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E – manuscript preparation
F – literature search

Application of the Kineros model for predicting the effect of land use on the surface run-off Case study in Brantas sub-watershed, Klojen District, Malang City, East Java Province of Indonesia

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Abstract

This study intended to illustrate the distribution of surface run-off. The methodology was by using Kineros model (kinetic run-off and erosion model). This model is a part of AGWA program which is as the development of ESRI ArcView SIG software that is as a tool for analysing hydrological phenomena in research about watershed simulating the process of infiltration, run-off depth, and erosion in a watershed of small scale such as ≤100 km^2. The procedures are as follow: to analyse the run-off depth in Brantas sub-watershed, Klojen District by using Kineros model based on the land use change due to the rainfall simulation with the return period of 2 years, 5 years, 10 years, and 25 years. Results show that the difference of land use affect the surface run-off or there is the correlation between land use and surface run-off depth. The maximum surface run-off depth in the year 2000 was 134.26 mm; in 2005 it was 139.36 mm; and in 2010 it was 142.76 mm. There was no significant difference between Kineros model and observation in field, the relative error was only 9.09%.

Key words*:* *Kineros model, land use, rainfall, return period, surface run-off*

INTRODUCTION

Indonesia is a water country which has rainy season period more than six months that causes the high enough of rainfall. The natural condition like this has to be more attended accurately because it is as a basic factor in regulating an urban region [SURIPIN 2004]. In addition, the development of infrastructure is compulsory to be carried out for guarantying the social prosperity of the society [SELMANI *et al.* 2017]. The development which is carried out is also meant to change the land use. Land use change will cause the rainfall cannot permeate again into soil on the rainy season, so it causes surface run-off which will be becoming as pool or flood [BISRI 2010a, b; TUNG *et al.* 1987]. This problem also influences the preservation of groundwater because the rainfall which permeates into soil is as the natural groundwater suffix [CZYŻYK, ŚWIERKOT 2017]. The process of infiltration and run-off is as one of the important process in hydrological cycle [LIMANTARA 2010]. Infiltration determines the rainfall capacity that permeates and enters into the soil directly, so due to the happened infiltration capacity, there can be determined the capacity of surface run-off [HARTO 1993; SOEMARTO 1987; SOSRODARSONO 2003]. The understanding about process, happened surface capacity and the influenced factors are increasingly needed as the references for implementing the water management and more effective land use.

The development of Malang City region is not coming out from the opened land use change which is becoming as built land so there is often happened run-off in this region. Rainfall run-off is a problem which is caused by unregulated land use change [ARSYAD 2000; ASDAK 2001]. Built land has less water absorption than the opened land. When the built land is increasingly wide, so there is much rainfall becoming as surface run-off [LUBIS, SUNARTO undated].

Klojen District is as a region where is more often happen run-off, but the process of run-off measuring directly needs the high cost, time, and energy. Therefore, it is often difficult to obtain the run-off data due to the measuring process which is so heavy. Therefore, it is needed a run-off simulation which is caused by land use change by setting a spatial run-off model for helping the decision maker in making effort for controlling the happened run-off. This study intended to analyze the surface run-off and the distribution in study location on 2000, 2005 and 2010; then to evaluate the conformity of Kineros model for analyzing the surface run-off in study location. There are land use changes on 2000, 2005, and 2010 which are presented as in Table 1.

Table 1. Land use changes on 2000, 2005, and 2010

Type of land use	Number area (ha) in		
	2000	2005	2010
Road	26.589	26.589	26.589
Residence	286.091	286.091	297.046
General and social facility	43.564	43.564	36.614
Economy and service	7.864	42.078	44.418
River	0.000	7.864	7.864
Residence spatial plan	0.400	34.298	27.953
Run-off coefficient	0.805	0.813	0.818

Source: own study.

MATERIALS AND METHODS

There are two types of soil such as alluvial and andosol in Brantas sub-watershed, Klojen District. The selection base of research area is that Brantas-sub watershed, Klojen District has relative small number area such as 4.405 km^2. The study location is as urban area with the population density is high enough if it is compared with the other district in Malang city. The study location is presented as in Figure 1 and 2.

The growth and development of a region especially in Malang city makes some changes to the spatial form in this region physically as well as non-physically. The land usage mainly from agricultural into non-agricultural function, catchment area into residence area, border river into residential become as a problem. In the end, the increasing of closed area causes the water catchment is dwindling. Malang city

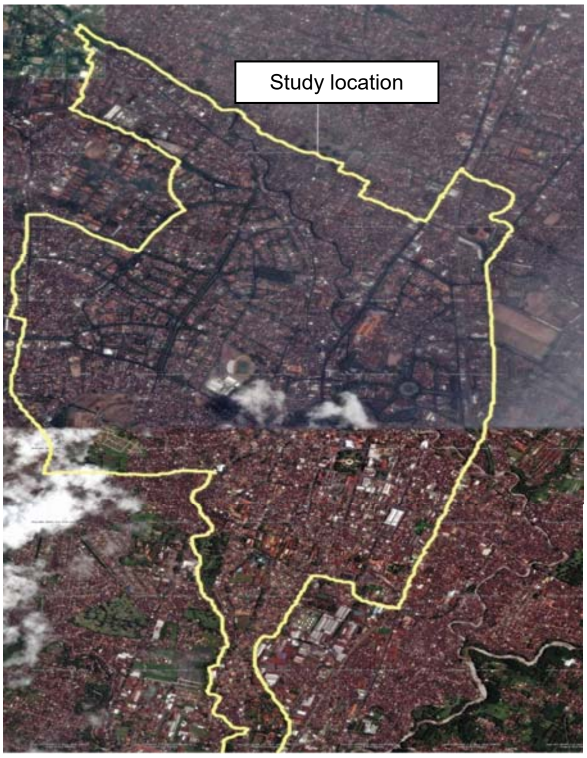


Fig. 1. Google Earth map of Brantas sub-watershed, Klojen District; source: Google Earth [undated]

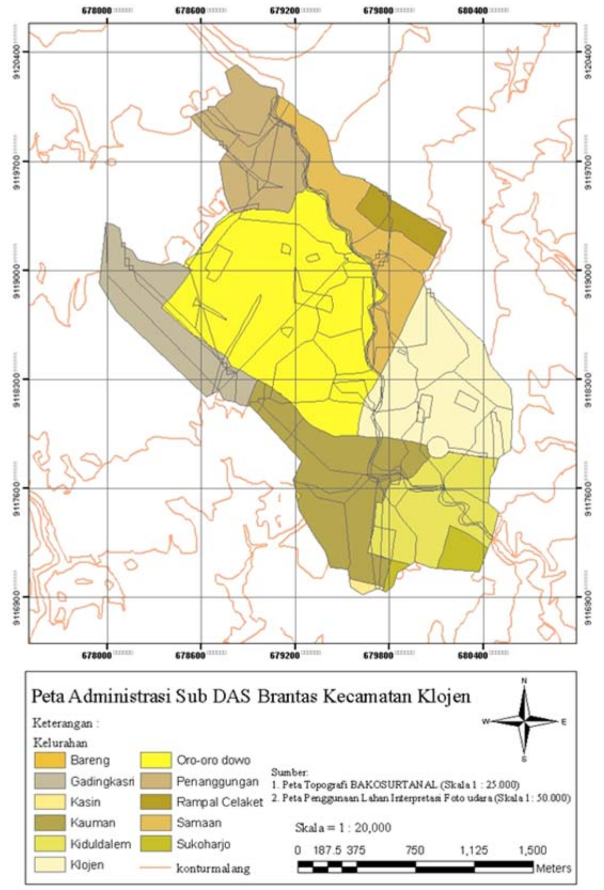


Fig. 2. Administration map of Brantas sub-watershed, Klojen District; source: own elaboration based on topography map of Bakosurtanal and interpretation land use map by Citra satellite [Bakosurtanal undated]

consists of some districts. The selected study location is Klojen district and has rapid population growth, so in this region is seldom found water catchment, so every rainy always causes the high surface run-off. Generally, the problems in Klojen district are as follow: 1) there is land use changing from catchment area into residential area; 2) the increasingly residential area will cause high run-off; and 3) there is needed an analysis tool for simulating the depth and area pool due to the many rainfall events and land use changing spatially.

METHOD OF ANALYSIS

To analyse the relation between land use and surface run-off rate as the reference in analysis on surface run-off of residence area in Klojen district is used some approaches. The approaches consist of topography map, land use map, and the other secondary data as infiltration rate, rainfall, soil physical characteristic, soil texture which is treated and analysed by the approached procedure of Geographic Information System (GIS) as the main helped tool.

To predict the surface run-off rate, it is used the method of Kineros because this method is assumed suitable with the characteristic of Brantas sub-watershed, Klojen District. Analysis of spatial data (spatial aspect) is carried out by using the ArcView GIS 3.3 software. However, analysis of non-spatial data is carried out by using the helped tool of Microsoft Excel and it is presented in the format of ArcView 3.3.

Distribution of surface run-off area in the residence of Klojen District is obtained by making the area map of surface run-off by using the helped tool of Kineros model. In addition, it is also made the classification of surface run-off area for looking which area has low until very high potency, so the study result or output of this study can be used as the reference in analysis of land use refered to the water conservation.

MATHEMATICAL THEORY OF KINEROS MODEL

Kineros model needs three basic parameters. The three parameters of soil hydraulic characteristic are the hydraulic conductivity of saturated effective area (Ks), encouragement of capillaries (G), and porocity (ϕ). To make a possibility to be carried out the estimation to the soil redistribution behavior, so the Kineros model needs an additional parameter such as distribution index of pore size (λ) and it is as the simple description of soil hydraulic characteristic which is used in this model.

For the series of impacts from the spatial variation which are normally happened in soil hydraulic conductivity (Ks), it can be simulated by giving a value on the variation coefficient of the parameter such as by using the selected parameter CvK (variation coefficient of conductivity parameter) which describes the random variation in soil hydraulic characteristic. For the plated two soil profiles, the parameters above have index 1 or 2. It indicates that the index is used on soil ply more over or under consecutively.

In Kineros model, there is the dependent variable such as maximum relative saturation on the beginning level of upper sub-soil (SI). The maximum relative saturation is as the scale value of water content, the value of 1 is as the water content which is the same as the porosity. Water content based on the volume is marked as θ and $\theta = \phi S$, and as the natural upper limit of S that is less than 1 (parameter of $S_{\max}$).

The soil infiltration model describes infiltrability (Fc) as the function of infiltration depth (I). In practice, the free pattern of rainfall level (R) before the selected time and infiltration capacity during the rainfall period is as the function of infiltrated depth total with $r > Ks$ before the selected time. Infiltrability is defined as the threshold value of water which can enter soil surface. The definition is often named as infiltration capacity, however, capacity is not the dynamic name.

General plated one model for infiltrability (fc) as the function of inflitration depth (I) is formulated as follow [CHOW *et al.* 1988; WILSON 1993]:

$$fc = Ks\left[1 + \frac{\alpha}{\exp\left(\frac{\alpha I}{B}\right) - 1}\right] \tag{1}$$

where: $B = (G + hw)(\theta_S - \theta_i)$ to be combined with the impact of net capillarity encouragement; hw = surface water depth; $\Delta\theta = (\theta_S - \theta_i)$ is as the capacity of storage unit.

Parameter of α shows the type of soil. For sand, the value of $\alpha = 0$, and in this condition, the equation (1) is close to the formula of Green–Ampt. The value of α on clay is close to 1, and in this condition, the equa-tion (1) illustrates the infiltration equation of Smith–Parlange, however, most of soil types use the value of α which is close to 0.85.

VOLUME OF SURFACE RUN-OFF IN KINEROS MODEL

Analysis of surface run-off in Kineros model is as the development of Hortonion Overland Flow (HOF) theory as follow [CHOW *et al.* 1988; LINSLEY 1986]:

$$Q = \alpha h^m \tag{2}$$

where: Q = discharge of surface run-off ($m^3 \cdot s^{-1}$ width); α and m = factor that is influenced by area slope and roughness; h = surface run-off per-unit area, mm.

Parameter of α and m is influenced by slope area, surface roughness, and flow regime. There are two formulas for obtaining the value of α and on the equation (1) such as based on the roughness coefficient which is used. If using the Manning equation, so the formula is as follow:

$$\alpha = \frac{S^{\frac{1}{2}}}{n} \quad \text{and} \quad m = \frac{5}{3} \tag{3}$$

where: S = area slope; n = roughness number of Manning for surface run-off.

If using the Chezy equation, the formula is as follow:

$$\alpha = CS^{\frac{1}{2}} \text{ and } m = \frac{3}{2} \tag{4}$$

where: S = area slope; C = roughness number of Chezy for surface run-off.

Factor of slope area in Kineros model can automatically be identified through the process of DEM. However, the roughness number of Manning is obtained from the soil type and land use as in Table 2.

Table 2. Roughness coefficient

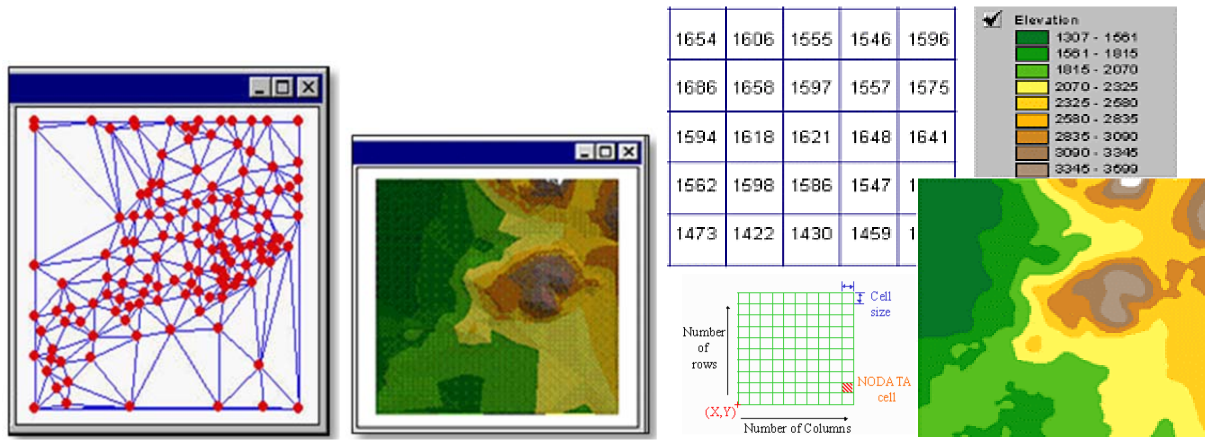
Type of soil hydrology	Roughness coefficient
Fresh water	0.000
Desert	0.050
Residence	0.015
Shrubs	0.055

Source: AGWA [2000].

DIGITAL ELEVATION MODEL (DEM)

Factor of land slope in Kineros Model can automatically be defined through the process of Digital Elevation Model (DEM), however, the roughness coefficient of Manning is obtained from the soil type and land uses. Digital Elevation Model (DEM) is as one of the approached methods that can be used for modelling of land surface relief in the three dimensions form. Nowadays, the development of GIS and digital surface model have been allowed to help the analysis process of a hydrological phenomena such as infiltration and surface run-off. The characteristic of infiltration and surface run-off will be very determined from the surface relief or condition of an area.

The usage of digital surface in infiltration and surface run-off analysis process is as an accurate step to present the earth relief surface for helping the research in identifying the land slope, direction of flow, and determination of flow area. Schematically, model type of Digital Elevation Model (DEM) is presented as in Figure 3.



TIN GRID

Fig. 3. Model type of Digital Elevation Model (DEM); source: AGWA [2000]

From some methods as above, DEM with grid raster data model is more frequently used because it is assumed easy in using. Data grid model has the cells with regular form and the same number area, so it makes easy in applying formula or analysis and for the further analysis.

SIMULATION RESULT OF KINEROS MODEL

Result of Kineros model is as the performance on the zoning map of parameter which is desired such as infiltration (mm), run-off (mm), sedimentation yield ($kg \cdot ha^{-1}$), peak discharge ($m^3 \cdot s^{-1}$), and peak sediment discharge ($kg \cdot s^{-1}$). However, the output result that is used is as the surface run-off distribution.

RESULTS AND DISCUSSION

Result of Digital Elevation Model (DEM) produces map of Brantas sub-watershed. Klojen District and synthetic river network as in Figure 4. Analysis result of Kineros model shows that every sub-watershed has the different value of surface run-off as presented in Figures 5, 6, and 7 each for surface run-off on 2000, 2005, and 2010 with the return period of 10 years.

The maximum value of run-off as the result of Kineros model where there is the highest surface run-off location are presented as in Table 3 for the year of 2000, 2005, and 2010.

Calibration of Kineros model (Tab. 4) indicates that there is the difference between surface run-off of model result and in the field which is as the result of maximum surface run-off in Penanggungan village.

Kineros model is made based on the study in USA, so for the calibration there are some items have to be atended such as the parameterization of land cover and soil regarding to the study location. In this case is the scoring of land cover value and roughness coefficient which is assumed right so the simulation

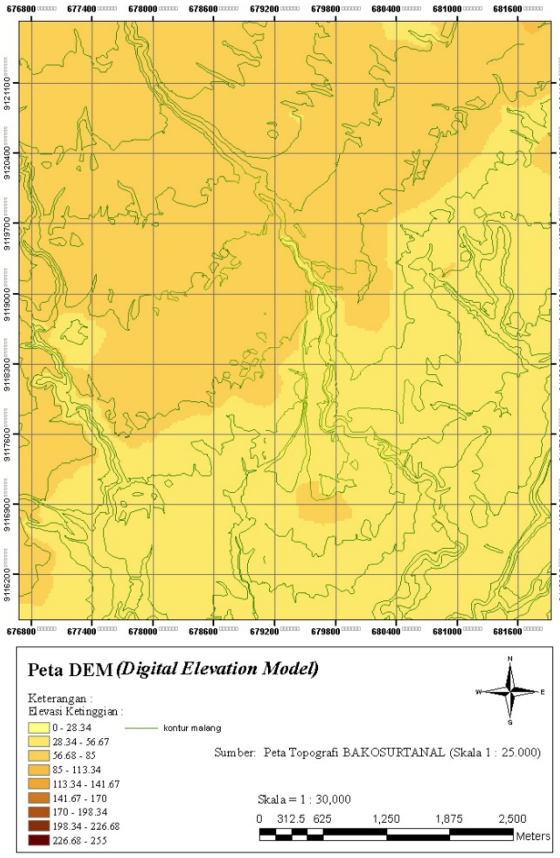


Fig. 4. DEM (Digital Elevation Model) map of Brantas sub-watershed, Klojen District; source: generated result of Kineros model by topography map of Bakosurtanal [Bakosurtanal undated]

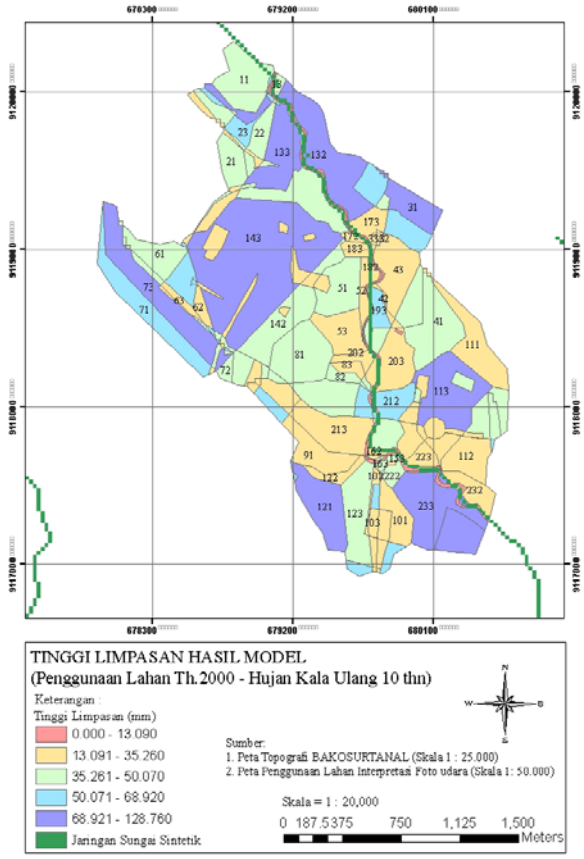


Fig. 5. Run-off of model result for land use on 2000 (return period of 10 years); source: generated result of Kineros model by topography map of Bakosurtanal and land use map by Citra satellite interpretation [Bakosurtanal undated]

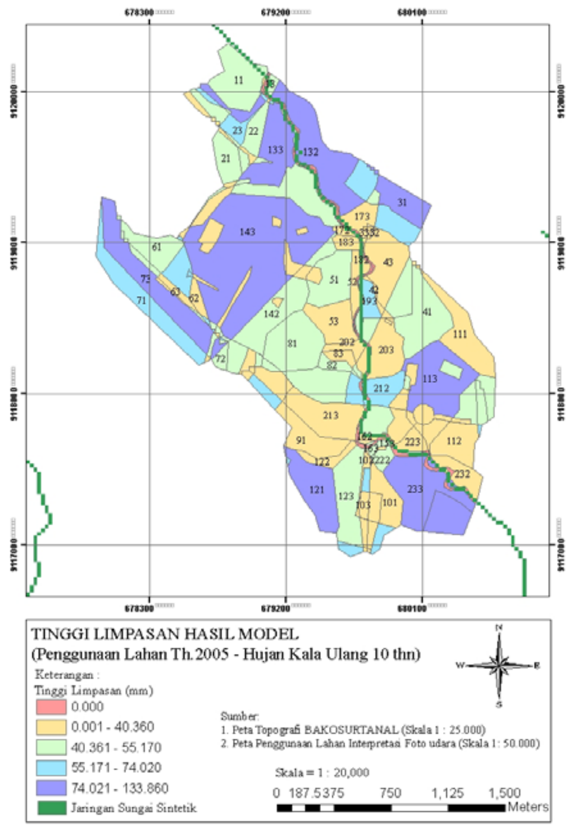


Fig. 6. Run-off of model result for land use on 2005 (return period of 10 years); source: generated result of Kineros model by topography map of Bakosurtanal and land use map by Citra satellite interpretation [Bakosurtanal undated]

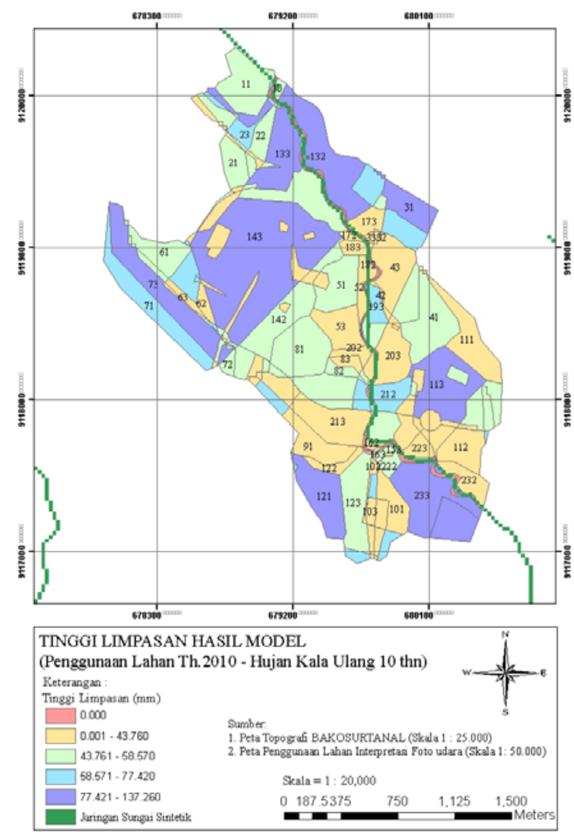


Fig. 7. Run-off of model result for land use on 2010 (return period of 10 years); source: generated result of Kineros model by topography map of Bakosurtanal and land use map by Citra satellite interpretation [Bakosurtanal undated]

Table 3. Surface run-off as the result of Kineros model on 2000, 2005 and 2010

Location of maximum run-off	Run-off depth (mm) with the return period of			
	2 years	5 years	10 years	25 years
2000				
Penanggungan village	60.54	123.36	128.76	134.26
Rampal Celaket village	56.75	113.56	118.96	124.46
Oro-Oro Dowo village	57.69	105.35	110.75	116.25
Klojen village	56.25	114.58	119.98	125.48
2005				
Penanggungan village	64.74	129.66	133.86	139.36
Rampal Celaket village	60.95	119.86	124.06	129.56
Oro-Oro Dowo village	61.89	111.65	115.85	121.35
Klojen village	60.45	120.88	125.08	130.58
2010				
Penanggungan village	66.74	133.06	137.26	142.76
Rampal Celaket village	62.95	123.26	127.46	132.96
Oro-Oro Dowo village	63.89	115.05	119.25	124.75
Klojen village	62.95	124.28	128.48	133.98

Source: own study.

Table 4. Calibration result of field surface run-off and surface run-off result of Kineros model

Location	Field run-off mm	Maximum run-off of Kineros model result (mm) with the return period of			
		2 years	5 years	10 years	25 years
Penanggungan village	60–200	66.74	133.06	137.26	142.76
Rampal Celaket village	55–150	62.95	123.26	127.46	132.96
Oro-Oro Dowo village	45–120	63.89	115.05	119.25	124.75
Klojen village	50–180	62.95	124.28	128.48	133.98

Source: own study.

process is on the soil hydrology type with trial and error of scoring and it can be known the upper and lower limit for approaching the calibration result of surface run-off regarding to the location study.

Based on the analysis result of surface run-off, it can be known the level distribution of surface run-off in study location. There is the increasing run-off from 2000 to 2005 and then to 2010 in all return periods. It indicates that the land use change causes the increasing of run-off to the maximum surface run-off which is produced, the value is 142.76 mm with the number area of 13.039 ha. The value is as the high surface run-off in sub-watershed or it can be mentioned as the pool depth [HOLKO, LEPISTO 1997] which is happened in the watershed. There is insignificant difference or relatively the same between surface run-off value as the analysis result of Kineros model and the maximum surface run-off in field mainly for the return period of 2 years and 5 years. It has the relative error of 4.92% [Soewarno 1995].

Based on the Indonesian Ministry Decision of Kimpraswil No 534/KPTS/M/2001 about drainage, the maximum pool for urban area is not more than 30 cm with the maximum time of pool is 2 hours. Analysis result of run-off depth indicates that the maximum surface run-off is 142.76 mm. However, based on the hydrological analysis such as estimation of design flood, it is obtained time to peak is 1 hour.

Based on the analysis above, it can be known that the value of surface run-off depth is still on the allowable limit. The analysis can be used for evaluating the reference of land use in study location. Location of Braintas sub-watershed as the centre of Malang city is still as the developed region. The area condition that has been functional changed is more enough so it causes the increasing of run-off depth from year to year. It indicates that the value of surface run-off depth is directly proportional with land use change that functional changes from water absorption area becoming as water proof area. Therefore, it is needed the alternatives of controlling for decreasing run-off in the centre of Malang city. Alternatives of residence run-off controlling are as follow:
1) rehabilitation of channel by carrying out the channel widening to the regions that experience surface run-off;
2) the areas which have not had the drainage channel, will be made the new channel;
3) there is needed inlet design in order to make easy the rainfall enters into the drainage channel;
4) there is needed the operation and maintenance of drainage system periodically.

In the scheme of environmental preservation as mentioned on the 4th closul in the law No 26/2007 that regional spatial plan of forest region is minimum 30% of watershed number area. In addition, it is needed the spatial setting which includes the process of spatial plan, the qualified spatial usage (to be effective and efficient) and the controlling. Spatial setting is as an effort to welfare and to give safety and comfortable feeling for the society, and to hold and increase the natural conservation or environmental preservation. Spatial design includes spatial structure plan (facility and infrastructure), and spatial pattern plan (zonal region) which is presented in the law No 26/2007.

CONCLUSIONS

The difference of land use (the land use change on 2000, 2005, and 2010) is influencing the surface run-off which is happened or there is correlation between land use and surface run-off depth. The maximum surface run-off per-year by using the Kineros model is as follow: 134.26 mm on 2000; 139.36 on 2005; and 142.76 on 2010. The values are still in the allowable limit of maximum surface run-off depth such as <30 cm for urban area. However, it is needed the effort of preventing so the run-off is not more than the allowable limit.

There is not significant different between result of Kineros model and maximum surface run-off in field, it can be said relative the same mainly for return period of 2 years and 5 years with the relative error of 9.09%.

REFERENCES

AGWA 2000. Tools guide. The automated geospatial watershed assessment tool [online]. [Access 02.01.2012]. Available at: https://www.tucson.ars.ag.gov/agwa/.../agwa_3.x_user_guid

ARSYAD S. 2000. Konservasi tanah dan air [Soil and water conservation]. Bogor. IPB Press. ISBN 9794930032 pp. 466.

ASDAK C. 2001. Hidrologi dan pengelolaan daerah aliran sungai [Hydrology and watershed management]. Yogyakarta. Gajah Mada University Press. ISBN 979-420-737-3 pp. 646.

Bakosurtanal undated. Topography map of Bakosurtanal and interpretation land use map by Citra satellite [online]. [Access 09.06.2012] Available at: www.preventionweb.net/organizations/2920

BISRI M. 2010a. Water Conservation mapping at Kali Sumpil watershed, East Java, Indonesia. International Journal of Academic Research. Vol. 2(5) p. 156–158.

BISRI M. 2010b. Depth and distribution analyses of surface run-off spatially at Kali Sumpil watershed, East Java, Indonesia. International Journal of Academic Research. Vol. 2(5) p. 184–187.

CHOW V.T., MAIDMENT R., MAYS W. 1988. Applied hydrology. New York. McGraw Hill. ISBN 0070108 102 pp. 572.

CZYŻYK F., ŚWIERKOT Z. 2017. Recharging infiltration of precipitation water through the light soil, in the absence of surface runoff. Journal of Water and Land Development. No. 32 p. 25–30. DOI 10.1515/jwld-2017-0003.

Google Earth undated. Map of Brantas sub-watershed, Klojen District [online]. [Access 09.06.2012]. Available at: www.GoogleEarth.com

HARTO S. 1993. Analisis hidrologi [Analysis of hydrology]. Jakarta. Gramedia Pustaka Utama. ISBN 979511235X. pp. 303.

HOLKO L., LEPISTO A. 1997. Modelling the hydrological behaviour of mountain catchment using TOPMODEL. Journal of Hydrology. Vol. 196 p. 361–377.

LIMANTARA L.M. 2010. Hidrologi praktis [Practical hydrology]. Bandung. CV Lubuk Agung. ISBN 978-979-505-205-2 pp. 324.

LINSLEY K. 1986. Hidrologi untuk insinyur [Hydrology for engineers]. Jakarta. Erlangga. ISBN 32000721 pp. 469.

LUBIS A., SUNARTO F. undated. Pola aliran limpasan permukaan dan implikasinya pada rencana regulasi penanganan wilayah (Studi Kota Malang) [Flow pattern of surface run-off and the implicationon on the area handling regulated plan (Study of Malang City)] [online]. [Access 02.01.2012]. Available at: https://pl.scribd.com/doc/54345374/Paper-Sunarto

SELMANI BOUAYOUNE K., BOUDI EL M., BACHIR A. 2017. Maintaining the water consumption, in an urban system: A probabilistic approach is applied. Journal of Water and Land Development. No. 33 p. 157–164. DOI 10.1515/jwld-2017-0031.

SOEMARTO C.D. 1987. Hidrologi teknik [Engineering hydrology]. Jakarta. Erlangga. ISBN 32002198 pp. 313.

Soewarno 1995. Hidrologi aplikasi metode statistik untuk analisa data [Statistical method of hydrological application for data analysis]. Jilid I. Bandung. Nova pp. 269.

SOSRODARSONO S., TAKEDA K. (eds.) 2003. Hidrologi untuk pengairan [Hydrology for watering]. Jakarta. PT Pradnya Paramita. ISBN 979-408-108-6 pp. 226.

SURIPIN 2004. Sistem drainase kota yang berlanjutan [Sustainable urban drainage system]. Yogyakarta. ANDI. ISBN 979-731-137-6 pp. 183.

TUNG B.Z., YEH Y. K., CHIA K., CHUANG J.Y. 1987. Storm resampling for uncertainty analysis of a multiple-storm unit hydrograph. Journal of Hydrology. Vol. 194 p. 66–384.

WILSON E.M. 1993. Hidrologi teknik [Engineering hydrology]. Bandung. ITB. ISBN 9798001885 pp. 328.

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Zastosowanie modelu Kineros w prognozowaniu wpływu użytkowania ziemi na spływ powierzchniowy Przykład zlewni cząstkowej Brantas w Dystrykcie Klojen, Malang, Prowincja Wschodniej Jawy, Indonezja

STRESZCZENIE

Celem badań było przedstawienie rozkładu spływu powierzchniowego za pomocą modelu Kineros (model kinetyki spływu i erozji). Model jest częścią programu AGWA, który stanowi rozwinięcie programu ESRI ArcView SIG, czyli narzędzia do analizowania zjawisk hydrologicznych w badaniach zlewni symulujących procesy infiltracji, spływu powierzchniowego i erozji w małych zlewniach o powierzchni mniejszej niż 100 km^2. Procedura obejmowała analizę głębokości spływu w zlewni cząstkowej Brantas, w Dystrykcie Klojen za pomocą modelu Kineros na podstawie zmiany użytkowania ziemi i symulacji opadów z okresem powtarzalności 2, 5, 10 i 25 lat. Wyniki wskazują, że różnice w użytkowaniu ziemi wpływają na spływ powierzchniowy i że istnieje korelacja między użytkowaniem ziemi i głębokością spływu powierzchniowego. Maksymalna głębokość spływu wynosiła 134,26 mm w roku 2000, 139,36 mm w roku 2005 i 142,76 mm w roku 2010.

Słowa kluczowe: *model Kineros, okres powtarzalności, opad, spływ powierzchniowy, użytkowanie ziemi*