

APPLICATION OF DIGITAL ELEVATION METHOD (DEM) FOR FLOOD ESTIMATION ON UPSTREAM CILIWUNG RIVER, WEST JAVA, INDONESIA

* Sri Legowo¹; Iwan. K. Hadihardaja¹; Tunggul Sutan Haji²; Enung^{3,4}

^{1,4}Civil Engineering and Environmental Faculty, Institut Teknologi Bandung, Indonesia

²Department of Agricultural Engineering, Brawijaya University, Malang, Indonesia

³Civil Engineering Department, Politeknik Negeri Bandung, Indonesia

*Corresponding Author, Received: 08 Jan. 2019, Revised: 14 Jan. 2019, Accepted: 30 Jan. 2019

ABSTRACT: Flood generally caused by the high speed of urban growth that is not balanced by efforts to avoid it. The decrease of vegetation closing and the disappearing of the natural reservoir can cause the lack of field ability to restrain rainfall and disturb surface stream flow that influences the balance of hydrology along the river basin. Hydrology models tended to be spatially distributed. By computer support with higher memory capability and faster speed, the increase of development and usage of spatially distributed models substitute lump parametric models or aggregate to spatially simple. Furthermore, there are many efforts of integration forms, either database or hydrology models with Geographic Information System (GIS). The approach of the integration of spatially distributed hydrology model and GIS is used to simulate the hydrology process interactively with the basis of spatiotemporal, with a variety of land use, rainfall, and detention reservoir volume changes (embung/ small dam). The DEM which emerges land surface morphology information is used to represent hydrology process of surface runoff. Topography structure extraction algorithm will be the slope and the current direction is an important factor in describing drainage network. The elevation numbers and its descendants are depicted in grid cells in 50 m x 50 m measurement. The result shows such as in flood hydrograph which is varied base on land use, design rainfall and detention reservoir (embung/ small dam).

Keywords: Hydrology model, GIS, DEM, Hydrograph flood, Embung

1. INTRODUCTION

The research aims to develop spatially distributed hydrology model integrated with GIS that later on will be unbreakable between system and software and operated by the user interactively and user-friendly. A model is developed to simulate the phenomenon of upstream Ciliwung river basin with any kinds of field closing scenarios or Field Function Change (FFC) and with a variety of detention reservoir volume and rainfall data. Based on the simulation result, it is arranged the relationship between River Basin Condition Level, Flood Index, and Reservoir Coefficient [1].

The main problem in calculating flood losses in determining the extent of the hydraulic flood component's influence on the damage that causes the loss [2]. The hydrometeorological hazards including flash floods are influenced by location, topography and climate of the region [3]. Most watersheds in Indonesia have a problem with data deficiency, especially in natural watersheds (ungauged river basins), which can affect the accuracy of water resources design and planning [4].

The model uses a spatially distributed approach where characteristic variety or properties of River Basin gets attention. River Basin is modeled as a neighborhood grid cell in which the attribute varies.

The performance enables many factors of physiographic consisting of the slope, current direction, abstraction speed, and surface roughness that can be extracted accurately in order to account on stream current [5].

Conceptually, excess rainfall on a certain cell will flow to the neighbor cell with the biggest slope. If the condition happens on all cells along River Basin, all rainfalls along the River Basin will be accumulated in the river network and eventually will be empty into one cell or outlet cell [6]. Rainfall depth and rainfall duration play a key role in determining the critical rainfall at the flood site [7].

The value of excess rainfall is determined by every cell by using the SCS method, where CN value is got based on field closing and land type. Running off water from each cell will overland flow from one cell to another following synthetic river network that is defined according to DEM. The stream above the land surface is assumed as uniform steady flow (neglecting backwater) or kinematics wave that is formed in continuity flow $dQ/dx + dA/dt = q$ and momentum $So = Sf$. These equations can be solved with linear finite difference method [8-10].

The hydrology model integration and GIS base concepts developed are "hydrology process in spatial media". The hydrology model constitutes

the hydrology process simplification with emphasizing on "mass/energy and dynamic," with basic elements is "water." On the other hand, GIS is a system that has the ability to catch, manipulate, process, and display spatial data, with pressing on "distribution and spatial relationship," with the basic element is "spatial object." On integration level and software used; it is determined and selected flexible refers to hydrology model need principle and the availability of GIS. In hydrology model, it is required data, controller equation, domain, and result. GIS, on the different party, provides data, analysis (catch, manipulate, process, and display), and spatial software [11]. ArcSWAT is one of the tools in Arc GIS use a digital elevation model (DEM) to delineate river basin boundaries and divide into sub-basins, using the hydrological response unit (HRU) as rainfall transformation mechanisms into streams and based on curve number methods [12]. The Arc-GIS USLE model was used to estimate the value of the actual distribution of soil erosion in the river basin, including information on the spatial allocation of each USLE parameter. The cell grid systems offered in GIS have robust functionality, resulting in each grid cell on the map overlay [13].

The biggest problem in the hydrology model here is in numeric solving. From the analytic test, it shows that error has an influence on flow volume prediction error in the number of 0.21 along 20 km and 100 m^3/s traveling of wave flow. The error that caused by rasterization or the implementation of a grid system as model spatial domain gives a spatial error that is not significant to flow. The error of River Basin at large gives 0.01 and line length error contributes 1.6. In model calibration, the error of the simulation hydrograph determination coefficient and observation are 0.91 [14].

The integration of spatially distributed hydrology model and Geographic Information System (GIS) is successfully applied and can simulate the hydrology process of running off rainfall of River Basin Ciliwung upstream interactively with the basis of spatiotemporal, with a large variety of field closing, rainfall, and detention reservoir volume changes [15].

The hydrology model developed (SIMODAS-ITB) enables the deterministic study of spatial change influence of the method of making land use and detention reservoir towards the properties of flood hydrograph (flood peak Q_p , peak time T_p , concentration time T_c , isochrones and hydrograph unit) river basin [16]

The model can be further developed to analyze other hydrology closely relates to spatial problems, for example, it is used to determine flow to the ungauged watershed river and can be applied in rationalization analysis of hydrology network [17,18]

The development of techniques and algorithms to determine synthetic river network, Catchment Area and reservoir determination, based on DEM and digital map with Morfo-Hydrology operator, and the improvement of display dynamic hydrology techniques in real-time mode, in the research, have given a large amount of contribution in "hydrography" branch of science. Moreover, the hydrology model integration - GIS developed, with their specialties in the River Basin flood studies that cannot neglect distribution parameter or spatial hydrology variable, has added the variety heritage of hydrology model that are existing today

2. METHODOLOGY

2.1 Processing of DEM

The developed models are divided into three main groups, namely DEM processing, preparation of model data or DTA data (Watershed) and hydrological models. DEM processing includes algorithms to get cell-grid heights and flow directions based on topographic maps.

Preparation of model data aims to prepare the DTA data that will be used as static data (altitude, flow direction, roughness coefficient Manning, slope, type of Curve Number and distribution of rain) to use in hydrological models. While the hydrological model aims to find out rain ridge, runoff (hydrograph) and inundation, by calculating the amount abstraction, runoff, and flow in each cell and inundation in the river channel as well display the results, based on previously prepared DTA and rain data.

2.1.1 Raster DEM approach

There are two approaches used to describe networks of drainage in a raster DEM. The first includes evaluating the local elevation in a small window that was moved to the DEM to identify land clearing (Peucker and Douglas, 1975). The cells at the base of the area are taken as components of the drainage channel. This approach is used by Band (1986) in the first stage of the separator of the topographic catchment area is to illustrate waterways. The main disadvantage of this approach is that this approach only generates un-continuous network segments that must be connected later (O'Callaghan and Mark, 1984), and perhaps necessary trimming and thinning to produce a reasonable network pattern (Douglas, 1986). This problem becomes more real for the land surface with topography and flatter reliefs (Band, 1986) which are obstacles in its application.

The second approach in determining the drainage network from the raster DEM is based on the simulation of runoff flow across the ground. This approach was introduced by O'Callaghan and

Mark (1984). This approach essentially includes identifying runoff flow towards the steepest slope between each raster DEM cell and its neighboring cells. This approach is considered a better approach because it relies on the runoff analogy to determine the flow trajectories. Therefore this approach is used for the development of the algorithm presented here. Some of the following sub-chapters will explain the algorithm for DEM evaluation.

2.1.2. Determining flow direction

This algorithm scans each cell of the DEM to modification and determines direction steepest slope of adjacent cells. The method used "method D8" (deterministic eight-neighbors) by Fairchild and Leymarie (1991). In this method, the slope of the relief for each adjacent cell is calculated with a greater horizontal distance for diagonal cells, and a direction code shows the steepest slope loaded in the cell. If there is more than one slope towards the steepest slope, any direction toward the first cell found in the line-by-line scan. When a neighboring cell is uncertain (perhaps, the elevation value is lost or the outside of the grid DEM), the slope toward the cell is assumed to be the steepest of the other neighboring cells that have certain values. Therefore the direction of flow at the edge of the DEM will point out. Even though the truth is not always the case. Therefore for practical purposes, elevation data should be available for the area which is wider than the drainage supply to be studied. The final result of this flow direction algorithm is an array that contains the direction of flow of all grid cells.

2.1.3. Slope

The slope value loaded in each cell on the grid-cell can be determined by the formula:

$$\beta = \arctan\left\{\max_{i=1,8} Q(i) \left| \frac{z_{\#} - z_i}{\lambda} \right| \right\} \quad (1)$$

Where:

- z = elevation
- i = numbering of neighboring grids (1 to 8)
- Q (i) = 1 for the direction of USTB (North, South, East and West), and 1/2 times the root two for the direction of TL, TG, BD and BL (Northeast, Southeast, Southwest and Northwest)
- λ = cell-grid size.

Land grids and land cover can be obtained by changing the land vector maps and land closure in a raster data structure with grid size following DEM data that has been obtained previously.

2.2. Preparation of Input DTA Data

There are two types of data that must be available for preparing this data, namely: 1) grid data with each cell containing altitude data, land cover, flow direction, soil type, slope and flow accumulation, and 2) data on station points in or around the DTA.

DEM which is the raster data resulting from the Morphological processing of the study area's soil surface is expressed in ASCII format raster data written. This data is used as the basis for writing other raster data, such as slope and flow direction. Data description (chopped columns, chopped row, coordinates the initial corner, and cell size) of other types of data must have the same value.

How is this connection between raster data and map coordinates explained in the grid coordinates transformation sub-section after this?

Also for other raster data such as flow direction, slope and land cover is written in the same format as DEM data. The value of the first six lines (data description) is the same, different only the elevation value is replaced with the value of the data in question (slope, flow direction, etc.).

2.3. Spatial Analysis

2.3.1 Downstream flow

Downstream flow is intended to find out the flow path from one cell to cell it began, so it can be known where the water will pass and go. This path will be formed because the water in a cell will flow to one of the neighboring cells, then it will be forwarded to the neighboring cell again. And so on the water journey from the selected cell to the other cell until it ends in the most downstream cell. This water trip will form a flow track. This algorithm is more clearly illustrated by Fig.1.

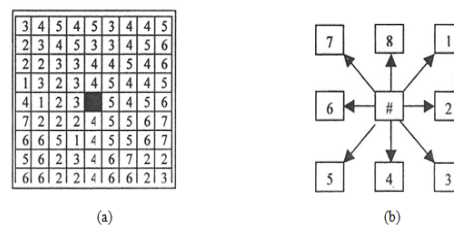


Fig.1 Algorithms for determining downstream flow: (a) flow direction grid data and (b) flow direction corresponds to 8 (eight) wind direction 1 (northeast), 2 (east), 3 (southeast), 4 (south), 5 (southwest), 6 (west), 7 (northwest) and 8 (north)

If one of the red cells is selected (a), then the water will flow towards the neighboring cell in the north according to the direction of flow 4 (b). And so on, so that it forms a blue color trajectory.

2.3.2 Identification of DTA

DTA is the general term of the watershed. DTA can be determined based on flow direction parameters which are the results extracted by DEM. Algorithm determination of DTA is developed

based on a simple principle, namely cell if the runoff reaches the outlet cell, then the cell is part of the intended DTA area. After the cells are joined together, then DTA will be formed for outlet cells. The outlet cell is the cell that can be selected just any. So by entering the selected cell as input data, it will automatically form DTA selected. The location of this cell must be converted from map coordinates become grid coordinates.

After identifying one cell as the outlet cell, at first, the cell gets flow from one or more adjacent ones that can be tested based on the flow direction properties. The cell becomes the selected cell that can be marked with the cell number selected first. The selected cells, in the same way, will be able to flow from adjacent cells which can be tested with a property in the direction of neighboring cell flow. And so on until a select cell is found which a cell that does not receive flow from the cell next to it. The selected cell is the catchment boundary for the first selected cell or peak/ridge. The illustration of this algorithm can be seen in Fig.2.

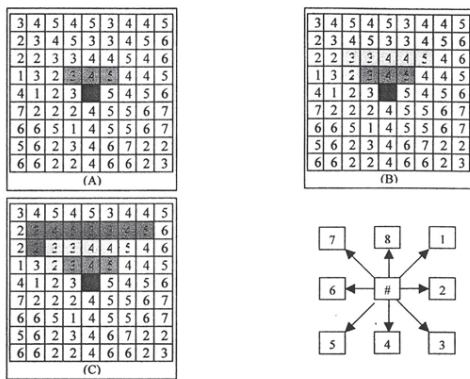


Fig.2 Determination of Watershed (DTA)

The area of the catchment can be determined by calculating the number of grid-cells identified as DTA cells multiplied by the area of each grid cell. If the grid used measures 50 m x 50 m, then the DTA area is counting DTA cells multiplied by 2,500 m². If the DTA unit is expressed by counting cells only, the DTA is referred to as 'specific DTA'.

The outer boundary of the outer cell is the DTA boundary which is the line interconnected at grid angles that can be used as a closed polygon of the DTA. This closed polygon is a "DTA zone" that can be stored as vector structure SIG data. So that it can be spatially analyzed with other vector digital maps. For example, to answer questions 'which areas include identified watersheds'. This algorithm can also be used to describe the accumulation of flow. If the amount of runoff rain for all study areas is the same, then the accumulation of surface runoff flow is directly proportional to the amount of DTA in each cell that is considered. Before carrying out

identification of DTA, it must be entered first at least DEM grid data and flow direction.

2.3.3 Rain Distribution

Rainfall data measured at rain stations can be distributed and loaded in whole cells in the DEM grid. One of the most popular ways is the Thiessen method. This method is also known as Voronoi tessellation, Dirichlet cells or proximal mapping. Thiessen's reasoning method is that the best estimate of the absence of information is the observation value at the closest proximal distance or the nearest Euclidean neighbor (Meijerink, 1994), as presented with the formula:

$$d_{min} = \sqrt{\{(x_0 - x_j)^2 + (y_0 - y_j)^2\}} ; \dots \dots j = 1, 2, \dots, n \quad (2)$$

Where d_{min} is the minimum distance between two points (X_0, Y_0) and observation station ($j = A, B, \dots, H$), (Figure 4.9). Rain data in grid cells that are enclosed inside DTA can be used to determine the average rainfall value in the identified DTA.

2.4. River Network / Drainage

A catchment area of water is required to form a river channel. A catchment area is smaller than the threshold value does not enough to produce surface runoff to form and remain as river channel. This threshold value depends among others by characteristics slope, soil propagation, surface closure, and climatic conditions. This threshold value can be 1 (one) hectare or several hundred hectares. Therefore, river networks start from cells that have more than the catchments threshold value. For this purpose, the entire cell is scanned and the cell it has a catchment area equal to or slightly greater than the threshold value is marked as the beginning of the network. With the method of determining downstream flow for all the initial cells of the network, it can be determined all river network in the whole River Basin. Then can be done ordering the river network stage. A more complete explanation of the river network and ordering can be seen in Sutanhaji (1999).

Basically, the determination of this river network is the same as the determination of the downstream flow path that has been discussed before, where cells which are the initial cells of the downstream flow are all cells that do not have a DTA area or is the most upstream cell. Downstream flow can also be started from the cell that is considered starting to form a drainage channel or river channel, usually determined in cells that have a certain DTA (in cell count).

2.5. Calculation of Runoff Q

Q is calculated based on 1) Q value in the same cell at the previous time, 2) Q entered into the cell at the same time, and 3) the amount of direct runoff or excess rain at the same time and cell. Because these numeric solving equations are long, so help variables are needed (Bantul, Bantu2 and Bantu3) to simplify.

2.6. Results Display

Surface runoff (Q), abstraction and direct runoff from the count besides being saved in a file can also be displayed on the monitor screen. This displaying has two ways, namely the amount of Q at a certain time is marked with a different color on each cell in the DTA sub-screen and the amount of rain, abstraction and Q on the sub-screen of the hydrograph and rain sub-screen (see Fig.3). This last displaying will be explained further.

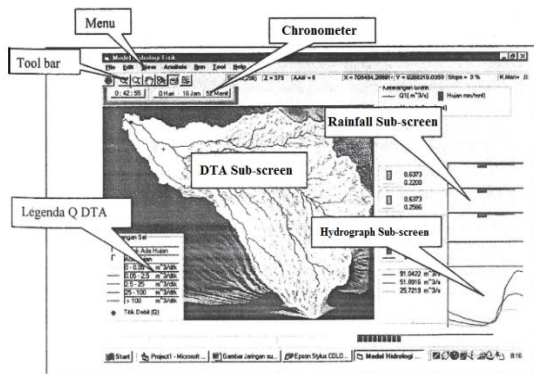


Fig.3 Display of Q, rain and abstraction on the monitor screen for DTA upstream Ciliwung river

Displaying Q, abstraction and excess rain-flow are displayed every certain time interval, of course, greater or equal to the interval count Q. For example, the interval of the Q count in one minute, then the results display can be done every time interval of 5 minutes, 10 minutes, 15 minutes, half hour or one hour.

The data is illustrated in the hydrograph sub-screen and rain sub-screen represent current data and 50 previous data. Current data are drawn on the right end of the abscissa and the previous data more and more into the left. So with an interval of 10 minutes, the data is displayed is the current data and the previous 500 minutes data. With the emergence of new data now, the other data will be shifted to the left so that the data 51th will disappear from the screen.

Q value is displayed the on sub-screen is called PicHidrograf, while the rain value and abstraction are displayed on the sub-screen named PicRain (K). Sub-screens are provided in the form of five arrays, to allow displaying rain value and abstraction at

several rain points with different sub-screens.

Displays on this screen are not permanent and only display a small portion of the overall long time. More complete and permanent data stored in the results file and the value can be displayed in a table or graph by using MS-Excel software.

The hydrograph sub-screen allows displaying the Q value from several Q points at the same time. Unlike the rain sub-screen, one rain sub-screen can only display the values of abstraction and rain at one point of rain. Therefore some sub-rain screens are needed in the form of arrays for allows display of abstraction and rain at some points of rain.

Entering data on Q points and rain points can be done selecting a specific location on the DTA sub-screen with the click event using the help toolbar pointer point Q and rain point.

2.7. Determination of Flood Inundation

Determination of flood inundation will be carried out only in the flow path where flooding is common or suspected flooding will occur. Cells which are river channels that will be known to be inundated is marked. While the determination of inundation depth is determined by the amount of discharge in the corresponding cell and the cross-sectional area formed based on the corresponding cells on the left the right perpendicular to the flow direction. In detail, it can be described as follows :

1. Mark the cells in the flow path that the inundation will be determined (a) with Flow_Hilir Procedure so that the cells will form flow lines starting from upstream (starting point) to downstream.
2. Select the first cell starting from the upstream of the cells that have been marked.
3. Determine the depth according to the cross section based on the size of the discharge flow in the cell (b). Cross section is determined based on the height of these cells and neighboring cells that are perpendicular to the flow direction. The formula used is $A = \alpha Q^\beta$ and $A = \Delta X (d_0 + (d_{r1} + d_{r2} + \dots + d_{rm}) + (d_{l1} + d_{l2} + \dots + d_{ln}))$, where the determination of this depth will be explained separately, still in this subchapter.
4. Based on this depth, inundate cells from the beginning to the boundary of cell cross section (c).
5. Continue with the second cell. Also determine the cross-section, the height of inundation and cells inundated as in the first cell (d).
6. Continue onwards to the other downstream cells until the last marked cell (e) and (f).

Algorithm for determining inundation depth in each cross section in detail can be described as follows (Fig. 4). Calculate the amount of cross-sectional area based on the value of the flow rate at one cell $A = \alpha Q^\beta$, then calculate the depth based on

the width of one cell $d = A/\Delta X$, where the flow direction is odd (1, 3, 5 or 7) then $\Delta X = \text{grid size}$ (DeltaX), but if the direction of flow is even (2, 4, 6 or 8) then $\Delta X = \text{grid size}$ (DeltaX) * $\sqrt{2}$.

Based on this depth, identification of sinking and cross-section cells include their respective height values (a), and sort the identified cells starts from the lowest to the highest.

Starting from the lowest cell enter the area into the cross-section of the cells until the whole thing goes into it (b), (c), (d) up to (g).

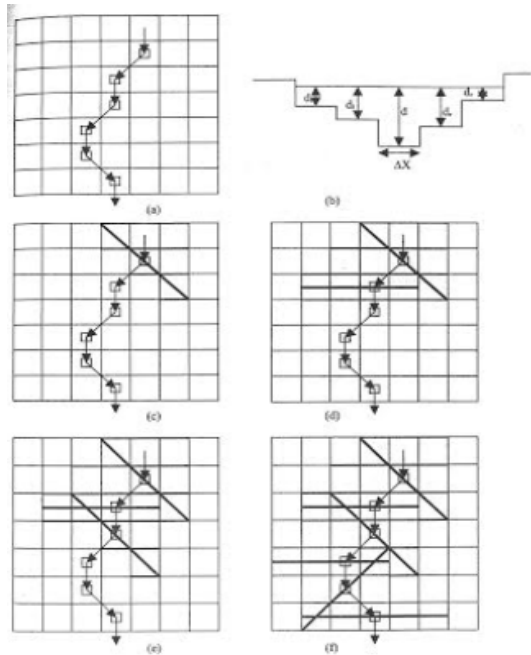


Fig.4 Determination of flood inundation algorithm based on the cross-section, discharge and other hydraulic properties.

With this depth value determines once again the sinking cross-section cells and how deep each cell sinks.

3. RESULTS AND DISCUSSION

After going through the testing stages and the model is considered valid, the model used to study the extent of changes in the characteristics of the hydrograph outlet (Katulampa) with various land cover scenarios. Aside from that will be discussed efforts to reduce the peak of flooding with water spatial arrangements or provide detention storage both on land and in river channels.

3.1 Scenario of Various Land Cover

How influential the magnitude of changes in land cover to the contribution of increasing Katulampa floods, will be studied here. For this reason, the rate of change in land cover will be estimated first. Determination of changes in land

cover is estimated by 'buffering'. Expansion of settlements at certain intervals will travel out as far as a certain distance from the boundary of the outermost polygon (see Fig.5).

Changes in the upstream Ciliwung settlement for five years (1994 – years 2002) covering an area of 12.4 km². If expressed by the area of a polygon, the buffer needed is 73.2 meters. If it is assumed that the next 8 years will be 73.2 meters in length, the total area of 2010 will be 54.4 km². What is the ratio of hydrographs to each land cover with the existence of settlement expansion can be observed in Table 1 and Fig.6?

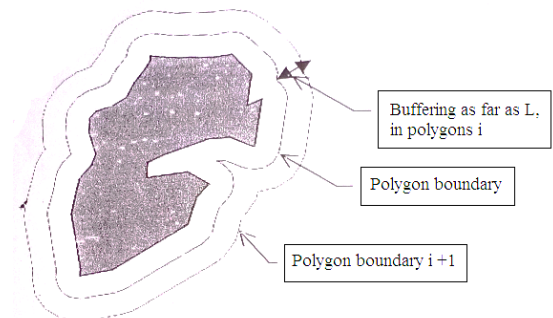


Fig. 5 Buffering polygon I as far as L to create a polygon I + 1

Table 1 Comparison of the characteristics of the Katulampa hydrograph with a wide variety of different settlements

| Land use | Settlement area | Peak time, T _p (minutes) | Flow peak, Q _p (m ³ /sec) | Drain Volume (m ³) |
|----------|-----------------|-------------------------------------|---|--------------------------------|
| I | 16.1 (10.6%) | 400 | 250.16 | 4,939,074.5 |
| II | 28.5 (18.8%) | 380 | 269.76 | 5,218,706.0 |
| III | 54.4 (35.9%) | 350 | 330.27 | 5,863,993.5 |

From Table 1 it is clear that the increase in residential land in the upstream Ciliwung watershed not only increases the Volume and Peak of the Flood but also shorten Peak Time to 20 minutes or 5% within 8 times year.

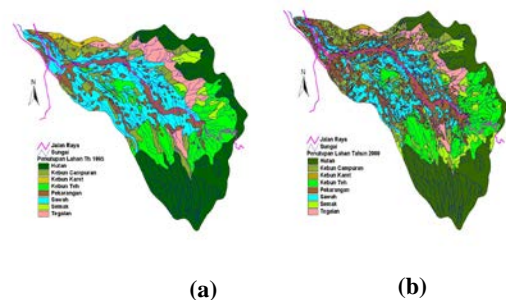


Fig.6 Land Closure (a) 1994, (b) Year 2000

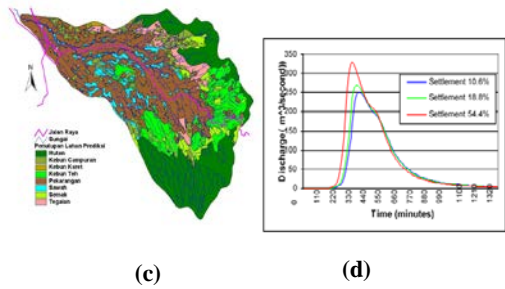


Fig.6 (c) Prediction in 2010 and (d) Various prognosis of hydrographs due to the change of land closure.

3.2 Variations in Forest-Settlements

In this section, it will simulate various flood hydrographs with various % variation of forest-settlement for the upstream Ciliwung watershed. The simulation starts from the best watershed conditions, where all watersheds are covered by forests (100% forest, 0% settlement) until the condition of the watershed is the worst, where all watersheds have been converted into settlements (0% forest, 100% residential). Whereas among them are variations of forest-settlements whose values contradict each other. The variation of forest-settlement that will be simulated can be seen in Fig.7. This forest-settlement variation is determined by spatial buffering analysis. The initial forest area used as the condition of the initial forest area is the current forest area (approximately 27 km²). With buffering analysis, the land area can be expanded out to be wider or depreciated to become smaller.

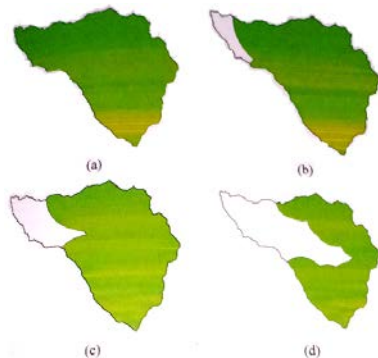


Fig.7 Various Forest Areas (a) 100%, (b) 94%, (c) 84%, (d) 62% to classify the level of damage to the watershed

The purpose of this simulation is to get a repair size or the upstream Ciliwung watershed gets worse if there are changes in the watershed either because of the effect of land conversion, watershed management or watershed improvement actions, one of them is by providing a detention center or water spatial arrangement.

Then the area of the watershed with % varies of this forest-settlement simulated to determine changes in hydrograph with various bulk rain given. Fig.8 is various hydrograph in % variations of forest-settlement with 78 mm rainfall. If we observe changes in the peak of the flood in various watershed conditions (forest-settlement % variations) on 78 mm of rain and in other major rainfall, it is obtained in Table 2. And if expressed in the form of a curve obtained as in Fig. 8.

Table 2 Flood peak Qp (m³/sec) at various levels of watershed conditions (% of forest area) with various rainfall

| No | Rainfall (mm) | Watershed condition level (% forest area) | | | | | | |
|----|---------------|---|--------|--------|--------|---------|---------|---------|
| | | 100 | 94 | 84 | 62 | 27 | 5 | 0 |
| 1 | 100 | 565.8 | 582.46 | 613.33 | 713 | 1207.02 | 1509.02 | 1567.89 |
| 2 | 78 | 346.87 | 359.58 | 383.61 | 469.58 | 872.44 | 1109.92 | 1151.89 |
| 3 | 60 | 195.74 | 203.93 | 218.83 | 312.11 | 602.97 | 775.25 | 802.44 |
| 4 | 50 | 129.97 | 136.07 | 147.25 | 235.39 | 462.25 | 596.20 | 615.52 |
| 5 | 40 | 75.91 | 75.91 | 87.82 | 164.52 | 327.82 | 423.24 | 435.39 |

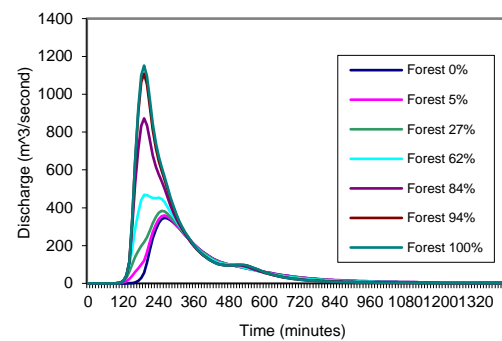


Fig.8 Hydrograph floods at various levels of damage or Watershed conditions (% of land area) in 78 mm rainfall

From Fig.9 it can be seen that the forest changes into settlements down from 100% to about 85% in small rainfall to 65% for heavy rain, not too influential on increasing Peak Floods or just small increases with a rather gentle curve. But after that in the direction of reduced forest area or increase in settlements at the same rate of change will greater influence on the increase in the Flood Peak, especially in bulk heavy rain. This means that after reaching 65% of the forest, there is reduced forest sensitive towards the increase in the Flood Peak. In actual conditions, a value of 65% it does not have to mean 65% forest area and 35% settlement, therefore, in fact, land use is not only forest and settlement. Though this, the condition of the actual watershed, which has a varied land cover, can be compared with the value of forest area 100% - 0% and settlements 0% - 100%, by comparing the Peak of the Flood.

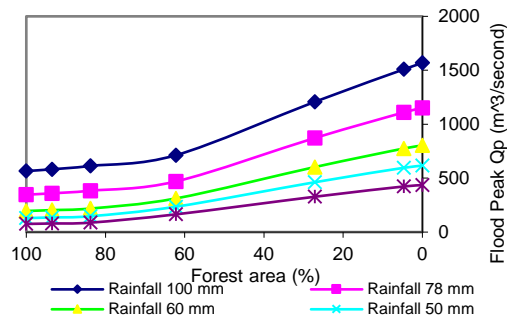


Fig.9 Flood Peak (Qp) in various watershed conditions (% forest area) and various Rainfall

If the % variation of the forest-settlement area is used as a watershed condition level whose values are between 100 and zero and the peak of the flood, Qp, in Table 2 and Fig.10 is stated as a flood index

$$\text{Flood Index} = (Qp - Qp_{100}) / (Qp_0 - Qp_{100}) \quad (3)$$

Where:

Qp₁₀₀ = peak flooding in the best watershed condition (100% forest)

Qp₀ = flood peak in the worst watershed conditions (100% settlement)

It will be obtained Table 3 and Fig.10, namely the relationships of various levels of watershed conditions with the Flood Index in various rainfall.

Table 3 Flood Index at various levels of watershed conditions (wide variation % forest-settlement) with various rainfall

| No | Rainfall (mm) | Watershed condition level (% forest area) | | | | | | |
|---------|---------------|---|-------|-------|-------|-------|-------|---|
| | | 100 | 94 | 84 | 62 | 27 | 5 | 0 |
| 1 | 100 | - | 0,017 | 0,047 | 0,147 | 0,641 | 0,941 | 1 |
| 2 | 78 | - | 0,016 | 0,046 | 0,152 | 0,653 | 0,948 | 1 |
| 3 | 60 | - | 0,013 | 0,038 | 0,192 | 0,671 | 0,955 | 1 |
| 4 | 50 | - | 0,013 | 0,036 | 0,217 | 0,684 | 0,960 | 1 |
| 5 | 40 | - | 0,011 | 0,033 | 0,246 | 0,701 | 0,966 | 1 |
| Average | | - | 0,014 | 0,040 | 0,191 | 0,670 | 0,954 | 1 |

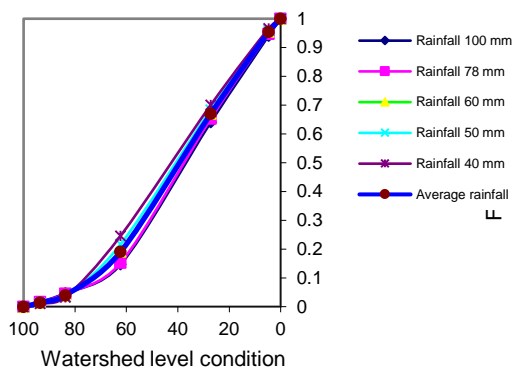


Fig.10 Relationship curve of watershed condition level and flood index on various Rainfall (mm)

Table 4 Equality of Watershed Conditions Level and % of Forest-Settlement area Variation

| No | Watershed condition level | % of forest-settlement area variation |
|----|---------------------------|---------------------------------------|
| 1 | 100 | Forest 100% - settlement 0% |
| 2 | 80 | Forest 80% - settlement 20% |
| 3 | 60 | Forest 60% - settlement 40% |
| 4 | 40 | Forest 40% - settlement 60% |
| 5 | 20 | Forest 20% - settlement 80% |
| 6 | 0 | Forest 0% - settlement 100% |

To change the flood index became the peak of the flood, Qp; Qp₀ (flood peak in the worst condition or 0% forest - 100% settlement) and Qp₁₀₀ (peak flooding in the best watershed or 100% forest - 0% settlement) in the same rainfall, must be known, where the curve can be made as in Fig.11.

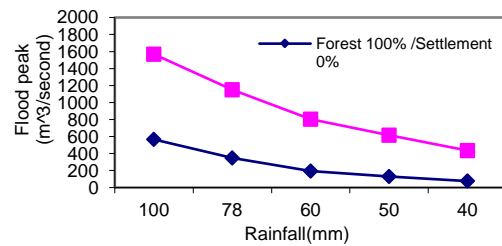


Fig.11 Flood-Peak (Qp) in Watershed Conditions are best (100% forest), and Watershed Conditions are Worst (0% forest) in Various Rainfall

3.3 Expansion of Settlements

With population growth and development, inevitably the area of the settlement will certainly increase. This increase in settlements can extend around existing settlements or open new land from other land uses. On this occasion, we will try to simulate changes in flood hydrograph if there is a change in the area of the settlement, which is considered to extend in all directions as far as a certain distance. So you can urge rice fields, moorlands, gardens or forests. Unless it is turned into a settlement, other land uses do not experience land conversion. See Fig 12.

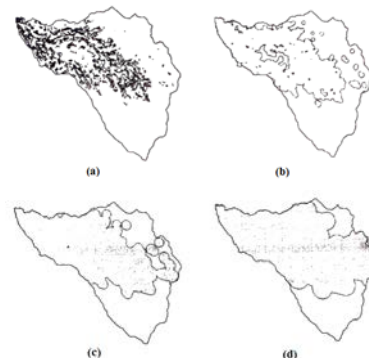


Fig.12 Expansion of settlements from current conditions, extends to until all watersheds change all into settlements; (a) 18%, (b) 49%, (c) 63%, (d) 75%

Each of the upstream Ciliwung watersheds with different settlements is simulated by giving the same rainfall, obtained by a hydrograph of various residential areas (Fig.13). And if each of the flood peaks is plotted on a graph similar to the decrease in watershed conditions or quality obtained from the previous simulation (Fig.14), then it can be seen how much the quality of the watershed decreases if there is a% increase in settlements from current land use conditions.

In the present condition (existing land use) the settlement is around 18%, with the effect of rain normalized, equivalent to 64% of the forest - 36% of the settlement. With the increase in the area of the settlement, it can be compared with the variation of the forest-settlement area by drawing a line to the right to the other curve, after meeting at a later point projected down, the forest area in question will be read. This means, in watershed conditions with a variety of land uses, with various types of land management and with various physical building efforts for flood mitigation within the watershed, it can be compared with variations in the forest-settlement area by comparing the Flood Peak or Flood Index.

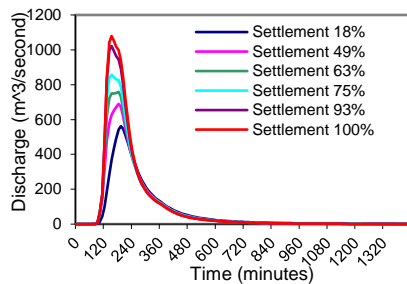


Fig.13 The flood hydrograph starts from the existing land use condition until the settlement extends to 100%

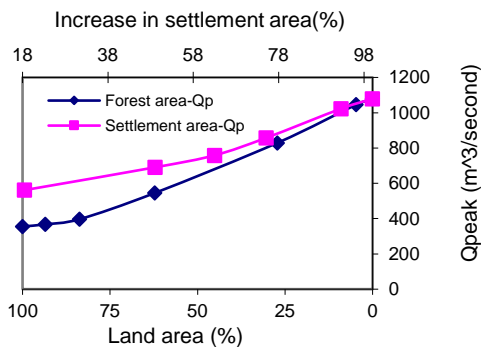


Fig.14 Decreasing tradeoff in the level of watershed conditions (blue line) with settlement expansion (pink line)

3.4 Water Spatial Planning/Detention Reserves

The problem of increasing surface flow or flooding cannot be overcome only by regulation and

land use planning. This is due to the dynamics of the development of areas for settlement/residential, urban, agricultural, Industry and public facilities require space and place that cannot be avoided.

The impact of the development of this region, of course, must be met by changing land use or transferring land. And not infrequently there is also changing ground conditions, such as deforestation, backfilling of fields, ponds. Thus it is very difficult to maintain a regional spatial plan with structuring patterns and land use planning. Therefore there must be other solutions to avoid flooding due to increased surface flow resulting from violations of the spatial planning pattern of the region. One of them is the construction of water buildings or water spatial arrangements.

There are two flood controls with building actions, namely (a) by making a reservoir (reservoir) of water in a catchment area, which aims to reduce runoff, and (b) with buildings in flooded areas, which aim to reduce flood hazards without reducing the amount of surface runoff.

Water reservoirs for flood control in catchment areas can be in the form of reservoirs in the flow path or river and can be in the form of a water reservoir on the land before entering into the river channel.

This water reservoir functions as detention, which is intended to hold runoff water in a short period of time before finally being released into the natural water course. The detention facility generally does not significantly reduce the total volume of surface runoff, but simply reduces the peak flow rate by redistributing the flow hydrograph. The terminology of detention is different from retention. Both of these terms are often misused, while retention is maintaining water in long-term storage facilities, for agriculture, consumptive, or other uses. Water may never be channeled to natural waterways, but even consumed by factories, evaporation, or infiltration in the soil.

3.5. Detention Reserves in Settlements

Settlements are often seen as the cause of floods or an increase in the peak of extreme flooding. This happens because the water that is supposed to be intercepted to the plant or infiltrated into the soil is disturbed, sometimes it does not even happen at all because all the land is covered by buildings and there is no open land left. Fig.16 to Fig.20 is a hydrograph of the simulation results if the settlements in the current watershed condition (Fig.15) are given storage with varying volumes with various rainfall.

In this simulation, the volume of storage is given to each residential cell. The first heavy rain will fill up the volume of this container to the full. After the storage is full, then runoff occurs which eventually

flows into natural channels. The selected volume is 0 (zero) m³ or no storage, 10 m³, 20 m³, 30 m³, 40 m³ and 50 m³. While the rain gave each has a total instantaneous rainfall of 40 mm, 50 mm, 60 mm, 78 mm and 100 mm with the same pattern of rain distribution. And spatial homogeneous rain.

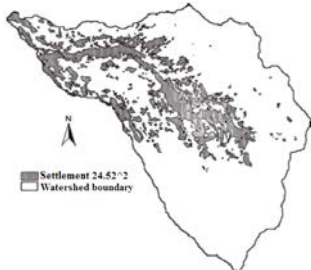


Fig.15 Map of the upstream Ciliwung Watershed Settlement

All Flood Peak events in each treatment can be issued, so that Table 5 can be obtained. And if it is drawn in the graph the relationship between the volume of the reservoir versus the Peak of the Flood of QP on various Rainfalls, the curves as shown in Fig.16-18 are obtained. Peak discharge increases near linearly as the rainfall depth increases. Meanwhile, the storage volume can reduce peak discharge quite significantly and varies for various scenarios of the depth of rainfall.

Table 5 Peak of Flood QP (m³/sec) if the settlement is given detention volume with various rainfall.

| No | Rainfall (mm) | Storage (m ³ /cell) or (m ³ /2500m ²) | | | | | |
|----|---------------|---|-------|-------|-------|-------|-------|
| | | 0 | 10 | 20 | 30 | 40 | 50 |
| 1 | 100 | 756.3 | 719.9 | 652.4 | 595.0 | 525.7 | 469.4 |
| 2 | 60 | 294.2 | 262.3 | 214.1 | 171.7 | 122.3 | 89.6 |
| 3 | 40 | 132.6 | 105.2 | 67.9 | 44.5 | 33.3 | 24.1 |

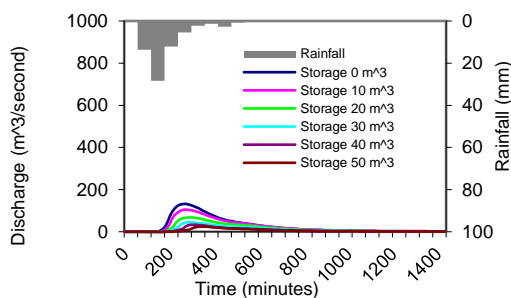


Fig.16 Flood hydrograph with various delivery volumes (in m³ / cell), starting with no storage to a reservoir of 50 m³/cell or 50 m³/2,500 m² in 40 mm rainfall.

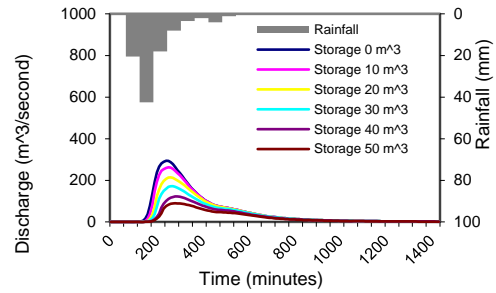


Fig.17 Flood hydrograph with various delivery volumes (in m³ / cell), starting with no storage to a reservoir of 50 m³/cell or 50 m³/2,500 m² in 60 mm rainfall.

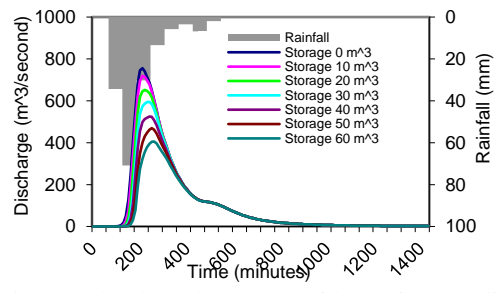


Fig.18 Flood hydrograph with various delivery volumes (in m³ / cell), starting with no storage to a reservoir of 50 m³/cell or 50 m³/2,500 m² in 100 mm rainfall.

The volume of storage per cell can also be expressed in the storage coefficient, which is the amount of storage volume divided by the amount of rainwater falling on the cell.

$$\text{The coefficient of Storage} = \frac{\text{Storage Volume}}{h_{\text{Total}} \cdot A_{\text{sel}} / 1000} \quad (4)$$

Where:

The storage coefficient has no dimension range of 0 (zero) to 1 (one). Inner Storage Volume (m³)
 h_{Total} = total rain during instantaneous rain (mm)
 A_{sel} = cell area (50 m x 50 m = 2,500 m²)

While the magnitude of the flood peak can be stated in the flood index using Eq. (4). So that we get in the form of a curve in Fig.19, and if combined with a watershed quality reduction curve, a tradeoff will be obtained that can illustrate the improvement in the quality level of the watershed if on a residential area given a certain storage volume. See Fig.20. Peak discharge significantly decreases in higher rainfall conditions. Meanwhile, the flood index decrease in almost the same slope for the whatever design rainfall.

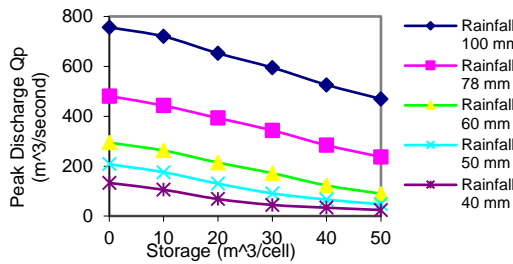


Fig.19 Peak of Flood (Qp) in various reservoirs with various rainfall.

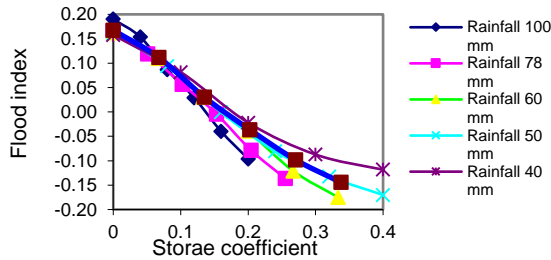


Fig. 20 Relation of Storage Coefficient and Flood Index with various Rainfall

The condition of the upstream Ciliwung watershed is 64 (Fig.21), meaning that the current watershed condition if experiencing rain will result in the flood peak being equal to if the upstream Ciliwung watershed consists of 64% of the forest and 36% of the settlement. After this value of 64%, an increase in settlement expansion is sensitive to the increase in the flood peak.

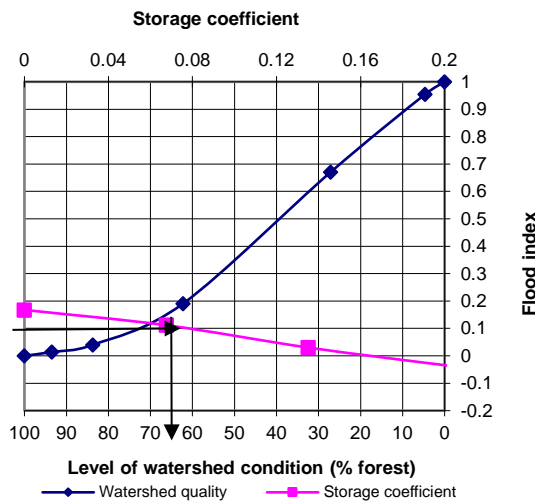


Fig.21 Nomographs for improving watershed conditions by providing detention reservoirs on residential land

4. CONCLUSIONS

1. DEM application and GIS combination with spatial distribution method (small element) could estimate peak flood better than lumped method ($Q = C.I.A$, where $A =$ total area) especially in the upstream which hilly topography.

2. Small watershed (cell element) has a unique behavior that is different in responding to the increase in flood peak in a non-linear manner to increase the depth rainfall.
3. Flood peak could reduce significantly by providing detention storage such as very small dam (embung) in each cell, the storage varies between 10-50 m³/cell (cell size 50m x 50m) and more significant if the depth rainfall increases.
4. The flood index and storage index is an important parameter to assess the watershed condition and as a direction for planning, watershed management based on land use planning (balance composition between % forest area and % settlement area).
5. The Nomographs flood index on watershed conditions and the storage coefficient can be used as standard operating procedures for managed watershed management, less flooding more water storage.

5. SUGGESTIONS

1. Follow up to deep study the relationship between flood index and storage coefficient for the values of storage coefficient of more than 0.4, is it asymptotic as seen in storage coefficient 0.3?
2. It is necessary to study the storm rainfall effect where the rainfall intensity is more than 200 mm/day or more than 250 mm cumulative 2 or 3 days
3. In this research, rainfall is considered evenly distributed throughout the watershed (uniform) even though the main purpose of a distributed system (cell system) is to also accommodate uneven rainfall which causes the various intensity rainfall in cells to be different. It can be future research to improve the results even now there happen phenomena of local rainfall.

6. ACKNOWLEDGMENTS

The authors wish to thank P3MI - ITB (Research, Community Service and Innovation Program) for good research collaboration.

7. REFERENCES

- [1] Amhar, F., DEM Geometry Quality from Interferometry Radar. Proceedings of the 8th MAPIN Annual Scientific Meeting: T1-T11, MAPIN, Jakarta,1999.
- [2] Sarminingsih., A., Soekarno, I., Hadihardaja, I.K., Syahril B.K., M., Flood Vulnerability Assessment Of Upper Citarum River Basin, West Java, Indonesia, International Journal of Applied Engineering Research ISSN 0973-

- 4562 Volume 9, Number 23, 2014, pp. 22921-22940.
- [3] Azmeri., Hadihardaja, I.K., Vadiya, R., Identification Of Flash Flood Hazard Zones In Mountainous Small Watershed Of Aceh Besar Regency, Aceh Province, Indonesia, The Egyptian Journal of Remote Sensing and Space Sciences, 2016, 19, 143–160.
- [4] Arnold, J.G., B.A. Engel, Dan R. Srinivasan., Continuous Time Grid Cell Watershed Model. Application of Advanced Information Technologies: Effective Management Of Natural Resources. 1993.ASAE Publication 04-93, 267-78.
- [5] Moore, LD., A.K. Turner, J.P. Wilson, S.K. Jenson, dan L.E. Band., GIS and Land Surface-Subsurface Process Modeling. Environmental Modeling with GIS, edited M.F, Goodchild, 196-230, New York: Oxford University Press, 1993.
- [6] Hession, W.c., V.O., Shanholtz, S., Mostahimi, T.A. Dillaha., Extensive Evaluation of the Finite Element Storm Hydrograph Model, 1987, ASAE Paper No. 87-2570.
- [7] Harlan, Dhemi., Hadihardaja, I.K., Kuntoro, A.D., Enung., Faturachman, D, Derivation Of The Critical Rainfall Level Needed For An Early Flood Warning In The Upper Citarum River Basin Indonesia, International Journal of GEOMATE, March., 2018 Vol.14, Issue 43, pp.167-174.
- [8] Olivera F., R. Raina, Development of Large Scale Gridded River Networks from Vector Stream Data. Journal of the American Water Resources Association, October 2003: 1235-1248.
- [9] Benavides, I.A., B. Pietruszewski, B. Kirsch., P. Bedient. Analyzing Flood Alternatives for Clear Creek Watershed a Geographic Information System Framework, 2001, Journal of Hydrologic Engineering.
- [10] Sutanahaji, T., B. Sulisty, Numerical Definition of River Drainage Area Networks from the Digital Altitude Model for Hydrological Models, Proceedings of the 8th MAPIN Annual Scientific Meeting: T1-TII, MAPIN, Jakarta, 1999.
- [11] Wolfe, M.L., C. Neale, Input Data Development for a Distributed Parameter Hydrologic Model (FESHM), Proceeding of the Modeling Agricultural, Forest, and Ranglan, Hydrology Conference, 462-69, 1988.
- [12] Nurcahyo, H., Soekarno, I., Hadihardaja, I.K., Rosyidie, A., Development Flow Duraton Curve For Criticality Assesment Of River Basin Applied At The Upper Citarum River Basin, Indonesia, International Journal of GEOMATE, Nov. 2017, Vol.13, Issue 39, pp.46-53
- [13] Chaidar, Ana Nurganah., Soekarno, I., Wiyono, Agung., Nugroho, Joko., Spatial Analysis Of Erosion And Land Criticality Of The Upstream Citarum Watershed., International Journal of GEOMATE, Sept. 2017, Vol. 13, Issue 37, pp. 133-140
- [14] Sutanahaji, T., I.K. Hadihardaya., Y. Suryadi, Flood Inundation Prediction using Altitude and Digital Map Models with Case Studies on the Ciliwung River. Proceedings of the XXI HATHI Annual Scientific Meeting (PIT): 331-343. HATHI, Denpasar, Bali, 2004
- [15] Sutanahaji, T., S. Legowo, Utilization of Geographic Information System (GIS) for Spatial Spread Hydrology Models. Proceedings of the VII Congress and HATHI XVIII Annual Scientific Meeting (PIT), Vol. 2:156-181. HATHI, Malang, 2001
- [16] Hasanudin, A, Effect of Land Use and Land Surface Conditions on Surface Flow Using Distributed Parameter Models, Dissertation of the Postgraduate Program, Parahyangan Catholic University Bandung, 2004
- [17] Sutanahaji, T., Hang Tuah, I.K. Hadihardaja., S. Legowo, Integration of Hydrological Models and Geographic Information Systems for Water Resources Management in Watersheds (Strategy and Application), Proceedings of the XXI HATHI Annual Scientific Meeting (PIT), 291-303, Denpasar, Bali, 2004.
- [18] Sutanahaji, T., A. Bagiawan, Operator Morpho-Hydrology on the Digital Altitude Model for River Basin Management and Planning. Proceedings of the VII Congress and HATHI XVIII Annual Scientific Meeting (PIT), Vol.2: 156-181, HATHI, Malang, 2001.