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LAND USE SCENARIO MODELLING FOR FLOODS MITIGATION IN BEDADUNG WATERSHED, EAST JAVA INDONESIA

ADELIA N. I. KARTIKASARI, GUSFAN HALIK*, RETNO U. A. WIYONO

Civil Engineering, Universitas Jember,
Jl. Kalimantan Tegalboto No.37, Jember, Jawa Timur, Indonesia
*Corresponding Author: gusfan.teknik@unej.ac.id

Abstract

The 2019 dry season in Bedadung watershed caused a catastrophic forest fire. The fires caused a significant reduction in forest area in a short period. As a result, there was an increase in downstream discharge when entering the rainy season. This study aims to determine the impact of land use change towards floods and the boundary of optimal land use in the flood management framework, and then it can be used as a basis for designing flood disaster mitigation strategies due to changes in land cover. The land cover map used as input flood model was obtained from the processing of Landsat-8 satellite imagery, meanwhile modeling of flood response to land cover changes was carried out using the SWAT model. After knowing the flood discharge response to land cover, the simulation process was carried out by making several land cover scenarios to find the appropriate and optimal land cover area. The results showed that the calculation of flood discharge after the calibration process resulted in the NSE and R^2 values of 70.7% and 0.709, meanwhile the validation values of NSE and R^2 were 82.1% and 0.88, respectively. The simulation of land-use scenarios shows that the optimal land cover condition of the Bedadung watershed is to use a scenario of 30% forest area of the total watershed area.

Keywords: Floods, Land use scenario, Remote sensing, SWAT.

1. Introduction

Climate change has an impact on changes in rainfall and discharge patterns in Indonesia [1]. In addition, changes in land use also have an impact on increasing flow rate. Land-use change is one factor that affects hydrological conditions and is a problem faced by the earth [2]. Increased population growth rate, development of residential areas, plantation areas, regional spatial planning patterns, and several natural disasters have resulted in changes in land use [3].

Changes in land use occurred in the Bedadung watershed Jember Regency, a watershed area of 1383.96 km^2. This change can be seen in the decrease in forest area as a catchment area of 47.98 km^2 for 17 years from 2001-2017 [4]. The National Aeronautics and Space Institute's Fire Hotspot data noted that a large fire occurred in the Bedadung watershed, precisely in the upper watershed on 19-22 October 2019, caused by a prolonged drought [5], this resulted in a significant loss of forest land cover in a short time. According to Saha, the changes in land cover in upstream have more impact on river flow than land cover changes located downstream [6]. One of the impacts of land-use changes is reducing water catchment areas, increasing surface runoff [7]. The impact of the decline in forest area in the Bedadung watershed is an increase in surface runoff when entering the beginning of the rainy season, as seen from the flood event on February 1, 2020, in Klungkung Village. This incident caused a bridge connecting Kalijompo plantation factory to be heavily damaged, 25 residents' houses submerged in mud, and one resident was injured [8]. Then the flood again occurred at the beginning of the rainy season in 2021, to be precise on February 26, 2021, which resulted in 143 houses being submerged and one bridge collapsed [9].

Bedadung watershed is the largest watershed in Jember Regency, an urban center area and densely populated area [10]. If a flood disaster occurs in the Bedadung watershed, many individuals will be affected by this disaster. Therefore, research is urgently needed on the impact of land use changes on the resulting flood discharge to produce an optimal land use management boundary within the framework of flood management. Based on J. Barredo's research in 2010 on land use scenario models for flood mitigation, there is a dynamic response between land use and flood modeling [11]. The general objective of this research is to assess the impact of land-use change on the flood peak and its mitigation strategy in the Bedadung watershed, Jember Regency. In contrast, the specific objectives of this research are 1). modeling the impact of land-use change on peak floods, 2). The assessing the impact of land-use change on the rise of the flood, 3). determine the boundaries of optimal land use management within the framework of flood management, 4). designing a flood mitigation strategy in the Bedadung watershed. The study results can be used to identify flood-prone areas and can then be used to develop flood disaster mitigation strategies of land cover changes.

2. Methods

This research method consists of the study's location and time, the data needed, and the data processing and flood modeling.

2.1. Location and time of research

The study was conducted from 2017 until 2020 in the Bedadung Watershed located in Jember Regency. Geographically, the location of Bedadung watershed is 7^0 58'

8" until 8^0 23' 31.872" south latitude and 113^0 35' until 113^0 28' 26.514 " east longitude. The research location is presented in Fig. 1.

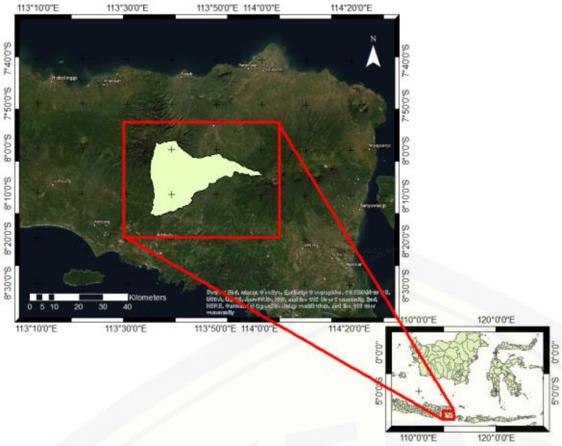

Fig. 1. Research location.

2.2. Data collection

Data collection was done by looking for secondary data from related agencies and satellite imagery data processing. The data needed in the study are described in Table 1.

Table 1. Data needed in the study.

Data	Data Type	Data Source	Note
DEM	Spatial	BIG	
Land Cover Map	Spatial	USGS	Landsat-8 Satellite Image Processing Results in 2017
Soil Type Map	Spatial	Ministry of Agriculture	
Slope Map	Spatial	BIG	DEM Processing Process
Rainfall Data	Non-Spatial	Department of PU BMSDA Jember Regency	Rainfall in Bedadung Watershed in 2008-2019
Discharge Data	Non-Spatial	Department of PU BMSDA Jember Regency	Bedadung Watershed Discharge 2008-2019
Climatological Data	Non-Spatial	Kaliwining Research Garden, Puslitkoka Jember	Bedadung Watershed Climate Data for 2008-2019

2.3. Data processing

This research begins with processing Landsat-8 satellite imagery and then continues with the flood modeling using Soil Water Assessment Tools (SWAT) to know the flood response of land-use changes. The methodology of this research is described in Fig. 2.

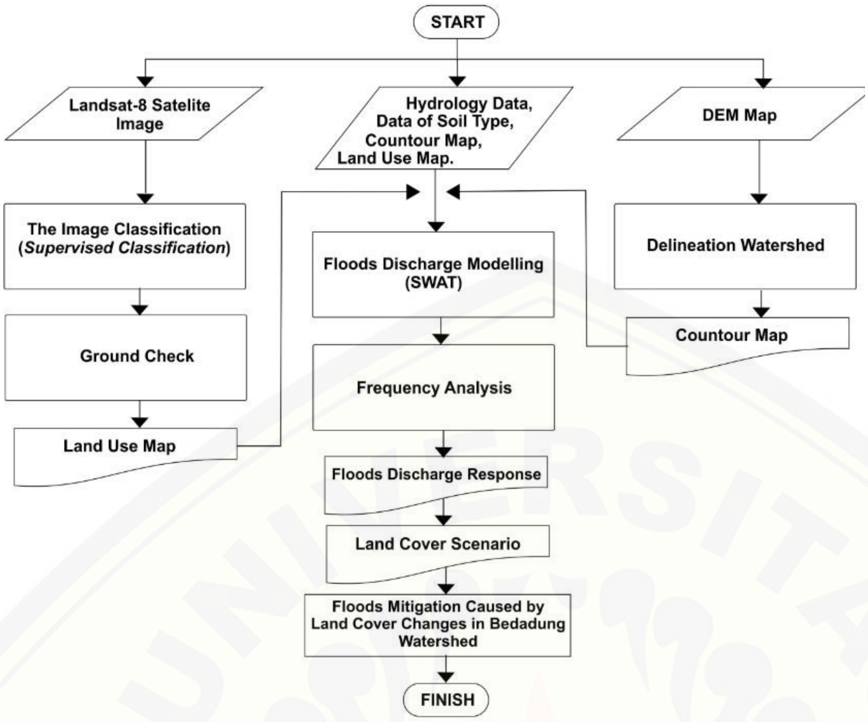

Fig. 2. Research methodology.

2.3.1. Land use management

Land use processing is carried out by remote sensing using Landsat-8 satellite imagery. This processing is carried out by supervised classification, namely the process of grouping land use by determining the training area. The expected output in this process is an input data in the form of an updated land use map. The map that has been generated is then calculated for accuracy with the accuracy of "Kappa". “Kappa” accuracy is a discrete multivariate technique used in assessing the accuracy of the contingency matrix [12]. The following is the formula for “Kappa” Accuracy [13]:

$$Kappa = \frac{N\sum_{i=1}^{r} Xii - \sum_{i-1}^{r} X_{i+}X_{+i}}{N^2 - \sum_{i=1}^{r} X_{i+}X_{+i}} 100\% \quad (1)$$

If the accuracy results are adequate, the land use map can be used as input in the flood discharge modeling process with SWAT.

2.3.2. Flood discharge modeling

Flood discharge modeling is a process to obtain flood discharge response. This process is carried out by creating a flood model with a data period from 2008 to 2019 using the Soil Water Assessment Tool (SWAT). The flow response of

Bedadung watershed is modelled based on rainfall, land use, and slope. Then calibration and validation are carried out to get the reliability of the model. Test the model's reliability using the NASH-Sutcliffe Criterion (NSE) and Coefficient of Determination (R^2). The calculation of flood discharge in ArcSWAT is showed in the flow chart of the SWAT computer program in Fig. 3.

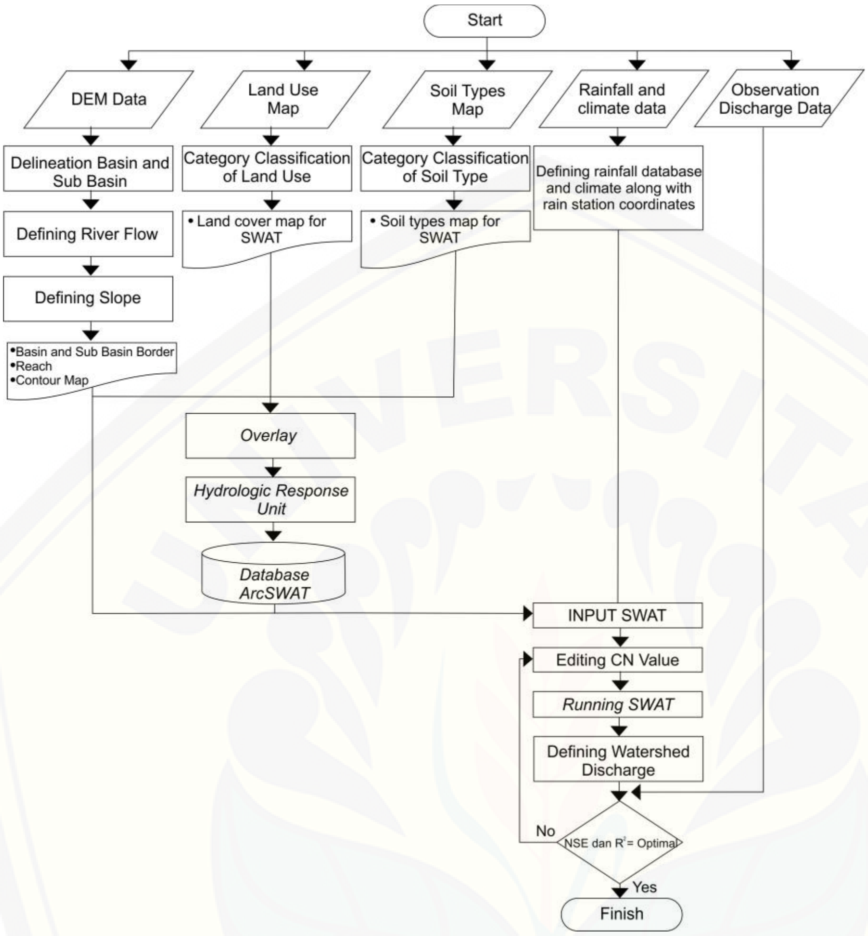

Fig. 3. SWAT computer program flowchart.

2.3.3. Assessment on the impact of land use change

In this process, analysis was carried out using the Geospatial Information System (GIS). This process is carried out by looking for critical sub-basin areas or those that contribute to the increase in discharge. Then, data will be obtained for the decrease in flood discharge that is influential.

2.3.4. Formulation of flood disaster mitigation strategy

Based on the previous assessment results, it was found that areas or sub-basins that have a significant role in increasing flood discharge, then a flood mitigation strategy will be planned with technical and non-technical approaches. The non-technical approach uses simulations of several land-use scenarios. The intended design is to increase the percentage of forest area in Bedadung watershed, which can later be used as a reforestation action plan. Then from several planned scenarios, the most optimal land-use scenario can be searched and can later be used as a guideline for watershed management. The Jember Regency Regulation guides the land-use scenario planning in this study on the 2015-2035 Regional Spatial Planning, a forest area planning of 27% of the Bedadung watershed area [14]. Therefore, this study will conduct a land-use scenario with the percentage of forest area close to the guidelines for the Jember Regency Spatial Plan.

3. Results and Discussion

The impact of land cover changes can be seen from the flood discharge response. Making a flood simulation model and a land cover scenario simulation makes it possible to know the appropriate and optimal land cover area. Furthermore, it will be discussed further in the results and discussion.

3.1. Results

The results of this study discuss DEM processing, land use, and flood modeling.

3.1.1. DEM processing results

The watershed boundary in the model is obtained from the National DEM, Fig. 4.. The national DEM is built from several data sources, including IFSAR data (5 m resolution), TERRASAR-X (5 m resolution), and ALOS PALSAR (11.25 m resolution), by adding the stereo-plotting Masspoint data. The spatial resolution of DEMNAS is 0.27- arcsecond, using the vertical datum EGM2008.

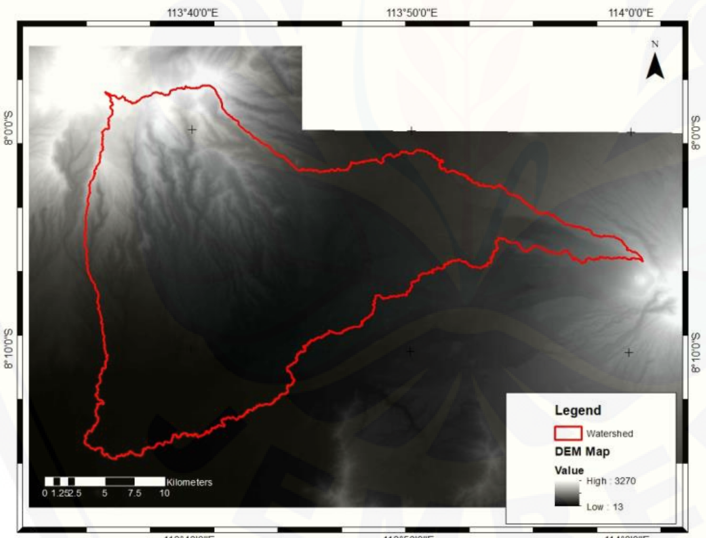

Fig. 4. DEM Bedadung watershed.

3.1.2. Land use processing results

Based on Landsat 8 satellite imagery processing, the kappa accuracy value is 81%, the kappa accuracy is said to be good if it has a value > 80% [15]. Land use in 2017 is shown in Fig. 5.

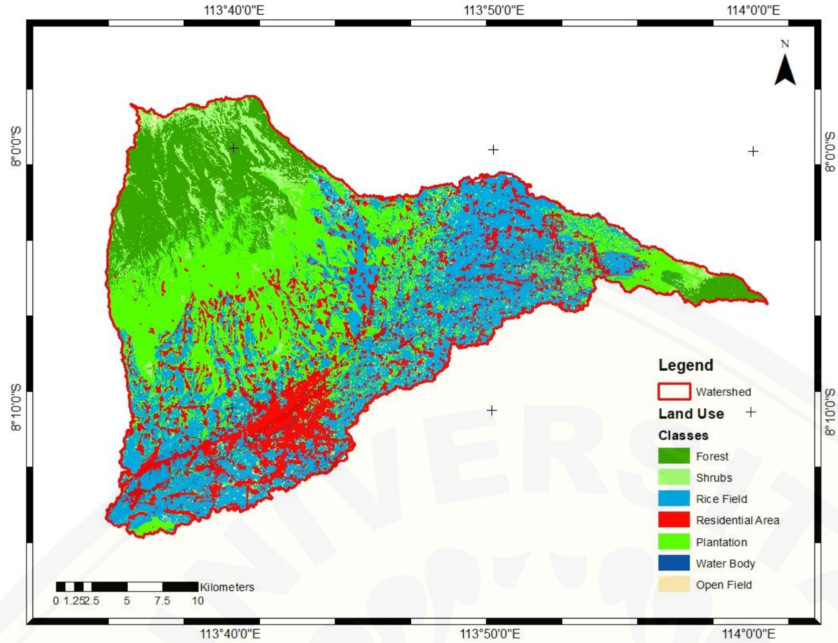

Fig. 5. Land use map 2017.

The area of each type of land use in the Bedadung watershed in Fig. 5 is described in Table 2.

Table 2. Land use 2017.

Land Use Type	Area (km^2)	Area (%)
Forest	99.26	14.94
Shrubs	45.27	6.82
Rice Field	218.88	32.95
Residential Area	107.58	16.20
Plantation	189.78	28.57
Water Body	2.02	0.30
Open Field	1.46	0.22

The results of land use processing showed that the Bedadung watershed is dominated by rice fields, which is 32.9% of the total watershed area of 664.25 km^2.

3.1.3. Flood discharge modelling results

Based on the results of the delineation process in the ArcSWAT program with outlet points at 8°13'49.12" south latitude and 113°35'2.94" east longitude, Bedadung watershed has an area of 664.25 km^2 and consisting of 29 sub-watersheds that are automatically formed by the program ArcSWAT. Synthetic river networks and other parameters were also obtained from the ArcSWAT program using DEM maps. The results of the delineation can be seen in Fig. 6.

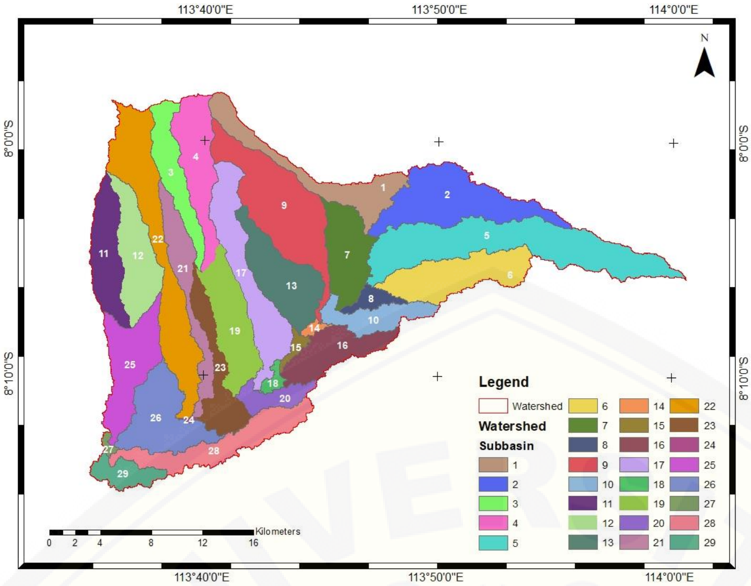

Fig. 6. Watershed and sub-watershed boundaries.

3.2. Discussion

This discussion consists of calibration and validation of the SWAT model, the study of the impact of land cover changes, and the flood mitigation strategy.

3.2.1. Calibration

In this study, the discharge model was selected in a normal rainy year. Based on data "Cold & Warm Episodes by Season" National Oceanic and Atmospheric Administration (NOAA), Normal years include 2012, 2013, 2014, and 2017 [16]. The SWAT simulation results before being calibrated have the Nash-Sutcliffe Criterion (NSE) and Coefficient of determination (R^2) values of 54.1% and 0.598, respectively.

The calibration process uses discharge data from the 2017 model year compared with the observed discharge data in 2017, while other normal rainy years are used to validate the model. Before the calibration process, the calculation of flood discharge resulted in a model reliability value of 54.1% with a maximum discharge of 470.9 m^3/s which occurred in 2017 with an average rainfall of 86.02 mm. Compared with the observation discharge in the same month, the modeling discharge is greater than the observation data, 240.73 m^3/s.

Several studies have revealed that each region has different river characteristics and there are several sensitive parameters that must be adjusted based on the characteristics of the river itself [17]. Therefore, it is necessary to look for river parameters that affect the discharge in Bedadung watershed. According to the Technical Guidelines for Utilizing Hydrological Models in Indonesian Watershed Management, several sensitive parameters must be calibrated to obtain more accurate model reliability [18]. Marhaento's research entitled "Hydrological response to future land-use change and climate change in a tropical catchment" shows that there are several sensitive parameters for rivers in the tropics, namely CN2, SOL_AWC, ESCO, CANMX, GW_DELAY and GW_REVAP [19]. Base on the several parameters tested in this study, six parameters are susceptible to the Bedadung watershed which are described in Table 3.

Table 3. Parameter in SWAT model.

Code	Parameter	Range	Fitted Value
CN2	Surface Flow Curve Number	35-98	64
ESCO	Soil Evaporation Factor	0-1	1
GW_DELAY	Groundwater Delay Time	0-500	93
CH_K2	Main Line Hydraulic Conductivity	0-150	80
GWQMN	Threshold depth of water in the shallow aquifer	0-500	50
CH_N2	Manning's value for the main channel	0-1	0.025

After the sensitive parameters in SWAT were calibrated and validated, the NSE and R^2 values were 70.1% and 0.709, respectively.

3.2.2. Validation

Validation is carried out to assess the reliability of the model using optimum parameters. This is done to see the reliability of the model in other years. Based on the validation results, the NSE and R^2 values were 82.1% and 0.88, respectively. The scatter plot of performance on validation step is shown in Fig. 7.

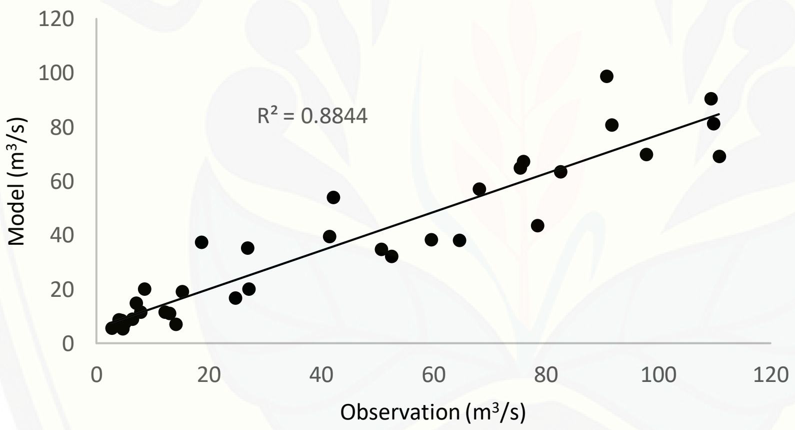

Fig. 7. Scatter plot validation step.

The model have good performance if the Nash-Sutcliffe coefficient is 0.65 <NSE and R^2 >0.7 [20, 21]. With the reliability of the model 82.1%, the maximum discharge was 232.8 m^3/s in 2017. It shows that the maximum discharge of the model is close to the maximum discharge of observation, which is 240.73 m^3/s. After calibration, the results of model reliability showed that the flood discharge in the modeling could approach the observed flood discharge pattern. Therefore, the SWAT model can be used to estimate flood discharge in the simulation process of several scenarios of land-use change in the Bedadung watershed.

3.2.3. Assessment on the impact of land cover change

Assessment on the impact of land cover changes on flood response was carried out through a simulation process with several land cover scenarios. The planned scenario is to add the percentage of forest area to the watershed area. Therefore, suitable and optimal land cover can be found and can be used as the basis for managing the Bedadung watershed.

Land cover that can be planned to become forest is land cover other than settlements and rice fields. Based on the existing conditions, rice fields and settlements in the Bedadung watershed are 49.2% of the watershed area.

The scenario of adding the percentage of forest area for each scenario is described in Fig. 8.

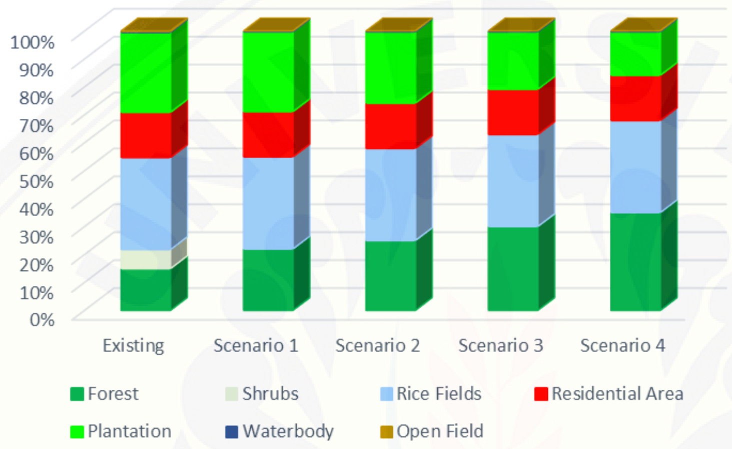

Fig. 8. Land use scenario.

The area of each type of land use scenario in Fig. 8 is described in Table 4.

Table 4. Land use scenarios.

Land Use Type	Existing Condition	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Forest	15%	20%	25%	30%	35%
Shurbs	7%	0%	0%	0%	0%
Rice Field	33%	33%	33%	33%	33%
Residential Area	16%	16%	16%	16%	16%
Plantation	29%	29%	26%	21%	16%
Water Body	0%	0%	0%	0%	0%
Open Field	0%	0%	0%	0%	0%

The decrease in discharge from some scenarios shows that land use is one factor causing significant flooding. It is in line with the previous research result by Jodar-

Abellan et al. explained that the increase of flooding risk in watersheds is caused by the changes in land use [22]. The relationship between the percentage of forest area and the discharge response is described in Fig. 9.

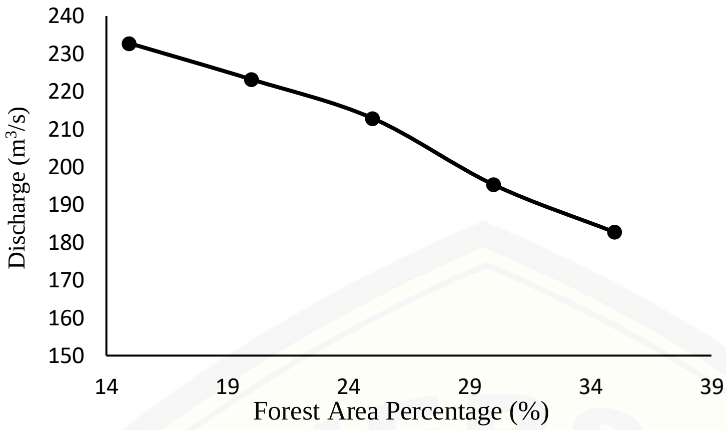

Fig. 9. Relationship between forest area percentage and flood discharge.

The forest area of each type of land use scenario in Fig. 9 is described in Table 5.

Table 5. Relationship between forest area and peak flow.

Land-use	Forest Area (%)	Peak Flow (m^3/s)	Water Level (m)
Existing	15%	232.8	2.17
Scenario 1	20%	223.2	2.11
Scenario 2	25%	212.9	2.05
Scenario 3	30%	195.3	1.93
Scenario 4	35%	182.7	1.85

Flood responses in each scenario are described in the simulated flood discharge graph in Fig. 10.

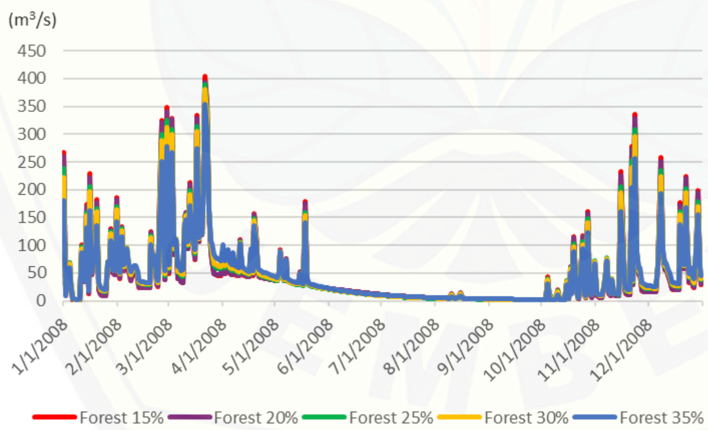

Fig. 10. Simulation of flood response.

Based on data from the Department of Public Works for Water Resources in Jember Regency, there are criteria for determining flood alert conditions at the outlet points of the Bedadung Watershed, which are described in Table 6.

Table 6. Bedadung watershed flood alert condition.

Flood Alerts	Water Level (m)	Peak Flow (m^3/s)
Green Alerts	0-2	0-205
Orange Alerts	2-4	205-580
Red Alerts	> 4	> 580

The orange alert condition in Bedadung DAM is a discharge of more than 205 m^3/s with a water level of more than 2 meters. Therefore the existing peak discharge in the Bedadung watershed is included in the orange alert category. Based on the simulation results, the appropriate scenario used is scenario 3. Because scenario 3 reduces the discharge by 37.5 m^3/s, it makes the peak discharge in the Bedadung watershed decrease to 195.3 m^3/s from the orange alerts category to green alerts.

3.2.4. Flood mitigation strategy

Jember Regency Spatial Planning (RTRW) has a forest area plan supporting scenario 3 to be implemented in the Bedadung watershed. Scenario 3 can be applied in line with the RTRW of Jember Regency, but in areas experiencing deforestation, it is necessary to carry out a flood mitigation strategy with upstream reforestation programs. Therefore the existing conditions can be following the RTRW and Scenario 3 that have been planned. The comparison of Scenario 3 with the RTRW of Jember Regency is described in Fig. 11.

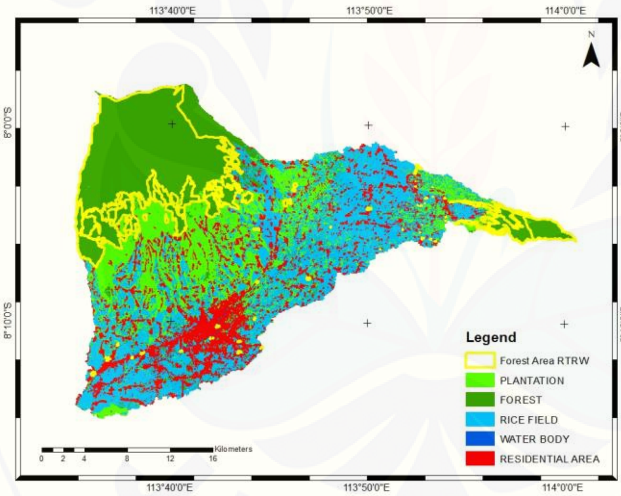

Fig. 11. RTRW forest area and Scenario 3.

Based on the modeling results on ArcSWAT, the Klatakan Sub-watershed, Kalijompo Sub-watershed, and Kaliwates sub-watersheds contributed significantly to the damage to the watershed. It is in line with the guidelines for flood-prone areas in RTRW of Jember Regency [14]. In addition to increasing the forest as a catchment area in Bedadung watershed, it is also necessary to carry out other flood mitigation strategies, namely by making an Early Warning System and education about flood disasters for people living in flood-prone areas. Figures of Sub-watersheds and flood natural disaster areas according to the RTRW of Jember Regency are described in Fig. 12.

Based on Fig. 12 show that the Bedadung watershed have a critical lands and flood-prone areas, including Klatakan Sub-watershed, Kalijompo Sub-watershed and Kaliwates Sub-watershed.

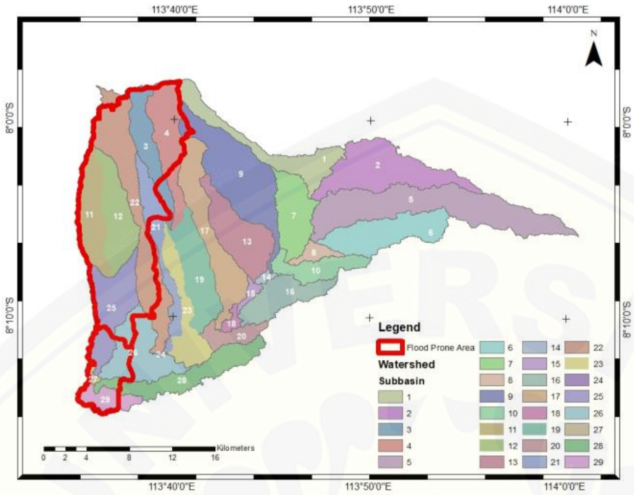

Fig. 12. Sub-watersheds and flood disaster areas.

4. Conclusions

This research resulted in several important points from the analysis results that had been done previously, namely:

- The land cover condition of the existing Bedadung watershed provides a response to peak flood discharge in the orange flood alert category. Therefore, optimal watershed management is needed to not rise to the red flood alert category.
- The scenario of 30% forest areas will provide the most optimal control in the Bedadung. The forest area of the Bedadung watershed is 15% of the total watershed area, so it is necessary to conserve critical land by 15% of the entire watershed area to reach optimal Bedadung watershed management.
- Mitigation strategies for the impact of land cover changes on flood response in the Bedadung watershed are focused on conservation on critical lands and flood-prone areas, including Klatakan Sub-watershed, Kalijompo Sub-watershed and Kaliwates Sub-watershed.

Nomenclatures

N	Total number of observations
R^2	Coefficient of Determination
r	Number of rows and columns in the error matrix

X_{+i}	Marginal total of row i
X_{i+}	Marginal total of column i
X_{ii}	Observation in row i and column i

Abbreviations

BIG	Geospatial Information Agency
DEM	Digital Elevation Model
NOAA	National Oceanic and Atmospheric Administration
NSE	Nash-Sutcliffe Coefficient
PU BMSDA	Department of Water Resources Jember District
RTRW	Jember Regency Spatial Planning
SWAT	Soil Water Assessment Tools
USGS	United States Geological Survey

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