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Runoff Modelling for Simulating Inundation in Urban Area as a Result of Spatial Development Change

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ABSTRACT

The change of landcover from pervious area into impervious area in urbanized area give an impact on the increasing of runoff depth and directly will cause flood and inundation area. The purpose of this research is to propose an effective method for estimating spatially distribution of runoff depth in order to to promote the spatial planning development. The research location was in the Klojen Sub District, located in Malang Municipality, East Java Province. The procedure analysis of runoff depth distribution in this research was performed by using hydrology model KINEROS based Geographical Information System (GIS). The model simulation was run based on the input of daily maximum rainfall and for each landuse 2006 and 2010. The outputs of the model were calibrated and verified by comparing the model results with field observation at each land utilization. The calibrated runoff model was used to simulate the runoff depth for other rainfall depth in order to know respon of runoff in regard with rainfall. The result showed that runoff depth distribution map in the study area greatly influenced by rainfall intensity and landuse type. The increasing of impervious area about 45% on 2010 cause increasing in the runoff depth in the study area. The highest of runoff depth in the study area was produced based on landuse year of 2010 where the depth of runoff showed 139.8mm, located in Penanggungan Village. Further, the result of the study also showed that some parameters closely influenced runoff yield, namely rainfall intensity, landuse type, and soil type. These results could be used as supporting information in the decision support system regarding the spatial planning and management in urbanized area, especially in the determination of water conservation area.

Keywords: runoff depth, hydrology model, landuse

1. INTRODUCTION

The processes of spatial planning and management on a watershed require an integrated analysis on many aspects included social, economic, and water resources. However, in recent situation, most of the land management and planning development are far from putting water resources as an important aspect in the process design. The spatial land management and planning is always associated with land use distribution and it is known clearly that the change on land use in a watershed will extremely impact hydrological processes. The impacts of land use changes have received considerable attention from hydrologist and ecologists, particularly with respect to effects on a hydrology system [1]. The effects of suburban development has been characterized in several studies; increased flood frequencies in areas with impervious surfaces were reported in the late 1960s and early 1970s [2]. More recent studies have focused on the effects of engineered aspects of catchments, (e.g. detention basins, riparian buffers and septic systems) on runoff volume and water quality [3]. The effects of landuse change on runoff characteristics are widely acknowledged to include: (1) decreased low flow and groundwater recharge, (2) increased surface runoff in annual streamflow, (3) increased magnitude of peak runoff, (4) decreased lag time between rainfall and runoff response, (5) increased rate of hydrograph rise and recession, and (6) decreased mean residence time of streamflow [4]. The influence of landuse change on hydrological variables, such as runoff, erosion, sedimen, etc mostly depend on interaction between climate factor and watershed characteristic. As we know, the degree of variability of both factors in a watershed or catchment area is very complex and need to great effort to assess their influence to those hydrological variables. Thus, the development of an integrated approach that can simulate and assess land use changes, land use patterns and their effects on hydrological processes which spatial analyses based at the watershed level is crucial to land use and water resource planning and management [5].

In this study, a hydrological model was employed to analyze the distribution of runoff based on spatial analysis on watershed study area as a result of land use change in an urban area. The analyses were included determination proper model parameter in accordance with hydrological environment of study area. The resulted

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runoff distribution map was used to identify the potential indundation area that can be used as consideration aspect in the spatial planning and management, especially in the study area.

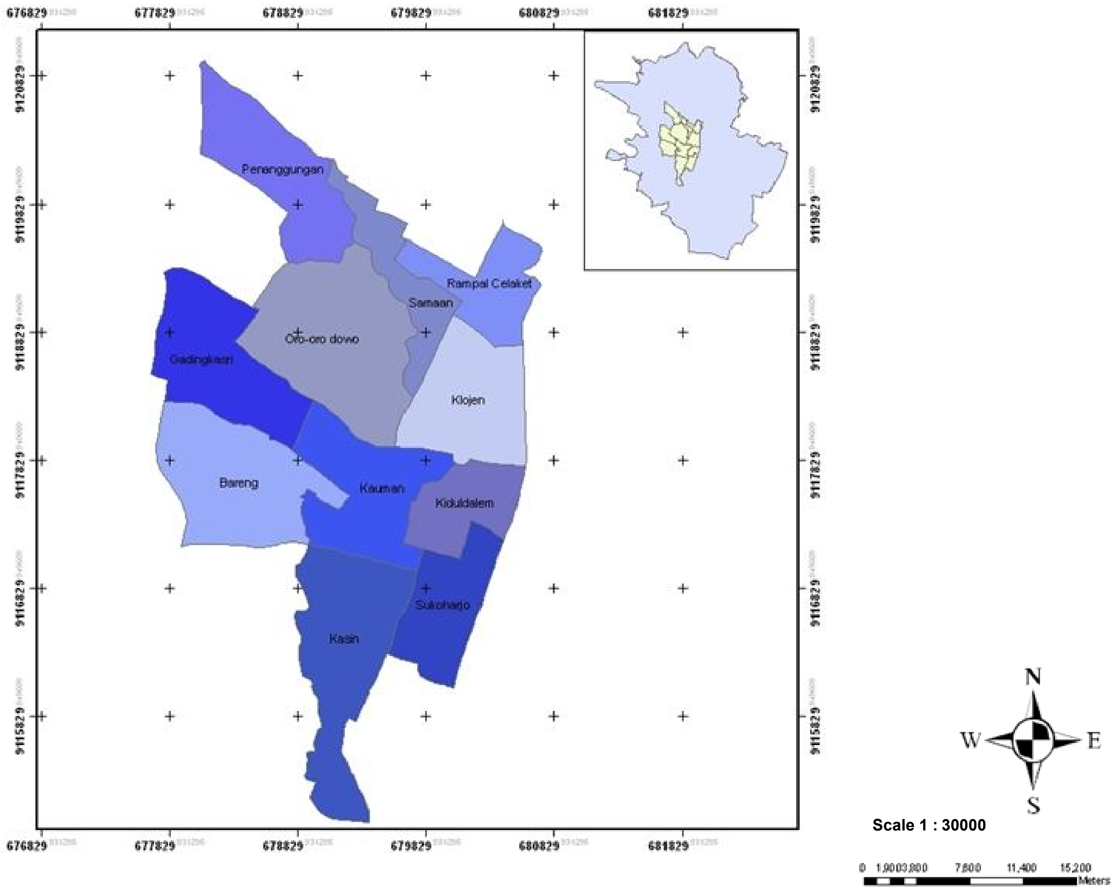


Fig. 1. *Location of study area*

2. DESCRIPTION OF STUDY AREA

The study area was located in the Klojen Sub District, one of the sub district with high density of population in Malang Municipality, East Java Province, Indonesia. The total area encompasses 8,83km^2 and included in the Brantas River basin. There were six types of land use distributed over the study area, those were fresh water, plantation, residential, irrigated rice field, shrubs and bare land. Figure 1 shows location of the study area.

3. METHODOLOGY

A. Data used in the study

Data used in this study consists of primary data and secondary data. Method of collecting data was performed using survey method. Primary data consist of infiltration rate data and soil physic characteristics (soil texture, porosity and soil content weight).Infiltration rate data was derived from laboratory analysis, determined using method of saturated hydraulic conductivity. The infiltration rate data will be used for calibration and verification tool of the infiltration rate resulted from KINEROS model analysis. Soil samples in the study area were collected and laboratory analysis was performed to obtained soil physics characteristic in the study area (soil texture, porosity, and soil content weight). In addition, soil texture data will be used for determining soil type classification on each land use and as input for KINEROS model. Soil sample was taken on each land use on various depth, those were 0 – 20 cm, 20 – 40 cm, and 40 – 60 cm. Soil laboratory analysis was conducted in the Laboratory of Soil Physics, Department of Soil Science, Faculty of Agriculture, University of Brawijaya, Indonesia.

Secondary data which were used in this study consist of daily rainfall data which were collected from 2000 – 2009, soil type, topographical map scale 1/25000 which was baed on year 2010 and derived from BAKOSURTANAL. Topogrpahical map has an important role in the process of watershed boundary delineation and generating synthetical river network in the watershed study area, land use map scale 1/50000 which wwas taken based on year 2000 and 2010. The usage of land use map was for determining existing land use type in the watershed study area. Further, it was also used as a basic to estimate landcover coefficient to be used as input to KINEROS model.

B. Method of analysis

Mathematically, model of spatial runoff consists of : (1) independent variable (Y), namely runoff spatially which is runoff depth in the urban area; (2) dependent variable (X). The dependent variable (X) can be categorized as follows: map of landuse in the Klojen Sub District (X_1), map of existing landuse (X_2), and map of runoff (X_3). Then, the following steps is overlaying technique based GIS system was employed for those dependent variables in order to obtain runoff depth in the study area. Followings are steps that employed in the runoff analysis in the present study:

– Landuse/Landcover classification analysis.
  The analysis were conducted by interpreting existing landuse condition in the study area based on aerial photo analysis. To increase accuracy of landuse/landcover resulted, image of study area derived from satellite remote sensing was used to compare between landuse/landcover resulted from aerial photo and from satellite remote sensing classification analysis. Afterwards, verification process of the result of landuse/landcover was performed by conducting field survey in the study area.
– Soil physics analysis
  The soil analyses were exhibited in Laboratory of Soil Physics, Department of Soil Science, Faculty of Agriculture, Brawijaya University. The analyses were consist of 3 soil parameter, those were: soil texture analysis, soil volume weight analysis, and soil prosity analysis.
  The result of laboratory analyses were used as input for the runoff model, especially in the process of calibration and verification where soil parameters become sensitive factor to obtain good results in the runoff model analysis.
– Runoff modelling analysis
  The runoff analyses were performed by inputting whole variables included soil properties, topography, landuse, and hydrological data into runoff model. In the present study, rainfall data was collected from Laboratory of Hydrology, Water Resources Engineering, Faculty of Engineering, University of Brawijaya within 2000-2009. The modelling process was done in the frame of Geographical Information System and comprise with delineation process of watershed and synthetic river network of study area from Digital Elevation Model (DEM), digital landuse map, digital soil map, and hydrological data analyses. Later, calibration and verification of results of the model was carried out by comparing runoff depth from model resulted with that of field measurement. The calibrated runoff model was then, used for runoff simulation process for each of rainfall depth in the study area.

C. Output of the model

The output of the model was a spatial mapping of runoff depth over the study area accompanied by attribute data such as inundation location, area of inundation, and depth of inundation. The spatial mapping of runoff depth was produced for each landuse year 2000 and 2010. Several of rainfall depth were used as input for simulating runoff process in the study area. Thus, several graphics which exhibit relationship among runoff depth and landuse for each rainfall depth were derived.

4. KINEROS MODEL

The kinematic runoff and erosion model KINEROS is an event oriented, physically based model describing the processes of interception, infiltration, surface runoff and erosion from small agricultural and urban watersheds ($\leq 100 km^2$) [4]. The model is a part of AGWA program (Automated Geospatial Watershed Assessment) developed by USDA-ARS (Agricultural Research Services), Southwest Watershed Research Centre cooperate with US EPA Office of Research and Development. In KINEROS model, the watershed is represented by a cascade of planes and channels; the partial differential equations describing overland flow, channel flow, erosion and sediment transport are solved by finite difference techniques. The spatial variation of rainfall, infiltration, runoff, and erosion parameters can be accomodated. KINEROS uses one-dimensional kinematic equations to simulate flow over rectangular planes and through trapezoidal open channels, circular conduits and small detention ponds.

The infiltration expressed used in KINEROS comes from Smith and Parlange (1978) :

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

$$B = (G + hw)(\theta_S - \theta_i) \quad (2)$$

where:

- fc : infiltration capacity (mm/min)
- α : indicate parameter which depend on soil type (for sand α = 0, while for clay α = 1)
- Ks : saturated hydraulic conductivity (mm/min)
- G : effective net capillary drive
- hw : depth of overland flow (m)
- θs and θi : saturated and initial water content, respectively

Overland flow analysis expressed in KINEROS comes from development of Hortonian Overland Flow (HOF) theory which described as follows:

$$Q = \alpha h^m \quad (3)$$

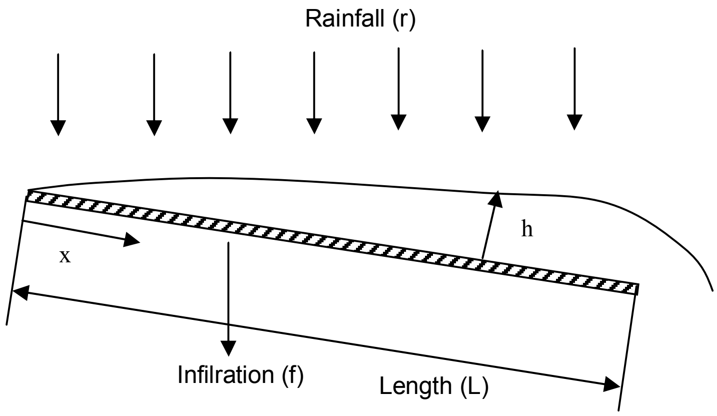


***Fig. 2.** Definition sketch of overland flow on a plane*

where :

- Q : discharge per unit width (m^3/sec/m)
- h : storage of water per unit area (m)
- α and m : parameters related to slope, surface roughness, and whether the flow is laminar or turbulent

Equation (3) is used in conjunction with the equation of continuity :

$$\frac{\partial h}{\partial t} + \frac{\partial Q}{\partial x} = q(x,t) \quad (4)$$

where :

- t : time
- x : spatial coordinate (m)
- $q\ (x,t)$: lateral inflow rate (m^3/sec/m)

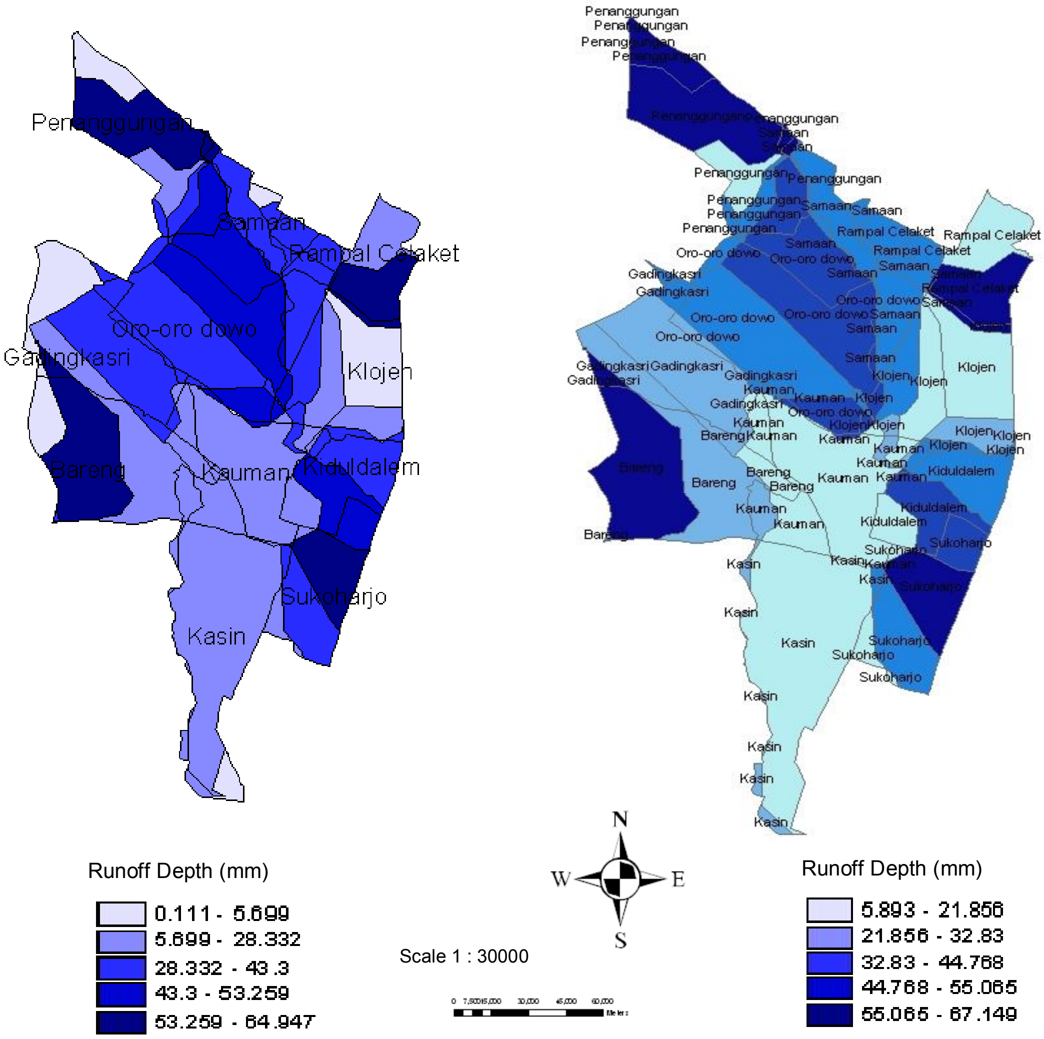
If Equation (3) is subtituted into Equation (4), we get:

$$\frac{\partial h}{\partial t} + \alpha m h^{m-1}\frac{\partial h}{\partial x} = q(x,t) \quad (5)$$

A definition sketch of one dimensional flow on a plane surface is shown in Figure 2. It must be emphasized that the depicted overland flow on a plane surface is not the type of flow found in most field situations. Furthermore, the kinematic assumption requires only that discharge be some unique function of the amount of water stored per unit area, it does not require sheet flow.

5. RESULTS AND CONCLUSIONS

The objective of the present study is to develop runoff model based on calibrated parameter resulted and ultimately, simulate runoff depth for each landuse 2000, 2006, and 2010 in the study area. The runoff model was built integrated with GIS system. Consequently, soil and landuse map must be converted into GIS file format in order to apply in the runoff model. Input of the runoff model was rainfall, soil type, and landuse data. Spatially runoff depth distribution map was produced for each landuse year of 2000, 2006, and 2010. Calibration of runoff depth resulted was performed by comparing the result of runoff depth and field observation in the study area. The results of runoff depth spatially for each landuse 2000, 2006, and 2010 on each village in the study area were shown in Figure 3 (a), 3 (b), and 4, respectively. The calibrated runoff model, then used for simulating runoff depth for each landuse year of 2000, 2006, and 2010 and based on rainfall input 80mm, 160mm, and 200mm, respectively. The result of runoff depth simulation for rainfall input 200mm and landuse year of 2010 on each village in the study area was shown in Figure 5. From those figures, it can be seen that the result of runoff depth distribution map in the study area greatly influenced by rainfall intensity and landuse type. The increasing of impervious area about 45% on 2006 cause increasing in the runoff depth in the study area. The highest of runoff depth in the study area was produced based on landuse year of 2010 where the depth of runoff showed 139.8mm, located in Penanggungan Village. Further, the result of the study also showed that some parameters closely influenced runoff yield, namely rainfall intensity, landuse type, and soil type.



(a) 2006 (b) 2010

Fig. 3. *Map of runoff depth for landuse (a) 2006 and (b) 2010*

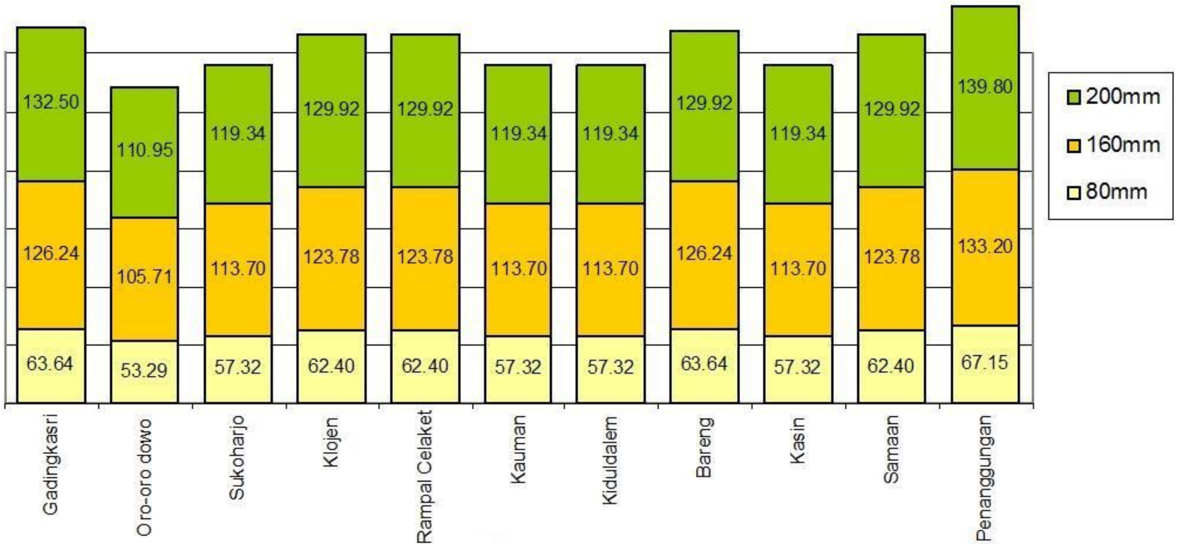


Fig. 4. *Runoff depth for rainfall 80mm, 160mm, and 200mm*

6. ACKNOWLEDGEMENT

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7. REFERENCES

[1] Turner, MG., Gardner, RH., and O'Neill, RV., "Landscape Ecology in Theory and Practice Pattern and Process", 2001, *Springer-Verlag pp. 401*, New York.

[2] Burns, D., Vitvar, T., McDonnell, J., Hassett, J., Duncan, J., and Kendall, C., "Effects of Suburban Development on Runoff Generation in the Croton River Basin, New York, USA", 2005, *Journal of Hydrology Vol. 311*, 266 – 281, Elsevier.

[3] Booth, DB., Hartley, D., and Jackson, R., "Forest Cover, Impervious-Surface Area and the Mitigation of Stormwater Impacts", 2002, *Journal of the American Water Resources Association (JAWRA), Vol. 38, 835 – 845,* 2011 American Water Resources Association.

[4] Rose, S., and N.E. Peters., "Effects of urbanization on streamflow in the Atlanta area (Georgia, USA): A comparative hydrological approach", 2001, *Hydrological Processes, Vol. 15, 1441 – 1457*, Wiley Online Library.

[5] Yu, PL., Nien, MH., Pei, JW., Chen, FW., and Verburg, PH., "Impacts of Land Use Change Scenarious on Hydrology and Land Use Patterns in the Wu-Tu Watershed in Northern Taiwan", 2005, *Environmental Informatics Archives, Vol. 3, pp. 14 – 23*, International Society for Environmental Information Sciences.

[6] Woolhiser, DA., Smith, RE., and Goodrich, DC., "KINEROS, A Kinematic Runoff and Erosion Model, Documentation and User Manual", 1990, *Agricultural Research Service, ARS 77*, United States Department of Agriculture..