Predicting flood hazards area using SWAT and HEC-RAS simulation in Bila river, South Sulawesi

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Predicting flood hazards area using SWAT and HEC-RAS simulation in Bila river, South Sulawesi

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Abstract. Sidrap Regency is one of the special economic zones in South Sulawesi. It has been growing rapidly from rural land to an industrial city since mid-2005. With the process of urbanization, flooding has become a threat to the security of the city area. In this study, Bila River basin in Sidrap Region was selected to investigate the effect of urbanization on surface runoff and peak discharge. The methodology involved hydrology database building, a detailed Digital Elevation Model (DEM), a land use cover and a soil map of the basin. With all these data, the SWAT model (Soil and Water Assessment Tool) was used to predict discharge values. These discharge values were used, along with the DEM, to predict flood hazard areas in the Bila river basin floodplains. This procedure was made using the HEC-RAS model (Hydrological Engineering Centre-River Analysis System). The results of SWAT Model showed that changes in land use had a significant impact on increasing river discharge. The results of HEC-RAS show that with a planned flood of a return period of 10 years (840 m³/s) can cause flooding on Bila River, because the existing capacity for this river is 412.70 m³/s.

The study shows the 2D capability of the new HEC-RAS 5 for flood inundation mapping and management studies.

Keywords: flood Hazards, Normalization, Embankment, AVSWAT 2000, HEC-RAS 4.1.0

1. Introduction
Flooding is a natural phenomenon that can cause loss of wealth as well as casualties. A flood is said to be occurring if there is water overflow due to lack of channel cross-sectional capacity. Floods in upstream regions usually have heavy flow and big scouring, but a short duration, while in downstream regions, the flow is not heavy because of the slight slope, but the flood duration is long [6].

Area development is to fulfil various needs such as residential facilities, agriculture, trade, industry, offices, roads and others. This has increased from year to year because of population growth and development activities, and causes a decrease in the quality of the environment, including reductions in the quality of the watershed as well as calamities that cause losses, the most obvious of which are droughts in the dry season and floods the in rainy season [1].

This condition occurs in the flow of Bila River, marked by phenomenon around the Bila River such as reduced river capacity, increased flood discharge, and overflowing of Bila River and tributaries,
resulting in damage to public facilities, agriculture, plantation, and residential areas, as well as disruption of traffic on the Trans-Sulawesi Highway. The condition becomes worse as scouring of river flow causes embankment damage that threaten important facilities around it. The purpose of this study is to determine the effect of changes in land use in Bila Watershed on flood discharge, and calculate the flood discharge plan for various periods and capacity of the Bila River reservoir, to provide an alternative to handling Bila River flood [2].

The benefit of this study is that the results of this study can help the parties involved in handling Bila River. In the research area, in an effort to manage watersheds in an integrated and sustainable manner, the results of this study can provide information to the public about flood-prone areas, which is expected to instil awareness and active participation in preserving the watershed ecosystem.

2. Material and Methods
Geographically, Bila Watershed is located within 4°52’04” – 5°03’04” East Latitude and 120°01’35” – 120°10’29” East Longitude. The watershed has an area of 1029.31 km² and the length of the main river is 64 km. Administratively Bila Watershed is located in Sidrap Regency, Enrekang Regency, and Wajo Regency, which can be seen in Figure 1.

![Figure 1. Map of Study Location](image)

The following are the data used in this study:
- Rainfall data for the years from 2000-2014
- Bila River AWLR discharge data for the years from 2000-2014
- Climatology data
- Indonesian topography map with a scale of 1:25.000
- Land use map for the years from 2000 – 2013, with a scale of 1:25.000
- Bila River geometry data
The method used in the assessment of this study is AVSWAT 2000 simulation and HEC-RAS 4.1.0.

3. Results and Discussion

Determining of Bila Watershed Boundaries
The study area boundaries in this research were based on the watershed hydrological area. The watershed boundary in this study was determined with the help of ArcView GIS 3.3 software, as shown in Figure 2.

Rainfall Data
The rainfall data used in this study were rainfall data over a period of 15 years, from 2000 to 2014. The three rain stations can be seen in Table 1 below.

<table>
<thead>
<tr>
<th>ID</th>
<th>Name of Rain Station</th>
<th>YPR</th>
<th>XPR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maroangin</td>
<td>9583163</td>
<td>811241</td>
</tr>
<tr>
<td>2</td>
<td>Talangriaja</td>
<td>9614463</td>
<td>829657</td>
</tr>
<tr>
<td>3</td>
<td>Tingaraposi</td>
<td>9574485</td>
<td>838238</td>
</tr>
</tbody>
</table>

Consistency Testing of Rainfall Data
Daily rainfall data consistency testing used the double mass curve fitting method. This test has the purpose to compare data from the observed stations with the surrounding stations in order to obtain a uniform data distribution.
AVSWAT Modelling Simulation

The modelling simulation process using AVSWAT 2000 was carried out in two steps [4]:

1. Initial simulation and calibration of discharge was performed using the default AVSWAT 2000 model. Default values involved the values of land parameters hru, sol, mgt, and gw. This was based on the availability of data in the field, which is very minimal for some of these parameters, and thus the values of these parameters were approached/filled in advance with the values owned by AVSWAT 2000.

2. Post-calibration simulation was performed using parameter values from the initial simulation process, with discharge calibration being added to the input factors and parameters that affect the amount of erosion and sedimentation for calibration purposes.

![Figure 3. Chart of Calibration Results for the Discharge Model for Measured Data (AWLR) for the Years of 2012-2014 (2013 Land Use)](image)

Correlation Fits of AVSWAT 2000 Simulation Results

Regression analysis establishes the linear relationship between two or more variables, being the independent variable(s) and dependent variable(s) [5]. The degree of relationship is generally stated quantitatively as a correlation coefficient. Correlation coefficient values range from \(-1.0 \leq R \leq 1.0\).

![Figure 4. Chart of Regression Analysis for Correlation Test Calibration Results for 2012-2014](image)

Based on the results of AVSWAT 2000 model discharge, a correlation test was conducted to see the relationship of AVSWAT 2000 modelled discharge with AWLR discharge. The results of the
correlation test (regression analysis) for the years from 2000-2002 showed a value of $R^2 = 0.9229$ and for the years from 2012-2014 showed a value of $R^2 = 0.9056$. This shows that the relationship between AVSWAT 2000 discharge and AWLR discharge is a positive relationship. The correlation test results are shown in Figure 4.

**Changes in Land Use in Bila Watershed**

The purpose of this analysis is to examine the rate of growth of land use or land cover in Bila Watershed, which describes the increase or decrease of land use.

Figure 5 and Table 2 show that in the period from 2000-2014 there were changes in land use or land cover in Bila Watershed, with reduction of forest area by 5.64% and paddy fields by 0.15%. On the contrary, there were expansions in residential area by 0.26%, agriculture by 4.71%, and shrubs by 0.81%. The most significant changes in this period were the increase in agricultural areas and the decrease of forest areas.

![Figure 5. Map of Land Use in Bila Watershed in 2013](image)

**Table 2. Changes in Land Use from 2000-2013**

<table>
<thead>
<tr>
<th>No</th>
<th>Land Use</th>
<th>In 2000 Area (Ha)</th>
<th>In 2000 Area (%)</th>
<th>In 2013 Area (Ha)</th>
<th>In 2013 Area (%)</th>
<th>Changes Area (Ha)</th>
<th>Changes Area (%)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Watershed</td>
<td>392.21</td>
<td>0.38%</td>
<td>392.21</td>
<td>0.38%</td>
<td>0</td>
<td>0%</td>
<td>Constant</td>
</tr>
<tr>
<td>2</td>
<td>Forest</td>
<td>45,798.05</td>
<td>44.49%</td>
<td>39,995.31</td>
<td>38.86%</td>
<td>-5802.74</td>
<td>-5.64%</td>
<td>Decrease</td>
</tr>
<tr>
<td>3</td>
<td>Agriculture</td>
<td>30,057.39</td>
<td>29.20%</td>
<td>34,907.52</td>
<td>33.91%</td>
<td>4850.13</td>
<td>4.71%</td>
<td>Increase</td>
</tr>
<tr>
<td>4</td>
<td>Residential</td>
<td>181.67</td>
<td>0.18%</td>
<td>454.15</td>
<td>0.44%</td>
<td>272.48</td>
<td>0.26%</td>
<td>Increase</td>
</tr>
<tr>
<td>5</td>
<td>Paddy Fields</td>
<td>8,092.76</td>
<td>7.86%</td>
<td>7,942.37</td>
<td>7.72%</td>
<td>-150.39</td>
<td>-0.15%</td>
<td>Decrease</td>
</tr>
<tr>
<td>6</td>
<td>Shrubs</td>
<td>18,409.22</td>
<td>17.88%</td>
<td>19,239.69</td>
<td>18.69%</td>
<td>830.47</td>
<td>0.81%</td>
<td>Increase</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td>102,931.29</td>
<td>100%</td>
<td>102,931.24</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Comparison of AVSWAT 2000 Annual Maximum Discharge Results and Annual Maximum River Discharge (AWLR)

From the AVSWAT 2000 model discharge data and AWLR Tanrutedong river discharge data over the 15 years from 2000 to 2014, a regression test was made to see the relationship between the AVSWAT 2000 model discharge and river discharge from the processing of Bila River AWLR data.

Results of data correlation test with the regression analysis method as shown in Figure 11 resulted in a coefficient value of 0.8912 between the intervals of $0.6 < R < 1$. The $R$ value of the annual maximum model discharge ratio and the maximum annual AWLR discharge overall shows a positive relationship.

AVSWAT 2000 Modelling Discharge Results

Based on the results of the AVSWAT 2000 simulation, Figure 6 shows the results of the annual maximum discharge of Bila Watershed value for land use conditions in 2013; there was a change in annual maximum discharge in July 2012 from 1156 m$^3$/sec to 1161 m$^3$/sec. An increase in discharge occurs in the Bila Watershed due to decreased forest areas as water infiltration areas and increased agriculture and residential areas.

![Figure 6. Chart of Relationship between AVSWAT 2000 Modelling and River Discharge (AWLR)](image)

![Figure 7. Comparison between AVSWAT 2000 Modelling Discharge and River Discharge (2000-2014)](image)
Frequency Analysis

The purpose of hydrological data frequency analysis is to find the relationship between the number of extreme phenomena and frequency of phenomena using probability distributions [10].

Table 3. Statistics of Parameter Testing

<table>
<thead>
<tr>
<th>Distribution Type</th>
<th>Terms of Statistical Parameters</th>
<th>Observation Data Statistical Parameters</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>$Cs \approx 0$</td>
<td>$Cs = 1.581$</td>
<td>Not Met</td>
</tr>
<tr>
<td></td>
<td>$Ck \approx 3$</td>
<td>$Ck = 5.69$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$Cs = Cv^3 + 3Cv$</td>
<td>$Cs = 1.581$</td>
<td></td>
</tr>
<tr>
<td>Log Normal</td>
<td>$Ck = Cv^8 + 6Cv^6 + 15Cv^4 + 16Cv^2 + 3$</td>
<td>$Ck = 5.69$</td>
<td>Not Met</td>
</tr>
<tr>
<td></td>
<td>$Cs \approx 1.139$</td>
<td>$Cs = 1.581$</td>
<td>Not Met</td>
</tr>
<tr>
<td></td>
<td>$Ck \approx 5.4$</td>
<td>$Ck = 5.69$</td>
<td></td>
</tr>
<tr>
<td>Gumbel</td>
<td>In addition to the above values</td>
<td>$Cs = 1.581$</td>
<td>Met</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$Ck = 5.69$</td>
<td></td>
</tr>
</tbody>
</table>

Source: Analysis Results

Frequency Distribution Fits Test

Examination of fit test was performed using the Chi Square test and the Kolmogorov-Smirnov test [7, 8].

a) Kolmogorov-Smirnov Test

The Kolmogorov-Smirnov Test is a test of data deviation towards the horizontal. This test is often called a non-parametric compatibility test [9].

b) Chi-Square Test

Similar to the Kolmogorov-Smirnov test, the Chi-Square test is also used to test the distribution of fit. Chi-Square analysis results are shown in Table 5.

Table 4. Chi-Square Test Results

<table>
<thead>
<tr>
<th>No</th>
<th>Class Boundary</th>
<th>Data Amount</th>
<th>OF-EF</th>
<th>(OF-EF)^2/EF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>OF</td>
<td>EF</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0 - 249.4</td>
<td>2</td>
<td>3</td>
<td>-1</td>
</tr>
<tr>
<td>2</td>
<td>249.4 - 348.9</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>348.9 - 483.5</td>
<td>3</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>483.5 - 663.7</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>663.7 ~</td>
<td>2</td>
<td>3</td>
<td>-1</td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>15</td>
<td></td>
<td>1.333</td>
</tr>
</tbody>
</table>

Source: Analysis Results

With degree of freedom ($dk$) = 1 and degree of goodness ($\alpha$) = 5%, the result was that $x^2 \alpha = 3.841 > x^2_{\text{calculate}} = 1.333$, which means the distribution can be accepted.
Existing River Capacity Analysis

Based on the HEC-RAS 4.1.0 simulation results shown figure 13, when maximum flood discharge in 2012 of 1157 m$^3$/sec occurs, the existing river condition cannot accommodate the flood discharge.

Results of Running HEC-RAS with the Planned Flood Discharge

Based on existing river capacity analysis, at maximum flood discharge conditions, overflowing occurred with a discharge of 1157 m$^3$/sec approaching the 50-year return discharge of 1249.08 m$^3$/sec. Therefore, this study used a planned flood discharge with a 50-year return period. The results of the HEC-RAS simulation are shown in Figure 8.

![Figure 8. Water Level Profile of Existing Conditions of Bila River with Planned Flood Discharge Q$_{50}$](image)

Normalization and Embankment Making

River normalization means the creation of cross-section improvements to narrows and shallows [3]. River width improvement is planned to be 75 m and 100 m, with the plan to handle flooding in Bila River. Based on the results of running HEC-RAS 4.1.0 with a planned flood discharge Q$_{50}$ = 1249.08 m$^3$/sec, normalization is not able to handle Bila River flooding because there are still overflowing river segments, and embankment planning is added.

Embarkment is an earth-fill structure along the river to prevent overflowing of water level. Dimensions of the planned embankment start at 1.00-3.00 m with a crest weir of 4.00 m, height of freeboard of 1.00 m, slope of 1:1, and embankment slope of 1:2. Normalization and embankment planning start at point P.174-P.167, embankment planning starts at point P.166-P.147 and P.117-P.115, and normalization planning starts at point P.24-P.1. The simulation results of the HEC-RAS model are shown in Figure 9.
Budget Plan
Budget plan analysis in this study only involve the calculation of construction costs. The costs are an estimated range for handling Bila River flooding. The total budget plan for handling Bila River floods is Rp. 60,690,000,000.00.

4. Conclusion
Based on the results of Bila River flood handling for Sidrap Regency, the following are the conclusions:

1. Based on the analysis of the land use map for the period from 2000-2014, there have been changes in land cover and land use in Bila Watershed, which are indicated by reductions of forest areas by 5.64% and paddy fields by 0.15%. Meanwhile, there were expansions of residential areas by 0.26%, agriculture by 4.71%, and shrubs by 0.81%. Changes in land use in the period from 2000-2014 have an impact of the change in response of Bila Watershed to rain. This is shown in the change of flood peak discharge in 2012 and land use in 2000 with a flood peak flow of 1156 m$^3$/second to 1161 m$^3$/second by land use in 2013. Changes in flood discharge that occurred in 2012 were not very significant due to the short time span to analyse changes in the Bila Watershed.
2. Based on Bila River discharge data from 2000 to 2014, it was found that the 2012 discharge data was the largest discharge with a value of 1157 m$^3$/second, approaching the 50-year return period. From the results of the HEC-RAS modelling of Bila River existing conditions, the river cannot accommodate the maximum flood discharge of 1157 m$^3$/sec because some sections of the existing water level profile exceed the capacity when the banks are at full capacity, from P.174-P167, P.165-163, P .161-P.159, P.156-P.147, P.117-115, to P.24-P.1. The existing river capacity can only accommodate discharge with a 2-year return period of 412.70 m$^3$/sec.

References


