Abstract. In the recent years, the function of Mamasa River Basin can not be performed optimally in maintaining sustainability hydrologic function of Garugu dam. It is indicated by the occurrence of floods in rainy season and in contrary water shortage in dry season. Unexpected hydrology functions can be attributed to inappropriate land use at the upstream. Therefore, in order to maintain the hydrologic function of the dam, it is necessary to formulate suitable land use at upstream of the river basin. This research is objected to formulate the suitable land use, in term of reducing sedimentation rate in Garugu dam. This study employed RUSLE (Revised Universal Soil Loss Equation) for calculating erosion as well as sedimentation rate. Fuzzy Multi Attribute Decision Making (FMADM) and Analytic Hierarchy Process (AHP) which are integrated with Geographical Information System (GIS), that ware used to formulate optimum landuse at the upstream. Focus Group Discussion (FGD) was conducted in order to validate the obtained land use model using FMADM formulation. The optimum land use composition for Mamasa River Basin that control of dead storage of sediment (DSS) is: 38.01% of agroforesty, 17.88% of forest, 15.66% of mixed agriculture, 11.30% of mixed garden and forest fruit crops, and the rest of the conservation actions and land use such as strip cropping, rotation of crops, use bench terrace in rice fields, reforestation, cover crops and coffee plantation. The optimal land use composition can control the sedimentation rate up to 127.22 m³/km²/year.

Keywords GIS, Fuzzy, landuse, river basin, sediment

INTRODUCTION

Multiple Criteria Decision Making (MCDM) was introduced as a promising and important field of study in the early 1970’es. Since then the number of contributions to theories and models, which could be used as a basis for more systematic and rational decision making with multiple criteria, has continued to grow at a steady rate. One of the methods employed in MCDM is fuzzy sets. The theory of fuzzy sets proposed by Zadeh (Maedah and Murakami, 1993) in 1965 has attracted wide spread attentions in various fields, especially where conventional mathematical techniques are of limited effectiveness, including landuse management and more.

This research is objected to formulate the suitable landuse, in term of reducing sedimentation rate in Garugu dam. The weighting factors for fuzzy process were determined by using the Analytic Hierarchy Process (AHP). Fuzzy process was applied for determining
suitable landuse at the river basin. Sedimentation rate was determined by using RUSLE (Revised Universal Soil Loss Equation) method. Geographic Information System was employed as a tool for providing input data for erosion and sedimentation simulation.

MODEL DEVELOPMENT

The model is composed of geospatial model, fuzzy set, and decision criteria. Input data for running the model is: soil properties (structure, textures, permeability and organic content), landuse, vegetation and social and economic condition and secondary data covers satellite image of landuse and digital image of slope, ground cover, soil type, rainfall and conservation data. The data were obtained from PT. PLN and Bureau for River Basin Rehabilitation and Conservation Services South Sulawesi.

All analog data were converted into digital form in GIS format, the data analysis employs mainly GIS operator such as overlay, subtract etc. A GIS software named ArcView was used for building geospatial model. Input data for geospatial model is: rainfall erosivity (R), soil erodibility (K), Length-slope factors (LS), crop management (C) and conservation factors (P). Sedimentation simulation was generated by prediction erosion rate using RUSLE model.

Geospatial Model for RUSLE

Input data for erosion model is realized using an interactive computer software ArcView. The software is applied for simulating geospatial of each input data. Each thematic map for RUSLE (Revised Soil Loss Equation) was created following the procedure described below. The thematic maps consist of erodibility, erosivity, and topographic, crop and conservation practice factors. The spatial pattern of erosion is calculated using RUSLE-model (Wischmeier & Smith, 1978):

\[ E = R \times K \times LS \times C \times P \]  

The erosivity factor (R) was calculated using the equation developed by Bols (1976) as:

\[ E_{10,9} = 6.19N^{1.21}R^{0.526} \]  

The topographic factor is computed following the formula suggested by Williams & Berndt (1972):

\[ LS = \left( \frac{1}{22.13} \right) \left( 0.065 + 0.0453S + 0.0065S^2 \right) \]  

The landuse map is used to determine the C-factor values for each sub-unit land following the table provided by the Department of Agriculture, South Sulawesi (1999). The C-factor is estimated based on the predominant landuse. The C-factor is highest for bare land (1.0), and
lowest for land that is fully covered with straw mulch (0.005).

The P-factor accounts for onsite practices that reduce the effects of topography, slope length and slope angle, such as strip-cropping, contouring and terracing. The P value for each surface unit of land containing various conservation treatments can be estimated using the formula of Williams & Berndt (1972):

\[
P = 1.0 \times SR + 0.30 \times SRWW + PT \times T
\]  

(5)

**Fuzzy Multi Attribute Decision Making (FMADM)**

Fuzzy Multi Attribute Decision Making (FMADM) was applied in this study in order to formulate optimum landuse. FMADM consists of: 1) building matrix of pairwise comparison \( w \); 2) weighting factors determination; 3) determination of \( C_j \); 4) determination of \( C_j \); and 4) determination of optimum alternatives. Description of each steps as follows:

a. Determination of weighting factors \( w \) of each alternatives on each identified landuse (agroforestry, forest, mixed agriculture, mixed garden and forest fruit crops, and conservation actions and landuse such as strip cropping, rotation of crops, use bench terrace in rice fields, reforestation, cover crops and coffee plantation). The matrix composition \( w \) for each identified landuse is:

\[
\begin{pmatrix}
  w_{11} & w_{12} & \cdots & w_{1p} \\
  w_{21} & w_{22} & \cdots & w_{2p} \\
  \vdots & \vdots & \ddots & \vdots \\
  w_{n1} & w_{n2} & \cdots & w_{np}
\end{pmatrix}
\]  

(6)

with \( w_{ij} \) is important attributes on each criteria \( w_i \) on criteria \( w_j \). Assessment criteria of each identified landuse consist of environmental, economical and social benefits. The Membership function of each criteria is described as:

\[
\bar{D}_j = \left\{ x_i, \min \left( \mu_{C_j}(x_i)^{w_i} \right) \right\} i = 1, \ldots, n; j = 1, \ldots, m \}
\]  

The fuzzy number of each weighting factor is figured as follow:
b. Setting weighting factor $W_j$ and obtaining consistency index by using eigenvector method as described by Saaty.

c. Calculation of the value of $(C_j(x_i))^w_j$.

d. Determination of interaction of $(C_j(x_i))^w_j$, using the following formula:

$$D = \left\{ x_i, \min (\mu_{ij}(x_i))^w \right\} \text{ for } i = 1, \ldots, n; \ j = 1, \ldots, m$$

where $x_i, \mu$ is computed using the following procedures.

e. Setting the $x_i$, using the highest discordance index of $D$, and determine the optimum alternatives using the following scheme:

Fig. 1. Fuzzy number of each weighting factor

Fig. 2. Hierarchy of landuse structure in FMADM
f. Evaluation of Dead storage sediment (DSS) was conducted inorder to set the optimum quantity of sediment inflow into dam. In this study, the value of DSS for Bakaru dam is 132,57 m³/km²/yr. This value can maintain 50 years operation periods of the dam.
g. Validation. This steps was carried out in form of Focus Group Discussion (FGD). The obtained landuse from the FMADM model is compared with the FGD. In this study, the participant of FGD consist of the community of each represented landuse as described above.

RESULT AND DISCUSSION

Landuse Decision Using FMADM

Fuzzy Multi Attribute Decision Making (FMADM) was applied for deciding optimum land use in Mamasa River Basin. Zhen, at al. (2007), this method is rarely applied for erosion management. However this method has a numerous potential for application in soil water conservation. The first step of this study is determination of weighting factors (w) of each alternatives on each identified landuse (agroforesty, forest, mixed agriculture, mixed garden and forest fruit crops, and conservation actions and landuse such as strip cropping, rotation of crops, use bench terrace in rice fields, reforestation, cover crops and coffee plantation). The matrix composition w for each identified landuse was determined using AHP method. Four scenarios were developed for FMADM inorder to obtain the most appropriate landuse at the basin.

<table>
<thead>
<tr>
<th>No.</th>
<th>Development Scenario of FMADM</th>
<th>erosion (ton/ha/yr)</th>
<th>sediment (m³/km²/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-</td>
<td>718,61</td>
<td>7760,98</td>
</tr>
<tr>
<td>2</td>
<td>scenario 1</td>
<td>189,04</td>
<td>2041,43</td>
</tr>
<tr>
<td>3</td>
<td>scenario 2</td>
<td>52,98</td>
<td>573,81</td>
</tr>
<tr>
<td>4</td>
<td>scenario 3</td>
<td>20,29</td>
<td>219,13</td>
</tr>
<tr>
<td>5</td>
<td>scenario 4</td>
<td>11,78</td>
<td>127,22</td>
</tr>
</tbody>
</table>

Landuse Evaluation

Landuse development using FMADM (development scenario 1) can decrease sedimentation rate to 73.69 %, however this value can not reach DSS of the dam. Therefore scenario 1 can not be recommended for optimizing landuse on the river basin. Base on these, landuse scenario must be further developed. Sedimentation rate on scenario 4 is 127.22 m³/km²/yr. This value can achieve below DSS of the dam. This value must be maintain for sustainability function of the dam for 50 years operation periods. Scenario 4 is recommended landuse for the river basin as shown in the following figure.
From FMADM, 38.01% of the total coverage of the basin are occupied by the agroforestry. This landuse type dominated the coverage of the basin. According to Angima, et al. (2003), benefits of agroforestry is not only for soil conservation but also for generating additional income for the community.

Mixed agriculture is the second level of landuse preferency of the community of the basin. Certain portion of the coverage must be reforested, especially at critical area as shown on the map. 7839.66 ha request reforestation. Coffee plantation is the most common plantation on the basin. This type of the plantation occupied 3.80% of the coverage.

Conservation practices is requested also for maintaining sustainability of hydrologic function of the basin. The most common conservation practice in the basin is strip cropping, crop rotation and cover crops. These type of conservation practices occupied the basin 2.92%, 1.59% and 0.08% respectively. The recommended landuse is presented in Table 2.

<table>
<thead>
<tr>
<th>No.</th>
<th>Landuse</th>
<th>Area (ha)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Forest</td>
<td>18994.10</td>
<td>17.88</td>
</tr>
<tr>
<td>2</td>
<td>Agroforestri</td>
<td>39525.63</td>
<td>38.01</td>
</tr>
<tr>
<td>3</td>
<td>Reforestation</td>
<td>7839.66</td>
<td>7.37</td>
</tr>
<tr>
<td>4</td>
<td>Agroforestry (fruit crops)</td>
<td>12009.14</td>
<td>11.30</td>
</tr>
<tr>
<td>5</td>
<td>Mixed agriculture</td>
<td>16633.80</td>
<td>15.66</td>
</tr>
<tr>
<td>6</td>
<td>Coffee plantation</td>
<td>4028.34</td>
<td>3.80</td>
</tr>
<tr>
<td>7</td>
<td>Bench terrace</td>
<td>2261.72</td>
<td>2.13</td>
</tr>
<tr>
<td>8</td>
<td>Strip cropping</td>
<td>3101.40</td>
<td>2.92</td>
</tr>
<tr>
<td>9</td>
<td>Crop rotation</td>
<td>1697.42</td>
<td>1.59</td>
</tr>
<tr>
<td>10</td>
<td>Cover crops</td>
<td>86.83</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>106178.03</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Validation of Landuse generated from FMADM

Model validation was carried out by conducting focus group discussion (FGD). This action is a qualitative study to compare between the landuse formulation obtained from FMADM simulation and the preferency of the community on the Mamasa River Basin. The parcipants
of the FGD consists of the represented community of each landuse type (forestry, paddy field, mixed agriculture, underbush). The result of the FGD is presented in the following table.

<table>
<thead>
<tr>
<th>No.</th>
<th>Landuse</th>
<th>Result of FGD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Paddy field</td>
<td>The communities represented by paddy field prefer to introduce bench terrace. The main reason is bench terrace is not only can reduce overland flow but also contributes to increase production rate of paddy field.</td>
</tr>
<tr>
<td>2.</td>
<td>Underbush</td>
<td>The community expect to carried out land clearing of the coverage occupied by underbush. Therefore underbush area can be explore to be productive land.</td>
</tr>
<tr>
<td>3.</td>
<td>Mixed agriculture</td>
<td>Numerous owners of mixed agricultural land prefer to change their land become agroforestry. Alley cropping is an alternative in mixed agriculture.</td>
</tr>
<tr>
<td>4.</td>
<td>Dryland agriculture</td>
<td>Strip cropping is the common preference of the represented community from dry land agriculture. The reason is strip cropping contributes not only for increasing benefit but also in soil conservation.</td>
</tr>
</tbody>
</table>

Generally from the FGD, it was obtained that the farmers managed theirs land, they consider not only economic orientation but also environmental point of view. They expect to make balance between economy and environment consideration. Mostly, the community suggest to implement agroforestry in farming practices. This is relevant with the results that were generated from FMADM model (the most suitable of conservation practices is agroforestry). Bench terrace is the most recommended conservation practices for paddy field. According to the farmer this conservation practices contributes to increment of biomass production. Table 4 presents landuse obtained from FGD and landuse obtained from FMADM. From Table 4, it was found that, mixed agriculture with strip cropping is recomended for conservation practices. This is relevant with the information obtained from FGD that was conducted in this area. Furthermore, the farmer who managed dry land agriculture expect their land to be converted become forest with fruit crops, agroforestry, strip cropping and change their cropping patterns.
CONCLUSION

Application of FMADM in landuse management at Mamasa River Basin can be effectively applied to reduce sedimentation rate to 98.36% which is equal to 127.22 m³/km²/yr. This level is below dead storage of sediment of Garugu Dam.

The generated sedimentation rate is contributed by the following landuse composition: 38.01% of agroforestry, 17.88% of forest, 15.66% of mixed agriculture, 11.30% of forest with fruit crops and the rest Strip Cropping, crop rotation, bench terrace at paddy field, reforestation, cover crops, and coffee plantation.

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