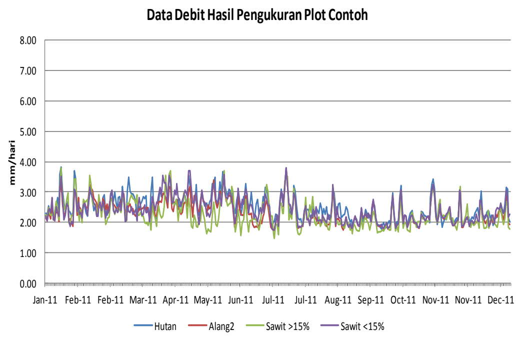
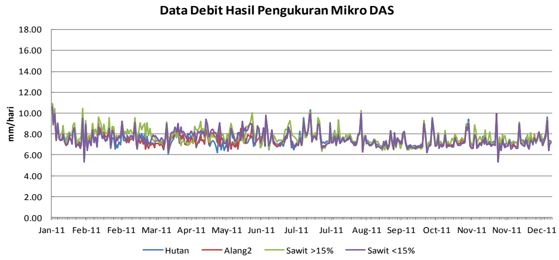


Figure 4. The Discharge Measurement Data From Calculation Result For Each Land-Use In Sample Plots in 2011

In addition, the discharge measurement is conducted at sub-watersheds in the area of 20.000Ha. the discharge measurement data at the sub- watersheds is influenced also by run-off from the garden area in the surrounding concession becoming the location of this research. The discharge data of sub-watersheds from direct measurement is presented in Figure 5.Figure



5. The Discharge Data of Direct Measurement on Sub-Watersheds in 2011

3.2. Tank Model Calibration in Sample Plots

The measurement result data in sample plots is used as a basis for calibrating the tank model to determine the magnitude of the tank model coefficient in the first tank. The calibration of each type of land result on sample plots for the first tank on tank models are presented in Table 1, while the graph of the calibration results for each type of land is presented in Figure 6-9. The analysis of tank model of on the sample plots is conducted to determine the land cover characteristic towards the water.

Table 1. The Calibration Result of Each Land Type on Sample Plots For The First Tank (Upper Part).

Parameter	Coefficient Value	Forest	Reeds	Palm oil > 15%	Palm oil < 15%
Ground water content of tank 1	xx1	200	150	180	185
The outlet coefficient of tank 1-1	a11	0.65	0.7	0.6	0.65
The outlet coefficient of tank 1-2	a12	0.55	0.6	0.5	0.45
The outlet height of tank 1-1	h11	75	50	85	80
The outlet height of tank 1-2	h12	60	45	70	65
The coefficient of tank 1 downwards	z1	0.009	0.003	0.004	0.005

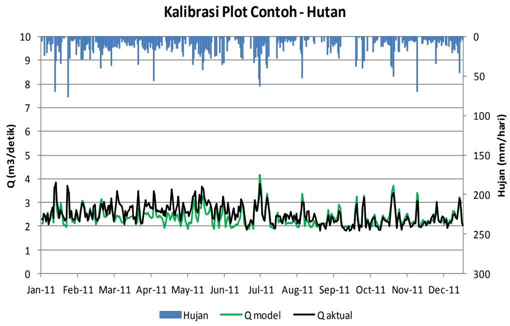


Figure 6 The Calibration Result Data for Forest Land on Sample Plots (R2 62.99%) in 2011

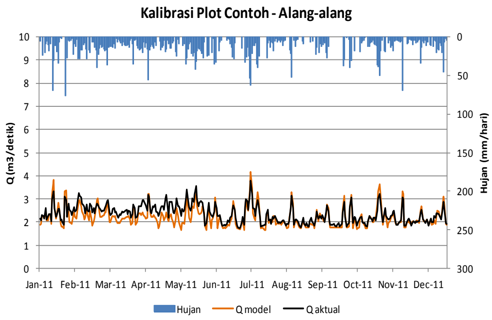


Figure 7 The Calibration Result Data For Reed Land On Sample Plots (R2 72.56%) in 2011

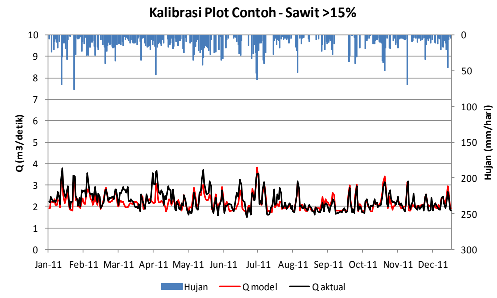


Figure 8 Calibration Data Results For Oil Palm Land With Steepness More Than 15% In The Sample Plots (R264.83%) in 2011

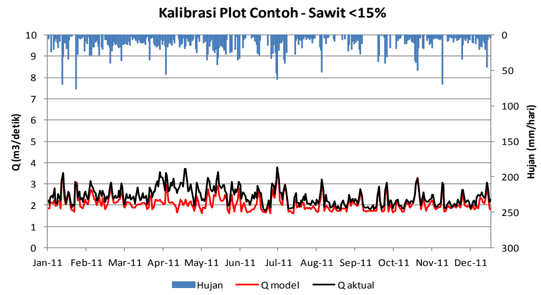


Figure 9 The Calibration Result Data Palm Oil Land With Steepness Less Than 15% In The Sample Plots ($R^2$73.13%) in 2011

3.3. Tank Model Calibration in Sub-Watersheds

In Table 2, the parameter coefficient values of the tank model calibration results in sub-watersheds is known using the data of 2011. From the calibration results, the coefficient of determination is obtained to be more than 70% for each land use.

Table 2. The Tank Model Coefficient Value of Calibration Results At The Sub-Watersheds in 2011

Parameter	Sub-watershed I	Sub-watershed II	Sub-watershed III	Sub-watershed IV
Ground water content of tank 1	500	300	850	900
Ground water content of tank 2	1100	800	1400	1300
Ground water content of tank 3	1500	1300	1800	1800
Ground water content of tank 4	2100	1800	2100	2000
The outlet coefficient of tank 1-2	0.8100	0.8500	0.8100	0.7900
The outlet coefficient of tank 1-2	0.7700	0.8200	0.7800	0.7700
The outlet coefficient of tank 2	0.7400	0.8000	0.7500	0.7600
The outlet coefficient of tank 3	0.0500	0.0500	0.0500	0.0500
The outlet coefficient of tank 4	0.0300	0.0300	0.0300	0.0300
The outlet height of tank 1-1	210	175	205	200
The outlet height of tank 1-2	180	170	190	195
The outlet height of tank 2	170	160	175	180
The coefficient of tank 1 downwards	0.0009	0.0003	0.0007	0.0008
The coefficient of tank 2 downwards	0.00005	0.00002	0.00005	0.00006
The coefficient of tank 3 downwards	0.00003	0.00001	0.00004	0.00005

Based on coefficient values of tank model from the calibration result, it is known that the coefficient of the tank outlet (a) is smaller to the lower part. It is due to the deeper soil layers, the ability of the soil to have water run-off is smaller. Similarly, the coefficient value of the tank downward (z) is smaller downward. it is due to the deeper layers of the soil, the soil capacity to carry water into the deeper layers (percolation) is getting smaller. From the results of the calibration tank model, it is known that ground water content (xx) is mostly found in the fourth tank. The water content in the soil at each level of the tank depth is greatly influenced by the type of plants that living above, as each model of discharge model outcome approaches the actual discharge model. Figure 10-13 is a graph of the calibration results between discharge model and the actual discharge of sub-watersheds in 2011.

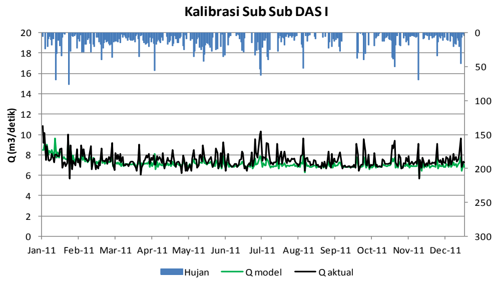


Figure 10. Calibration Result Data From Sub-Watershed I (R^2 78.31%) in 2011

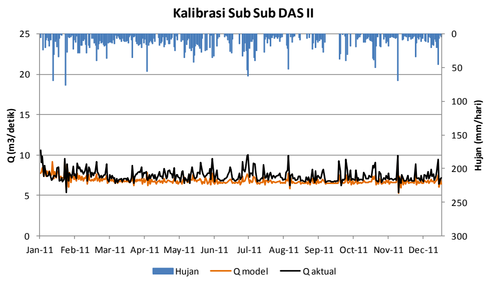


Figure 11 Calibration Result Data On Sub-Watershed II (R^2 72.30%) in 2011

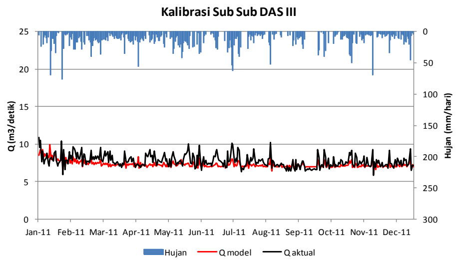


Figure 12 Data From The Calibration Result On Sub-Watershed III (R2 73.13%) In 2011

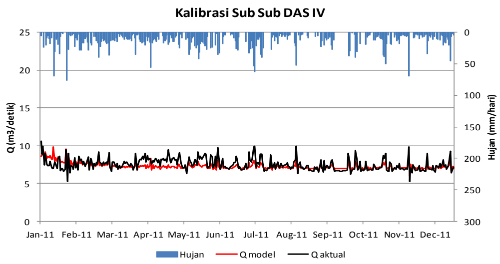


Figure 13 Data From The Calibration Result On The Sub-Watershed IV ($R^2$73.13%) in 2011

In the process of model validation, the coefficient value of tank models that have been obtained from the calibration results in 2011 from the previous stage is used. The calibration results of tank in model of sub-watersheds are later validated in the downstream region which is a part of the Lalindu Watershed. The discharge validation data results in gardens sub-watershed and the surrounding other land of 2011 are presented in Figure 14. The figure is a graph showing the relationship among rainfall, discharge models, and actual discharge of the model validation process. This validation process is obtained from the model discharge in the sub-watersheds of gardens and other surrounding land, describing the response towards the rainfall. The validation result has determination coefficient of 74.52%, and a tank model is then used to perform scenario of land conversion into oil palm plantation using conservation methods.

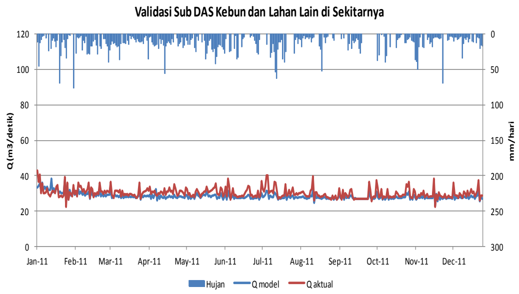


Figure 14 Discharge validation result data in sub-watersheds of gardens and other surrounding land ($R^2$74.52%) in 2011

3.4 The Analysis of Land Cover Changes on Water Supply

The next stage is to analyze the model in order to determine the total runoff and the total infiltration value of each different land cover. The total runoff and total infiltration value from the model analysis results in sub-watersheds in 2011 at each different land cover is presented in Figure 15-16. The amount of runoff and infiltration rate is used to determine the state of water in Lalindu Sub-watersheds for the amount comparison of the runoff value, and the infiltration is being simulated for area of 500 hectares from each land cover type.

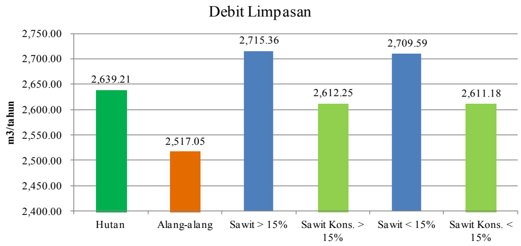


Figure 15 The Total Discharge Runoff Data of Each Land Cover at Sub- Watersheds in 2011

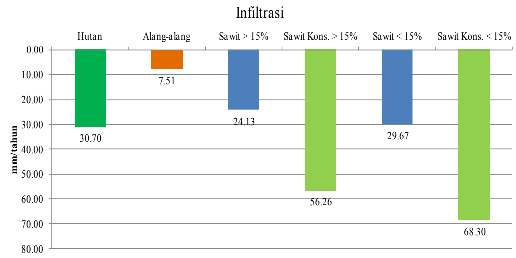


Figure 16. The Existing Condition of Total Infiltration of Each Land Cover at Sub-Watersheds in 2011

3.5 The Analysis of the Relationship among Soil Components, Water and Vegetations

The results of the runoff total value and infiltration on model analysis are later used to examine the relationship among land of soil components, water and vegetation of each unit. There is a close relationship among the soil components, water and vegetations. Land is a medium for the vegetation growth. Different soil types will have distinctive characteristics in terms of the soil physical, biological, and chemical properties. Soil properties can determine the type of nutrients in the soil, amount of water that can be stored in the soil, and root systems reflecting the circulation of water movement in the soil. The soil ability in absorbing water is reflected in the vegetation types at the ground level. The vegetation function can effectively reflect the ability of the soil to absorb rainfall, maintain or increase the infiltration rate, and demonstrate the ability in restraining water or water retention capacity (KRA) (Schwab et al., 1992).

1. Forest Land

Forest land in the research location has Anionic Acrudox soil type. The discharge runoff on forest land is at 2,639.21 mm/ year. The infiltration capacity on the use of forest land is larger compared to the oil palm land use, i.e. 30.70 mm/ year. The Infiltration capacity is the maximum rate of the soil to absorb water. In general, factors affecting the infiltration are soil texture, vegetation type, biological activity, groundwater depth, soil moisture, and soil permeability (Subagyono, et al., 2003).

The forest land among the research sites is generally included in the classification of rapid infiltration. Itis mainly due to factors supporting infiltration in the use of forest land, namely: the structure ranges from cloddy, slightly rounded, smooth, weak until crumbly. The soil texture is mainly clay to dusty clay. The soil pores show sufficient macropores dan sufficient mesopores. The drainage of land or the speed of water absorption from the soil / the circumstance indicating the term and frequency of saturated water is good/ moderate and groundwater depth is included deep, i.e. 200 cm. The effective depth of soil determines the extent/ depth of the roots of plant roots. The chance of plant root to absorb the nutrients available in the soil can be seen from the effective depth of the soil. The deeper the soil effective limit, the better the growth ability of plants growing on it. Soil is measured from the ground surface to the horizon of host materials tor soil layer that cannot be penetrated by plant roots.

2. Reed Land

Reed land have a smaller runoff discharge and infiltration rate or have the slower ability to absorb water compared to the forest land, i.e. 2,517.05 mm/ year and 7:51 mm/ year. If it is associated with the type of soil found in the reeds land, it has the Fluventic Eutrudepts soil type. The characteristic of Fluventic Eutrudepts soil type is having the structure of the soil surface and lower structure is cloddy. It indicates that the upper layer and lower pores are quite conform, thus the soil below the surface is not quickly saturated. It leads the soil infiltration rate in reeds land with Fluventic Eutrudepts decreases. The small infiltration is also driven by the damage of soil structure as the reeds are frequently on fire.

Interestingly, in reed land, the ground water content is considerably large (172,385.49 mm/ year) compared to forest land, and only a small portion of which is used for evapotranspiration and only a small proportion can also be infiltrated into deeper soil layers. Instead, most of the water will become the river discharge. As when the soil reaches a saturation point, the water content will become large for it will be held below the surface and later flows becoming the inter stream flow. Furthermore, the subsequent rain water becomes the runoff of the surface water. The use of water by small plants is 1,341.50 mm/ year. It is resulted from the reeds vegetation having root fibers with very limited depth, less supportive for the infiltration process and the water use of plant vegetation. The vegetation effect on infiltration is determined by the different root systems, among short, medium and deep-rooted plants. According to Winanti (1996), the influence of vegetations (plants) on the ground level contains two things, i.e. is serving to inhibit the surface water flow, thus the infiltration chance is greater, while the second is that the root system will scarify soil structure. Thus with the more plants existing, the infiltration rate tends to be higher.

3. Oil Palm Land

The palm oil land in the research location has Anionic Acrudox soil type (steepness > 15%). In the palm oil land with Anionic Acrudox soil type, it has a low value of water holding capacity, thus plenty of rain water is flowed into the surface flow, by 2,709.59 mm/ year. It is due to the soil condition palm oil planting is still open, it means the growth of the ground cover plants is still imperfect and is in the newly planting process. However, it has a fairly high infiltration capacity, i.e. 29.67 mm/ year. It is because in this soil type, the soil drainage is good/ medium, clay; cloddy, loose, many micro pores, many meso pores, many macro pores. Macro and meso pores on the ground are large, thus the infiltration capacity is huge/ good. The total pore space (TRP) is closely related with the infiltration rate. With the high TRP, the more water passing down. Similarly, if the TRP is low, the water traffic becomes hampered. According to Haridjaja, et al., (2010), what determines the infiltration capacity is the quite large pores. From the runoff discharge and infiltration graph above, it is known that the condition of oil palm plantations have a role in increasing the river discharge, and in addition it also can improve the water infiltration capacity to absorb into the soil. This type of soil has loose soil structure, thus the water holding capacity is huge. The loose soil (nest) has a fairly large aggregate with balanced macro pores and micro pores.
Effects of oil palm on the ground, especially the percentage of pore space, in which the oil palm grows older, are there will be changes in the percentage of the increasing soil pore space. Changes in the percentage of increasing soil pore space indicate the increasing ability of land to absorb water. The addition of the percentage of pore space is resulted from the activity of oil palm roots. In case the root development is getting vigorous or has more roots, then the water infiltration is increasing and it is similar with the increase in the percentage of soil pores, which finally will affect the increasing water holding capacity.

The palm oil vegetation has root fibers with quite high density, thus the vegetation creates cavities in the soil, resulting the water more easily infiltrated into the soil. Plant roots are capable of penetrating the soil and form cavities between the items, thus the water is easy to enter the cavities between the items.

Conclusions

The results indicate that:

1. The Tank Model application in Lalindu sub-watersheds on land cover type results in the forest parameter of $R^2$62.99%, reeds of $R^2$72.56%), and oil palm land with a steepness e> 15% $R^2$64.83% and <15% $R^2$73.13%). The hydrological condition in Lalindu sub-watersheds can be presented quite accurately by Tank Model with calibration result achieving the coefficient of determination (R^2) by 74.52%.
2. The analysis of runoff and infiltration in the tank model at each land cover generates:
   a. runoff discharge in the forest is 2,639.21 mm/ year, reeds of 2,517.05 mm /year, oil palm with a steepness of more than 45% is 2,715.36 mm/ year and oil palm with steepness less than 45% is 2,709.59 mm/ year.

b. The Infiltration value in the forest is 30.70 mm/ year, reeds of 7:51 mm/ year, palm oil with steepness more than 45% is 24.13 mm/ year and oil with steepness of less than 45% is 29.67 mm/ yr.

3. The difference in land cover on Anionic Acrudox soil type shows that oil palm plantation with steepness more 15% has low water holding capacity, thus there is a large amount of rain water flowed into surface runoff, but the infiltration is quite high as this type of soil has good/ moderate drainage, clay; cloddy, loose, many micro pores, meso pores, and macro pores. Macro and meso pores on the soil are large, thus the infiltration capacity is large/ good.

Suggestions

In order to obtain the water resources management, it is necessary to conduct the proper land cover management, thus the risk of floods can be avoided due to uncontrolled runoff and a tank model application should be socialized in the Central Watershed Management (BPDAS) agencies as a consideration in the planning of watershed management.

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