HYDROGRAPH SIMULATION AND FLOOD MAPPING USING REMOTE SENSING AND GIS IN CITARUM WATERSHED, INDONESIA

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ABSTRACT: Parts of Citarum watershed in Indonesia faces problem of flooding almost annually due to high rainfall. This problem is aggravating with a rapid landuse change and an increasing population over the recent years. In the years 2007 and 2010, there were severe floodings in the region contributing to major economic losses. The study used IFAS (Integrated Flood Analysis System), developed together by PWRI (Public Work Research Institute) and ICHARM (International Center for Water Hazard and Risk Management), Japan to compute the hydrograph at the outlet of the upper Citarum watershed in an objective to improve the discharge simulation for an accurate prediction of water availability and flood early warning system. A comparison was carried out for IFAS and the existing GR4J (Ge´nie Rural a` 4 parame`tres Journalier) model. For this purpose, ground based rainfall from 9 stations were used and the model was calibrated for the year 2005.The study was extended with the simulation of a flood model HEC-RAS (Hydrologic Engineering Centers River Analysis System) to map the flooded area for the year 2007. For this purpose two DEM (Digital Elevation Model)s were used to observe the difference in the flood extent. ALOS/PALSAR images were utilized to delineate the flood for the year 2010. IFAS showed a coefficient of efficiency of 51 percent for the year 2005. For the same year, GR4J achieved a coefficient of efficiency of 64 percent. The flood map achieved with the DEM generated from the contour and the local spot heights gave a better match for the extent on the ground. It also showed that a bigger area under flood was covering paddy of varying maturity. The flood extracted by the PALSAR images estimated about 57 km^2 for the year 2010 in the study area.

INTRODUCTION

The Citarum River, with a length of 269km and a basin area of 6,080km^2 plays an important role in the lives of the people of West Java. It is also one of the largest rivers in Indonesia. The river originates from Mount Wayang and flows through the middle of the Western part of the Java island finally its way to the Java Sea. The river besides working as a major support line for agriculture, electricity generation, fishery and water supply, acts as a carrier of sewerage of industrial and domestic use. So far, there have been three dams that have been built on the river to store water and generate electricity. They are Jatiluhur in 1963, Saguling in 1986 and Cirata built in1988. The watershed is divided into upper and lower parts. It receives an average annual rainfall of 2,300 mm. The Citarum River receives contribution of water from four major tributaries. These are Citarik, Cisangkuy, Cisokan, and Cipamingis. The main river of Citarum can be divided in three parts. The segment above Bandung is considered as the upper reach which lies in the mountain areas between Mount Tangkuban and Mount Patuha. The river between Bandung and Jatiluhur is the middle reach and after Jatiluhur is considered as the lower reach of the river. The whole watershed experiences problems related to water specially flooding and draughts in varying temporal and spatial dimensions. The major floods experienced were in the years of 1931, 1986, 1978, 2007 and 2010. The major areas affected during these floods were Bekasi, Purwakarta, karwang district and also the south of the Bandung City. These floodings were associated with destructive landslides and mud flows. In the upper watershed in the Bandung area, severe flooding and mud flows occurred in February 2005 affecting an area of 20km^2. The flooding submerged parts of the area for 7 days and up to 2 meters deep resulting in 50,000 inhabitants evacuated. Those flood prone areas were mostly the southern area of the city along the Citarum River. In the lower part, the flooding is experienced mostly in the Bekasi Town. It is attributed partially due to the converging floodwater from the two tributaries Cikeas and Cileungsi.

There is an existing rainfall runoff model GR4J on Citarum Hulu River Watershed. The area is 1,771 km^2 and is located at the lowland of Bandung. This study involves a comparison of the results from GR4J with IFAS for this watershed. For this purpose, ground based rainfall from 9 stations were used and the models were calibrated for the year 2005. The remaining part of the study was on the simulation of a hydrodynamic model HEC-RAS to map the flooded area in parts of the lower sub watershed. This has been done with the use of two sets of DEMs in order to see which one gives a better approximation of the real flood situation. For the study area, ALOS/ PALSAR images have been used to delineate the flood in the year 2010.

DESCRIPTION OF THE STUDY AREA

The study area is within the parts of the Citarum Watershed. It is roughly located within the co-ordinates of -5.92° to -7.24°Lat. (N-S) and 108.08° to 106.89°Long. (E-W).

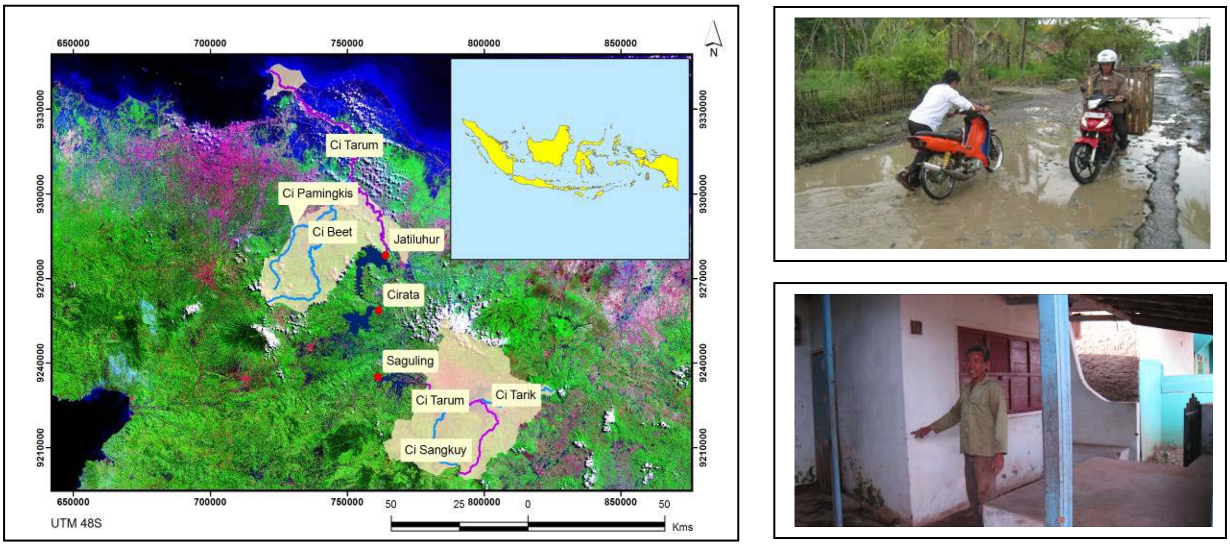

Figure 1: The study area showing a part of the problem in the lower sub watershed in the year 2010

It is divided into two sub watersheds namely the upper and the Lower Citarum as shown in Figure 1. The two major tributaries of the Citarum River in the upper part are the Cisangkuy and the Citarik with lengths approximately 32 kms each. A major tributary of the lower Citarum is the Cipamingis with a length of about 53 kms. Another river Cibeet joins the Cipamingis about 18 kms upstream from its confluence point with Citarum. The area experiences mainly two seasons namely rainy season and dry season. The rainy season occurs during the months of November to April, while the dry season occurs during the remaining months. The average annual rainfall varies from 1,500 mm in the coastal areas to 4,000 mm in the mountainous areas in the upper part of the watershed. January is the wettest month, while August is the driest month. The simulation of the IFAS was carried out in the upper sub watershed and the lower part was selected for the flood mapping. It is located at the lowland of Bandung and is surrounded by volcanic quaternary mountains. The elevations of these mountains surrounding the area are between 2,000 and 2,600m. The locations of the three dams in dots are shown in the Figure 1. The Saguling dam is located at the upstream reaches, the Cirata and the Jatiluhur is in the middle reaches. The Jatiluhur dam besides being the main hydropower source in the region, also releases water for irrigation to Subang, Cikampek, Karawang and Bekasi areas which are some of the main rice producing areas of west Java.

Brief Description of the Model IFAS

IFAS is a distributed hydrological model to calculate runoff from a watershed. The model makes use of rainfall data, topographic data, landuse landcover information, soil and geological information that is either ground based or satellite derived. It has the advantage as runoff analysis can be applied to basins with insufficient hydrological and geophysical information (Sugiura T., 2009). In Version 2 of the PWRI distributed Hydrological model, the vertical direction is classified into two tanks. The upper tank or the surface tank simulates the surface flow, rapid intermediate flow or subsurface flow and percolation to the groundwater tank. The groundwater tank simulates the unconfined groundwater flow. River flow or river discharge is simulated by flow between the river channel tank using kinematic wave method.

Brief Description of the Model GR4J

GR4J is a rainfall runoff model based on the four parameters of the daily rainfall data. It is the recent version of GR3J proposed by Edijanto and Michel and improved upon successfully by Nascimento and Edijanto (Harlan D., 2010). The four parameters used by this model are-
Maximum capacity of the production store (mm), Groundwater exchange coefficient (mm), Maximum capacity of routing store (mm), Time peak ordinate of hydrograph unit UH1 (day).
To evaluate the quality of discharge simulation, coefficient of efficiency is calculated as shown in Equation1 given by (Nash and Sutcliffe, 1970)

$$CE = 1 - \frac{\sum_{i=1}^{n}\left(Q_{obs_i} - Q_{sim_i}\right)^2}{\sum_{i=1}^{n}\left(Q_{obs_i} - \overline{Q_{obs}}\right)^2} \qquad \text{Equation 1}$$

CE : *Coef. of efficiency (CE <1.0)*

Q_{obs} : *Observed discharge*

Brief Description of the Model HEC-RAS

HEC-RAS is a one-dimensional hydrodynamic model developed by U.S. Army Corps of Engineers that can simulate open channel, steady or unsteady flows. For steady flow, it uses the continuity equation which is the basic law for conservation of mass and allows one to track the change in velocity and cross sectional area from one location to other.

It is expressed in Equation 2

$$Q = A_1 V_1 = A_2 V_2 \qquad \text{Equation 2}$$

Q = the flow rate (m^3/s)
A = cross-sectional area (m^2)
V = average velocity for the cross-section (m/s)

For unsteady flow, the continuity equations cover how the flow will vary in both time and space. These equations are called the St. Venant Equations. The final equations required to define flow behavior are called the energy equations. It is a modified version of the Bernoulli energy equation. The equation essentially states that the sum of the kinetic energy plus the potential energy at a particular location is equal to the sum of the kinetic and potential energy at any other location, plus or minus energy losses or gains between those locations.

OBJECTIVES

There were mainly two objectives this study wanted to achieve. The first one was the simulation of the hydrological model IFAS for the upper sub watershed and compare the results with the existing GR4J model. The second objective was to simulate the model HEC-RAS in Citarum River in the lower sub watershed.

METHODOLOGY

A schematic diagram of the methodology in brief is shown in the Figure 2. Globally available data like elevation from GTOPO 30, landcover from Global Map with 30 sec. resolution and rainfall data from 9 ground based stations were used for the initial simulation of the IFAS for the year 2005. The model was tuned for the observed discharge from the same year.

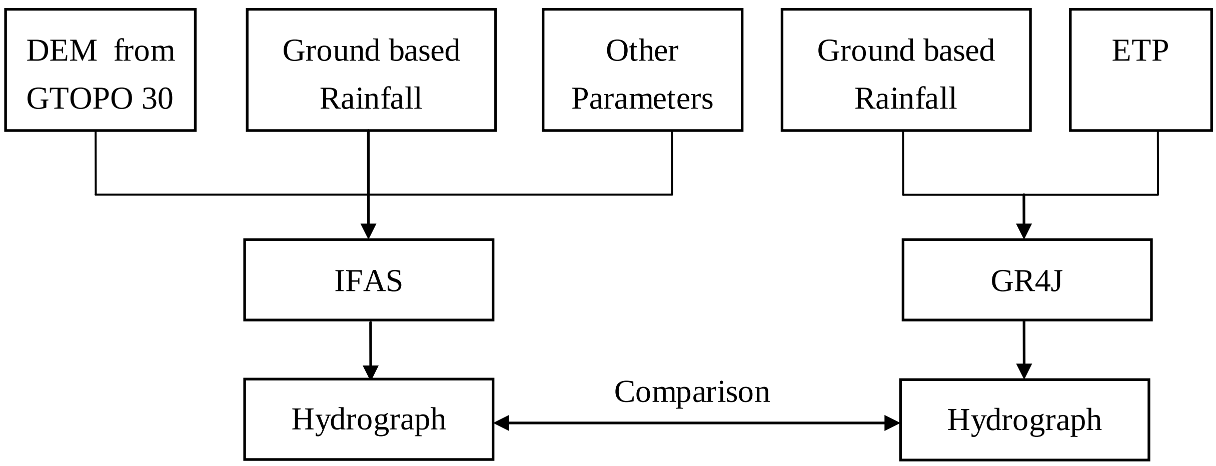

Figure 2: Schematic diagram of the methodology of hydrograph simulation

In case of IFAS, two parameters of aquifer i.e. HCGD (unconfined ground-water outflow retention amount) and HIGD (initial value for calculation) had been optimized manually by iteration process. In case of GR4J model, four of its parameters were optimized for hydrological event from 1 Jan. –31 Dec. 2005.

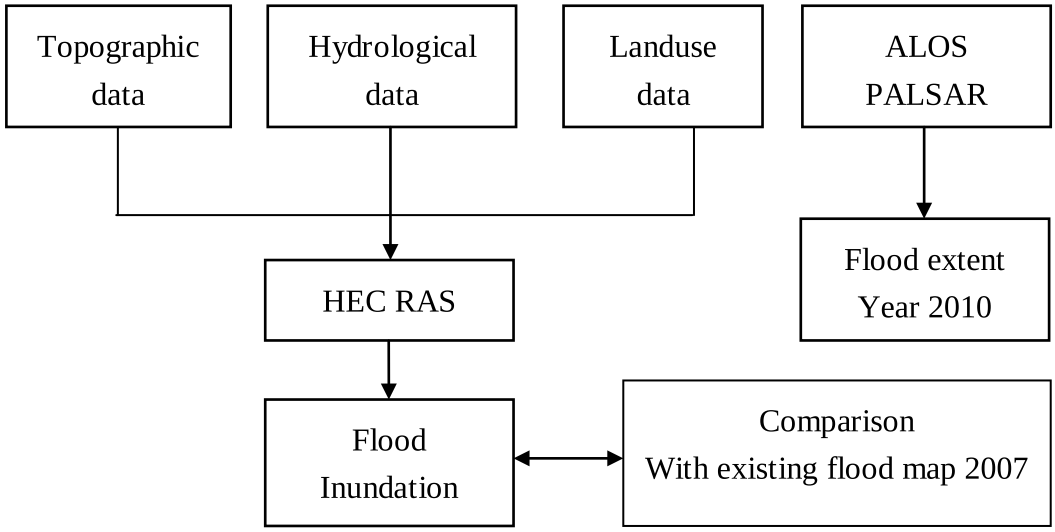

Figure 3: Schematic diagram of the methodology of flood mapping

HEC-RAS was simulated for the maximum discharge for the year 2007 for the lower sub watershed. The topography for the model was built by using ASTER DEM and the bathymetry surveyed at three cross sections in the Citarum River. Contour derived from 1:25,000 maps and spot heights were also used for creating a DEM. The output of the model was verified in extent by overlaying it with the existing flood map for the year 2007 in the study area. ALOS/AVNIR2 image of the area was used for land use classification which was further used to delineate Manning's Roughness Coefficient necessary for the model. ALOS/PALSAR images of pre and post flood were used for the flood area delineation in the year 2010 using different threshold of decibel values.

RESULTS

The results show that with the initial default parameters, two models IFAS and GR4J produced outputs with efficiency of 48% and 57% respectively. The flexibility of models was tested by tuning the parameters to get a better simulation. For a period of hydrological cycle from 1 Jan. –31 Dec. 2005, GR4J model gave a better simulation than IFAS with efficiency of 64% and 51% respectively. The Figure 3 shows the results of the simulated vs. the observed flood hydrographs for the upper sub watershed after the final tuning of these models for the period of 2005. In the inundation model, a scenario was created for the flood event of 4 Dec, 2007. The extent was compared with the existing flood map of the same period. The result in Figure 5 shows an area of $96km^2$ and $105km^2$ to be under flood. A further analysis from a landuse map derived from a satellite image of AVNIR2 showed that paddy of different maturity was affected by the flood water of various depths as shown in the Table1. ALOS/ PALSAR images of dates 19 January and 26 March, 2010 were used in extracting the flooded

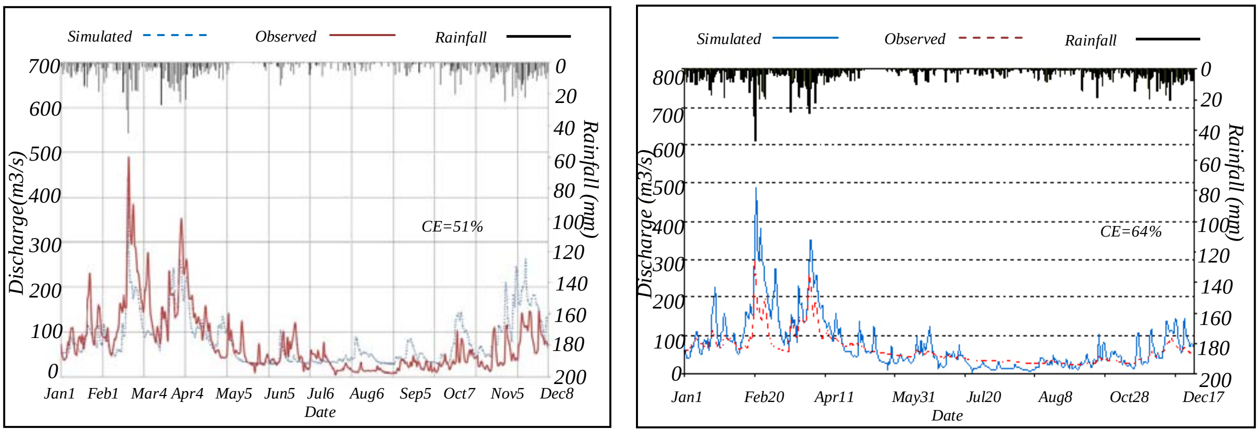

Figure 4: Results of the simulated vs. observed hydrographs for year 2005, IFAS and GR4J

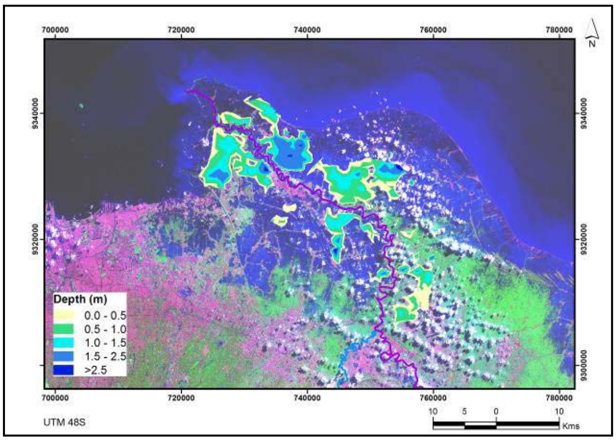

Figure 5: Flood extent December 4, 2005, HEC-RAS

Table1: Landuse affected by the flood of 2007, as by the model

Area Under flood (km^2)	
Paddy (<1)month	2
Paddy (2-3)months	29
Paddy (3-4)months	45
Settlements	20
Total	96

area using the methodology of applying threshold of the backscatter values. It was found that about 57 km^2 area was under flood when a threshold of 3 decibel was used. Figure 6 shows the flooded area derived from these images.

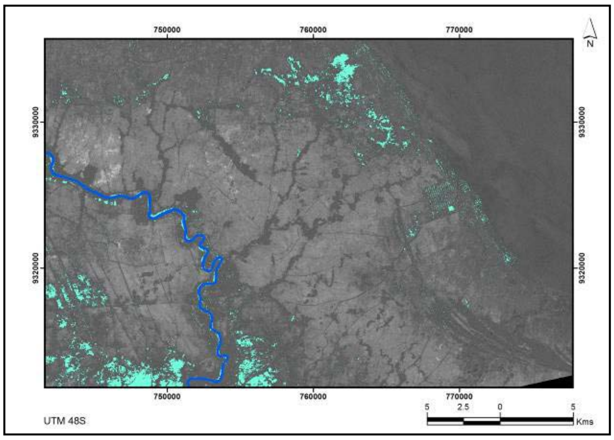

Figure 6: Flood extent March 26, 2010, derived from ALOS/ PALSAR

CONCLUSION

IFAS was tested in the study area for the year 2005 with globally available dataset and rainfall from 9 rain stations in the watershed. When compared with the established GR4J model, it gave a less accurate result with the observed data for that period. From the output of HEC-RAS, an impression was achieved that there remains a need of a further improvement in the satellite derived DEM specially for a hydrological application like the one in the study.

ALOS/PALSAR proved to be a quick and a good way to delineate flooded area with the methodology used in the study.

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