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FUZZY MULTI ATTRIBUTE DECISION MAKING FOR RIVER BASIN MANAGEMENT

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Mamasa River Basin is situated in South Sulawesi, Indonesia. In the recent years, the function of this 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 landuse at upstream of the river basin. This research is objected to formulate the suitable landuse, 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 is combined 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 landuse model using FMADM formulation. The optimum landuse is: composition for Mamasa River Basin that control of dead storage of sediment (DSS) is: 38.01% of agroforestry, 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 landuse such as strip cropping, rotation of crops, use bench terrace in rice fields, reforestation, cover crops and coffee plantation. The optimal landuse composition can control the sedimentation rate up to 127.22 (m^3/km^2)/year.

INTRODUCTION

Multiple Criteria Decision Making (MCDM) was introduced as a promising and important field of study in the early 1970's. 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 [4]), 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 this study 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 Burou 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.

GIS model for Geospatial Model

Input data for erosion model is realized using an interactive computer software ArcView. The software is applied for simulating geospatial of each input data. The thematic maps consist of erodibility, erosivity, and topographic, crop and conservation practice factors. The spatial pattern of erosion is calculated using RUSLE (Wischmeier and Smith [8]) as $E = R*K*LS*C*P$. The erosivity factor (R) was calculated using the equation developed by Bols [2]. The result of the erosivity calculations is processed in the geospatial model that is programmed in ArcView. The soil erodibility factor (K) is computed following the nomograph prepared by Wischmeier and Smith [8]. The topographic factor is computed following the formula suggested by Williams and Berndt [7].

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) (Munir *et al.* [6]). 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 and Berndt [7].

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 pairweise comparison (w); 2) weighting factors determination; 3) determination of $(C_j(x_i))^{w_j}$ 4) determination of $(C_j(x_i))^{w_j}$ interaction and 4) determination of optimum alternatives. Description of each steps as follows: 1) 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). With $\frac{w_i}{w_j}$ is important attributes on each criteria w_i and 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: $\tilde{D} = \left\{ \left(x_i, \min \left(\mu_{Cj} \left(X_i \right)^{w_j} \right) \right) \mid i = 1,...,n; j = 1,...,m \right\}$. The fuzzy number of each weighting factor is figured follows fuzzy graph; 2) Setting the weighting factor W_j and obtaining consistency index by using eigenvector method as described by Saaty; 3) Calculate the value of $(C_j(x_i))^{w_j}$; 4) Determine of interaction of $(C_j(x_i))^{w_j}$, using the following formula: $D = \left\{ \left(x_i, \min_j \left(\mu_{cj} \left(x_i \right) \right)^{w_j} \right) \mid i = 1,\ldots,n; j = 1,\ldots,m \right\}$ where Xi, μ is computed using the following procedures; 5) Setting the x_i, using the highest discordance index of *D*, and determine the optimum alternatives using the following the scheme described by Saaty; 6) Evaluation of *Dead storage sediment* (DSS) was conducted inorder to set the optimum quantity of sediment flow into dam. In this study, the value od DSS for Garugu dam is 132.57 m^3/km^2/yr. This value can maintain 50 years operation periods of the dam; 7) 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 consists of the community of each represented landuse as described above.

RESULT AND DISCUSSION

Estimation of Sedimentation

Erosion rates were computed using the RUSLE method (Wischmeier and Smith [8]). Sedimentation due to surface erosion (*SEP*) was computed using *SEP* = *E* $\cdot$ *SDR*, where *E* is erosion rate (t ha^{-1} $year^{-1}$) and *SDR* is sediment delivery ratio computed using the formula described by Roehl (1962) $SDR = 36 \cdot A^{-0.20}$ (Munir *et al.* [5]), where *A* is drainage area (km^2). Sedimentation rate (m^3 km^{-2} $year^{-1}$) was computed using a density of the soil of 1200 kg • m^{-3}. The value of *SDR* for Mamasa River Basin with the total area of 106178.03 ha is 8.97% or 0.09. Sedimentation rate of each existing landuse is:

Table 1. Sedimentation Rate of each existing landuse

No.	Penggunaan Lahan	Area(ha)	Sediment ($m^3/km^2/yr$)
1	Forest	54126.20	59.51
2	Paddy Field	2261.72	128.63
3	underbush	37254.55	2767.90
4	Mixed Agriculture	2684.70	2627.10
5	Dry land agriculture	9850.86	2177.82
Total		106178,03	7768.98

Contribution of sediment from the existing landuse on Bakaru dam is 7768.98 $m^3/km^2/yr$. According to Lin *et al.* [3], the susspended sediment that have high bulk density can settled on water body and in a certain condition, it will increse operation cost of hydrologic infrastructure. This situation is occured in Bakaru dam.

Landuse Decision Using FMADM

Fuzzy Multi Attribute Decision Making (FMADM) was applied for deciding optimum land use in Mamasa River Basin (Zhen *et al.* [9]), 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 (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 was determined using AHP method.

Tabel 2. Contribution of sediment of landuse development using FMADM

No.	Development Scenario of FMADM	erosion (ton/ha/yr)	sedimen ($m^3/km^2/yr$)
1	-	718.61	7760.98
2	scenario 1	189.04	2041.43
3	scenario 2	52.98	573.81
4	scenario 3	20.29	219.13
5	scenario 4	11.78	127.22

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 $m^3/km^2/yr$. 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 recommende 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*. [1], 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 practice 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 3.

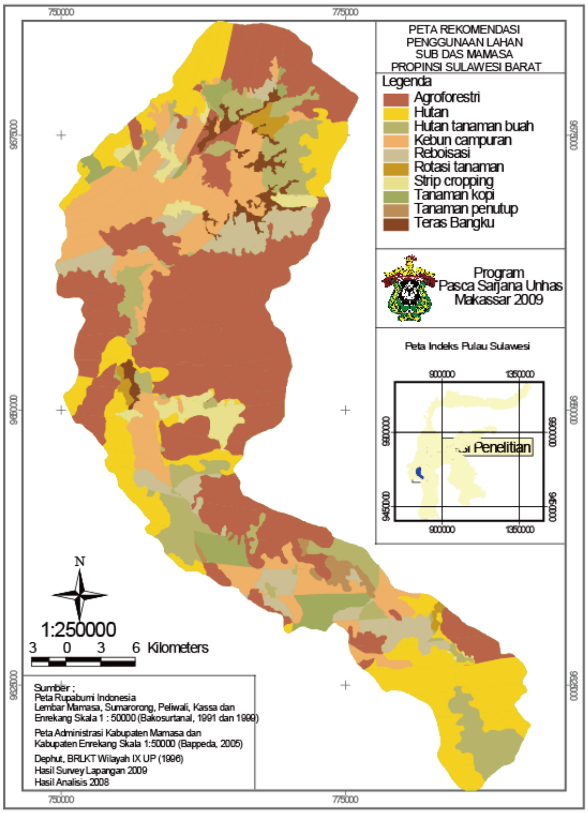

Figure 1. Recommended landuse for the Mamasa River Basin

Tabel 3. Recommended landuse composition using FMADM for Mamasa River Basin

No.	Landuse	Area (ha)	Persentage (%)
1	Forest	18994.10	17.88
2	Agroforestri	39525.63	38.01
3	Reforestration	7839.66	7.37
4	Agroforestry (fruit crops)	12009.14	11.30
5	Mixed agriculture	16633.80	15.66
6	Coffee plantation	4028.34	3.80
7	Bench terrace	2261.72	2.13
8	Strip croping	3101.40	2.92
9	Crop rotation	1697.42	1.59
10	Cover crops	86.83	0.08
Totol		106178.03	100

Validation of Landuse generated from FMADM

Validation of generated landuse 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 4. Results of FGD on each representative landuse of Mamasa River Basin

No.	Landuse	Result of FGD
1	Paddy field	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
2	Underbush	The community expect to carried out land clearing of the coverage occupied by underbush.Therefore underbush area can be explore to be productive land
3	Mixed agriculture	Numerous owners of mixed agricultural land prefer to change their land become agroforestry. Alley cropping is an alternative in mixed agriculture
4	Dryland agriculture	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

Generally from the FGD, it was obtained that in managing their 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 5 presents landuse obtained from FGD and landuse obtained from FMADM.

Table 5. Landuse obtained from FGD and FMADM

No.	Existing landuse	Landuse obtained from FMADM	Area (ha)
1	Forest	Forest	18994.10
		Agroforestry	35132.10
2	Paddy Field	Benc terrace	2261.72
3	Underbush	Mixed agriculture	16633.80
		Reforestration	7839.66
		Forest with fruit crops	8752.75
		Coffee	4028.34
4	Mixed agriculture	Strip Croping	37.41
		Forest with fruit crops	1054.74
		Reforestration	0.14
		Agroforestry	1592.42
5	Dry land agriculture	Forest with fruit crops	2201.65
		Cover crops	86.83
		Agroforestry	2801.11
		Strip Croping	3063.99
		Crop rotation	1697.28
Total			106178.03

Furthermore, from FMADM, it was obtained 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.

CONCLUSIONS

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 $m^3/km^2/yr$. 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, reforestration, cover crops and coffee plantation.

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