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Water Infiltration Into Soil and ITS Effect to Surface Runoff in Subdistrict of Kasihan, Bantul Regency

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***Abstract*—Water infiltration into the soil is one of the important processes in hydrology, because its effect on water quantity that could infiltrate into the soil. Decreasing of infiltration rate can make increasement of surface runoff and flood discharge in a region. In the other hand, decreasing of infiltration rate cause decreasement of groundwater input into aquifer. This study was conducted to (1) measure and analyze the behavior of water infiltration into the soil, (2) analyze the influencing factors to the quantity of surface runoff in the researched region, and (3) analyze the role of infiltration rate to the quantity of surface runoff in the researched region. In achieving them, it was conducted infiltration measurement using double ring infiltrometer and it was analyzed the results using Horton Model. Evapotranspiration estimation was determined using Thornthwaite Method and the quantity of surface runoff was determined using the equation of water balance. The study results showed that the highest rate of soil infiltration was occurred in land use of farm, and then rice field and residential. Viewed from the kinds of soil, the regosol had higher constant infiltration rate than grumusol, and so it was also with the initial infiltration rate. The volume of evapotranspiration in the researched region was 4,705,455.393 m^3/month and infiltration volume was 3,357,158.400 m^3/month. By having volume of rain of 5,997,747.4 m^3/month, the ground surface in the subdistrict of Kasihan could still absorb all of the rainfall. So, artificial recharge can be applied as groundwater conservation model.**

***Keywords—Infiltration, surface runoff, subdistrict of Kasihan*.**

I. INTRODUCTION

Water infiltration into the soil is one of important processes in a system of water management in a region. The quantity of infiltration could influence water quantity that could be absorbed into the soil, and then would influence the quantity of flood discharge in a region. It was proved that by decreasing infiltration rate of soil as the result of land use change to residences, could make flood disasters in several big towns in Indonesia such as Jakarta and Semarang (Kodoatie and Sjarief, 2008).

According to Garg (1979), infiltration is a process of absorption of rainfall and other water on the land surface into water soil layer through land surface. Infiltration has an important role in the cycle of hydrology. Its quantity could determine the availability of groundwater in a region.

Infiltration could be explained in two dimensions i.e. infiltration capacity and infiltration rate (Sosrodarsono and Takeda,1977; Martha and Adidarma, 1985; Purnama, 2010; Mawardi, 2012). Infiltration rate is a real speed of infiltration, while infiltration capacity is a maximum speed of infiltration that could be reached. In general, infiltration capacity could be obtained in an early great rain and then it would decrease to a constant infiltration.

According to Asdak (1995) and Triammodjo (2010), there are several factors that affect infiltration such as the amount of rainfalls, type of soil (especially the texture of soil), and land use. Land use can affect the infiltration because of its ability to determine the impregnation and long period of rain puddles on the land surface. In general, farm land has a higher infiltration rate than the rice fields and residential lands. This is due to farmland has more rarely traveled humans or animals, so that the land compression would be lower and the water would more easily seep into the soil.

Rice field land generally has lower infiltration than farm land because of higher humidity factor of the soil. Whereas the residential land has the lowest infiltration rate among other uses, because the residential land has more frequently traveled and trampled human and other living things, so that it has resulted in more significant compression.

The existence of vegetation could also affect the infiltration size because of it has not only protected the soil surface from the force of rainfalls compression, but would also accelerate the humus layer in exploring the ground insects. In the clay-mixed ground that is not covered with vegetation, the top layer would be compressed by precipitation and clogging of fine materials. But if the ground is covered with a layer of leaves, then this layer would expand and become very permeable.

Seyhan (1977) stated that soil compaction by humans and animals activities, land cover condition, land condition and water characteristic could also affect the infiltration. According to Wilson (1993), the capacity of infiltration is greatly influenced by physical properties of soil such as soil texture, porosity and early moisture, while the infiltration rate is influenced by soil type, soil density, soil moisture and its plants (Harto, 1993). Although it has similar type the soil, but infiltration rate would be different if it has different density and soil moisture.

Kasihan is one of the subdistricts in Bantul Regency that is growing rapidly. It is not so surprising because this subdistrict located on the peri-urban of Yogyakarta. The development of this area could be looked at the increasing number of population and residential land.

In 2010, subdistrict of Kasihan had 93,677 people or 10.52% of total population in Bantul Regency. The growth of population was 1,947 people/year or 2.53% per year (second highest rate in Bantul Regency), with people density of 29 people/ha.

Together with subdistricts of Bantul, Sewon, and Banguntapan, Kasihan subdistrict classified oftenly as urban residences, which covered 18,048 ha or 35.6% of Bantul Regency total wide. According to the Office of Agriculture and Forestry of Bantul Regency (2012), the four subdistricts were also experienced the largest functional conversion in Bantul Regency. In 2012, subdistrict of Kasihan had 6 ha of rice field land that had been converted to another uses. This land conversion could probably change the pattern of water infiltration into the soil in this area as indicated by the runoff coefficient.

Viewed by the type of soil, there are two types of soil in this subdistrict i.e. regosol and grumusol. The differences of these soil types were probably caused by the differences of geological conditions such as volcanic rock type of Formation of Yogyakarta and limestone rock types of limestone of Formation of Sentolo. This differences could also affect the infiltration condition and surface flow in this region.

Based on the background, it was conducted the study to (1) measure and analyze the behavior of water infiltration into the soil, (2) analyze the influencing factors to the quantity of surface runoff in the researched region, and (3) analyze the role of infiltration rate to the quantity of surface runoff in the researched region.

II. METHOD

Materials and Tools

The used materials in the study include:

- Several types of maps such as Administrative Map, Topographic Map, Soil Map, Geologic Map and Land Use Map.
- Reports of the study results and institutional data related to the characteristics and resource potential in the region of Kasihan subdistrict.

The needed equipment in this study include a set of double ring infiltrometer, stopwatch, and GPS.

A. Data

The required data in the review of this infiltration include:

- Data of climatological characteristics, including rainfall condition and the monthly average of air temperature,
- Data of geomorphological characteristics, including the processes of geomorphology and rock/constituent materials and structures.
- Data of geology and soil types.
- Data of hydrological characteristics i.e. the position of the groundwater level.
- Data of previous study results and reports related to the infiltration condition in the researched region.

B. Data Collection

The method of technic of data collection was conducted through a survey of primary data that was supported or complemented by available secondary data. Primary data survey was data collection through directly observation and measurement in the farm, that was the conducted infiltration measurements in nine locations (Figure 1). Determining the measurement location was performed purposively by observing the different types of soil and land use.

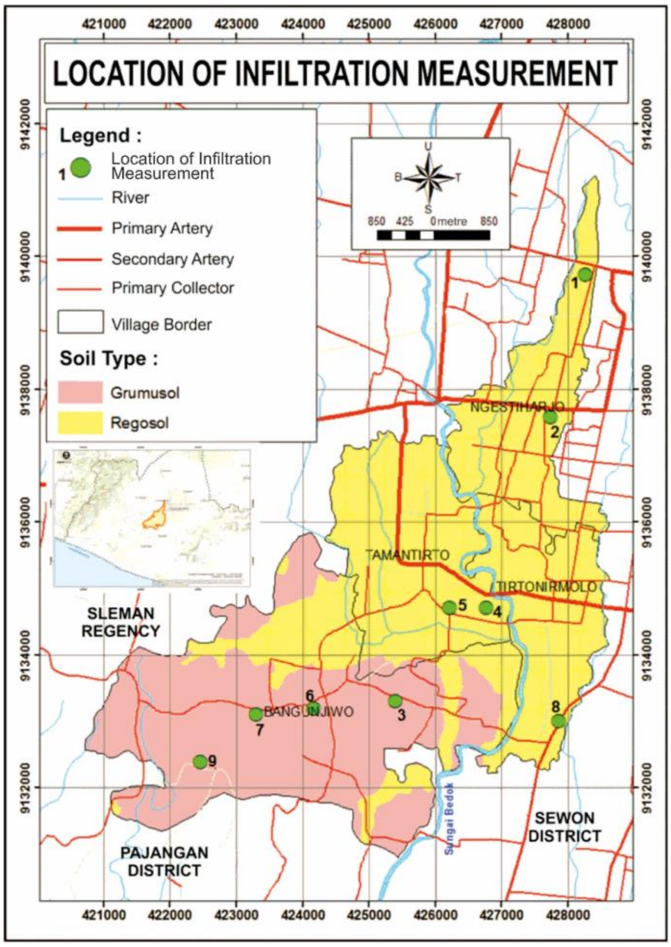

Fig. 1. Location of infiltration measurement

It was inserted into the ground the double ring infiltrometer with the depth in about of 10 cm to make the measurement. The outside ring was filled with water up to certain limit. Then, the inside ring was filled with water and at the same time it was turned on the stopwatch. The water level in the ring was kept in the specified limit filling the water at a certain time. It was noted the volume of loaded water. Infiltration rate (f_t) was calculated by dividing the volume of water that was loaded with a wide inside ring.

Survey of secondary data was an activity of data number collection and a map of the previous study results, and a description of the available territory which has been available on various related agencies in Bantul regency, such as Statistical Central Bureau, Office of Ecology, and Office of Mines and Energy.

C. Data Analysis

The data analysis was conducted on the analysis of infiltration, analysis of evapotranspiration, and analysis of surface runoff. One method to analyze the infiltration data is Horton Model (Dhalhar, 1972; Sudibyakto, 1989). Horton Model is one of the empirical approach, that is the infiltration model of time dependent equation. The equation that used is:

$$f_t = f_c + (f_0 - f_c) \cdot e^{-K.t}$$

Where f_t is infiltration rate at a certain time of t, f_0 is initial infiltration rate, f_c is constant infiltration rate, t is time, and K is a constanta. $f_c$value is estimated from plotting results of the relationship between the infiltration rate (f_t) and time (t).

Constanta (K) and f_0 were searched using the following equation:

$$K_{n-(n-1)} = \frac{1}{(t_{(n+1)-tn})} \ln \frac{(f_1 - f_c)}{(f_{(n+1)} - f_c)}$$

$$f_{0n} = f_c + \frac{(f_1 - f_c)}{e^{-Kn.t1}}$$

Where f_0 is first measurement time of t, t_n is time of next measurement, f_1 is infiltration rate at t_1, f_n is infiltration rate in the next t, and f_c is constant infiltration rate. After all the parameters have been already calculated, it could determined the best model using the following equation of Fleming:

$[(f_{measured} - f_{supposed})^2] \rightarrow$ smallest

The potential evapotranspiration is counted using Method of Thornthwaite (Kijne, 1974):

$$Ep = f.\, Epx \quad \text{mm/month}$$

$$Epx = 16 \left(\frac{10T}{I}\right)^a \quad \text{mm/month}$$

Where f is factor of latitude location, T is temperature (°C), I is $\Sigma^{12}_1{}^i$ with i = $(T/5)^{1.514}$ and a = 0.000000675 I^3 - 0.000077 I^2 + 0.01792 I + 0.49239.

Amount estimation of surface runoff was based on the concept of water balance meteorologically (Seyhan, 1977):

$$RO = P - Ep - Inf \pm \Delta S$$

Where RO is runoff, P is rainfall, Ep is evapotranspiration, Inf is infiltration, and ΔS is storage. In this study, the change value of storage is ignored because it is very small.

III. FINDING AND DISCUSSION

In the land use of rice field, infiltration measurement was carried out in 3 point measurement, i.e. 2 points in Ngestiharjo village and 1 point in Tirtonirmolo village. The results of measurement showed that the constant infiltration rate in Ngestiharjo village was 0.22 cm/min and 0.02 cm/min, with the initial infiltration rate was 3.34 cm/min and 0.28 cm/min. The value K was accounted for 0.34 and 0.17.

In Tirtonirmolo village, the constant infiltration rate in the land use of rice field was 0.18 cm/min with initial infiltration rate was 0.74 cm/min. The value of K was accounted for 0.06. It is shown in Table 1 the value of f_c, f_0 and K and also the complete equations of soil infiltration in the land use of rice field in the researched region.

TABLE 1. VALUES OF f_c, f_0, K IN THE LAND USE OF RICE FIELD

No	Location	Soil Type	f_c cm/min	f_0 cm/min	K
1.	Ngestiharjo	Regosol	0.22	3.34	0.34
2.	Ngestiharjo	Regosol	0.02	0.28	0.17
3.	Tirtonirmolo	Regosol	0.18	0.74	0.06

A. Infiltration in Farm Land Use

In the land use of farm, infiltration measurement was also performed at 3 points, 2 points of measurement were located in Tamantirto village and one other was in Bangunjiwo village. The results of measurement showed that the constant infiltration rate in Tamantirto village was 0.38 cm/min and 1.22 cm/min, the initial infiltration rate was 0.92 cm/min and 1.41 cm/min. The value of K was accounted for 0.15 and 0.05.

Whereas in Bangunjiwo village, the measurement results showed that the constant infiltration rate of the soil in the area was 0.04 cm/min, with initial infiltration rate was 0.49 cm/min, and the value of K was 0.04. It could be seen in Table 2 the value f_0, f_c, K, and soil infiltration equations on the land use of farm in the researched region.

TABLE 2.VALUES f_c, f_0, K IN THE LAND USE OF FARM

No.	Location	Soil Type	f_c cm/min	f_0 cm/min	K
1.	Tamantirto	Regosol	0.38	0.92	0.15
2.	Tamantirto	Regosol	1.22	1.41	0.05
3.	Bangunjiwo	Grumusol	0.04	0.49	0.04

B. Infiltration in Residential Land Use

Similar to the infiltration measurements in the land use of rice field and farm, the infiltration measurement in the residential land use was also conducted at 3 measurement points, which incidentally were located in Bangunjiwo village. The results of measurement showed that the constant infiltration rate of infiltration in Bangunjiwo village was 0.01 cm/min, 0.08 cm/min and 0.01 cm/min, the initial infiltration rate was 0,10 cm/min, 0.50 cm/min and 0.05 cm/min. The value of K was accounted for 0,11, 0,13, and 0.04. Table 3 showed the value of f_c, f_0, K, and infiltration equations on residential land use in the researched region.

TABLE 3.VALUES f_c, f_0, K IN RESIDENTIAL LAND USE

No	Location	Soil Type	f_c cm/min	f_0 cm/min	K
1.	Bangunjiwo	Grumosol	0.01	0.10	0.11
2.	Bangunjiwo	Grumosol	0.08	0.50	0.13
3.	Bangunjiwo	Grumosol	0.01	0.05	0.04

C. Infiltration in Rice Field, Farm, and Residential Lands Use

It was presented in this section the behavior of infiltration analysis in the use of rice field, farm, and residence. The results of calculation and analysis are presented in the following Tables 4 and 5.

TABLE 4. THE RANGE VALUES OF f_c, f_0, and K ON THE LAND USE OF RICE FIELD, FARM, AND RESIDENCE

No	Land Use	f_c, cm/min	f_0, cm/min	K
1.	Rice field	0.02 – 0.22	0.28 – 3.34	0.06 – 0.34
2.	Farm	0.04 – 1.22	0.49 – 1.41	0.04 – 1.22
3.	Residence	0.01 – 0.08	0.05 – 0.50	0.04 – 0.13

TABLE 5. THE AVERAGE VALUE OF fc, f_0, and K ON THE USE OF RICE FIELD, FARM, AND RESIDENCE

No	Land Use	f_c, cm/min	f_0, cm/min	K
1.	Rice field	0.14	1.45	0.19
2.	Farm	0.55	0.94	0.08
3.	Residence	0.03	0.22	0.09

Regarding Tables 4 and 5, it appeared that the constant infiltration rate in the land use of rice field ranged from 0.02 to 0.22 cm/min with an average of 0.14 cm/min. In the land use of farm ranged from 0.04 to 1.22 cm/min with an average of 0.55 cm/min, and in residential land use ranged from 0.01 to 0.08 cm/min with an average 0.03 cm/min. Based on these results, it could be said that the highest constant infiltration rate in the researched region was the land use of farm, followed by the land use of rice field, and then the lowest was the residential land use.

Considering from the initial value of infiltration rate, the highest initial infiltration rate in the researched region was the land use of rice field, and then the land use of farm, and the lowest was the residential land use. In the land use of rice field ranged from 0.28 to 3.34 cm/min with an average of 1,45 cm/min. In the land use of farm, the initial infiltration rate was 0.49 to 1.41 cm/min with an average of 0.94 cm/min, while the residential land use ranged from 0.05 to 0.50 cm/min with an average of 0.22 cm/min.

In the value of K, a constanta indicating physical properties of a soil and early groundwater content, showed that the highest value of K in the researched region was the land use of rice field, followed by residential land use, and the lowest was the land use of the farm. In the land use of rice field, the value of ranged from 0.06 to 0.34 with an average of 0.19, in the residential land use the value of ranged from 0.04 to 0.13 with an average of 0.09, while in the farm land use the value of K values ranged from 0.04 to 1.22 with an average of 0.08.

D. Effect of Soil Type to Infiltration

It has been explained in the background that the types of soil in the researched region were regosol and grumusol. This discussion has attempted to seek the significant effects of these two types of soil to infiltration in the researched region compared with the effect of different land uses. Table 6 and 7 showed the calculation and the analysis of these.

Regarding Tables 6 and 7, it could be seen that the constant infiltration rate of the type of regosol ranged from 0.02 to 1.22 cm/min with an average of 0.40 cm/min, while the grumusol types ranged from 0.001 to 0.08 cm/min with an average of 0.04 cm/min, so that the constant infiltration rate of the regosol type was significantly higher than the type of grumusol.

TABLE 6. THE RANGE OF VALUES OF F_C, F_0, AND K OF THE REGOSOL AND GRUMUSOL TYPES

No	Soil Type	f_c, cm/min	f_0, cm/min	K
1	Regosol	0.02 – 1.22	0.28 – 3.34	0.05 – 0.34
2	Grumusol	0.01 – 0.08	0.05 – 0.50	0.04 – 0.13

TABLE 7.AVERAGE VALUE OF F_C, F_0, AND K OF THE REGOSOL AND GRUMUSOL TYPES

No	Soil Type	f_c, cm/min	f_o, cm/min	K
1	Regosol	0.40	1.34	0.15
2	Grumusol	0.04	0.23	0.08

For initial value of the infiltration rate, it was also higher in regosol type than grumusol type. The constant infiltration rate beginning of the regosol type ranged from 0.28 to 3.34 cm/min with an average of 1.34 cm/min, while in the grumusol type ranged from 0.05 to 0.50 cm/min with an average of 0.23 cm/min.

Similarly to the value of K, the regosol type had higher value than the grumusol type. In regosol type, the value of K ranged from 0.05 to 0.34 with an average of 0.15, while in grumusol type the value of K ranged from 0.04 to 0.13 with an average of 0.08.

E. Evapotranspirational Count

It has been explained in the research methods that potential of evapotranspiration in the researched region was calculated using Tornthwaite method, with the following formula:

$$\mathrm{Epx} = 16\left(\frac{10T}{I}\right)^a \quad \mathrm{mm/month}$$

Where f is factor of latitude location, T is the temperature (^{o}C), I is $\Sigma^{12}{}_1 i$ with $I = (T/5)^{1.514}$ and $a = 0.000000675\ I^3 - 0.000077\ I^2 + 0.01792\ I + 0.49239$.

The calculations showed that:

$i = (27/5)^{1.514}$

$= 12.84825514$

$I = 154.1790617$

$a = 2.47388762 - 1.830381096 + 2.762888786 + 0.49239$

$= 3.898785315$

so that,

$$Epx = 16 \left(\frac{10 \times 27}{154.17906171}\right)^{3.898785315} \quad mm/month$$

$$= 142.18 \text{ mm/month}$$

Because Kasihan is located at the latitude of 7°42'20" – 7°45'24" SL, then referring to the table of mean possible duration of sunlight in the Northern and Southern hemispheres Expressed in units of 30 days of 12 hours each, it f-factor is 1,022083333, so that:

$$Ep = 1.022083333 \times 142.18$$

$$= 145.3198083 \text{ mm/month}$$

With a width area of 3.238 ha, the volume of evapotranspiration in researched region was 0.1453198083 x 32,380,000 = 4,705,455.393 m^3/month.

F. Runoff Volume Count

The average infiltration in the researched region was 0.24 cm/min or 103.68 m/month. With a width area of 3,238 ha, the volume of infiltration in researched region was 103.68 x 32,380,000 = 3,357,158,400 m^3/month.

With the monthly average of rainfall was 185.23 mm/month, and a total width area of 3,238 ha, the volume of rainfall in researched region was 0.18523 x 32,380,000 = 5,997,747.4 m^3/month. Based on the equation of water balance, the volume of runoff in researched region was:

RO = 5,997,747.4 – 4,705,455.393 – 3,357,158,400
= 1,292,292.007 – 3,357,158,400
= -3,355,866,108 m^3/month

The calculations showed a negative value, which means that based on the result of this water balance calculation, the really hydrological land surface in Kasihan was still able to absorb all of the rainfalls. Therefore, the existed runoff in the region was caused by the less infiltration time. The rainfall has already flowed on the land surface, before being absorbed at all. So, artificial recharge can be applied as groundwater conservation model.

IV. CONCLUSION

Viewed from the land use, it was known that the highest soil infiltration rate in the researched region was occurred in the land use of farm, followed by the land use of rice field, and then in the residential land use. For the initial value of infiltration rate, the highest initial soil infiltration rate was in the land use of rice field, followed by the land use of farm, and the lowest was in the residential land use.

Viewed from of the soil types, the regosol type had higher infiltration rate than type of grumusol. Similarly to the initial infiltration rate, the regosol type was also higher than the grumusol type.

The study results showed that the volume of evapotranspiration in the research region was 4,705,455.393 m^3/month and the infiltration volume was 3,357,158,400 m^3/month. With the rainfalls volume of 5,997,747.4 m^3/month, actually all of rainfall in the subdistrict of Kasihan were able to be absorbed by the land surface.

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