Fuzzy Multi Attribute Decision Making (FMADM) for Land Use Management

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ABSTRACT

Jeneberang Basin is situated in South Sulawesi, Indonesia. In the recent years, the function of this basin could not be performed optimally in maintaining sustainability hydrologic function of Jeneberang dam. 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 policy for the suitable landuse, in term of reducing sedimentation rate in Jeneberang Dam. This study employed RUSLE (Revised Universal Soil Loss Equation) for calculating of erosion as well as sedimentation rate. Fuzzy Multi Attribute Decision Making (FMADM) and Analytic Hierarchy Process (AHP) whichis combined with Geographical Information System (GIS) were employed for obtaining the formulation. AHP was applied for obtaining of weighting factor that ware used to formulate optimum landuse at the upstream. There are ten conservation alternatives were observed (natural mulch,plastic mulch, strip cropping, crop rotation, cover crops application, plough paralleled with contour, terrace, agro forestry, tree cultivation and replanting) by considering seven criteria (material availability, farmer knowledge, acceptance level of technology, supporting of institution, suitability of farming system, financial affordability, others criteria). The result of this study indicated that, the value of intersection vector of 0.799 is attributed to the conservation practice of crop rotation. From the research, it was proved that by applying of FMADM, sedimentation rate can be reduced of 18.43 m^3/km^2/year becomes 4.63 m^3/km^2/year.

Keywords: GIS, Fuzzy, land use, river basin, sediment

INTRODUCTION

Fuzzy Multi Attribute Decision Making (FMADM) 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 development, 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. 1965 has attracted wide spread attentions in various fields, especially where conventional mathematical techniques are of limited effectiveness, including land use management and the other fields.

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 combined with Geographical Information System (GIS) were employed for obtaining the formulation. AHP was employed for obtaining of weighting factor that ware used to formulate optimum land use at the upstream river basin. This study was applied at the Jeneberang River Basin, South Sulawesi Indonesia, around 30 km from the city of Makassar.

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REVIEW OF LITERATURE

Fuzzy Multi Attribute Decision Making (FMADM) was introduced in 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 FMADM is fuzzy sets. The theory of fuzzy sets proposed by Zadeh (Sri Kusumadewi et al., 2006). In this research, this method was applied in soil conservation, in term of finding the best alternative for conservation practices in river basin.

Conservation practices such as application of natural mulch can be applied in order to maintain organic material as well as can protect the soil from rain drops and decreasing of overland velocity during the storms (Arsyad, 2001). Crop rotation can be also applied in order to maintain nutrient balance in the cultivation area (Bowman et al., 1999; Vyn et al., 2000) and decrease soil erosion as well as increase of crop production (Sutrisno dan Nurida, 1995).

Land preparation can be also considered in soil conservation, plough parallel with contour can increase crop production if this practice is applied simultaneously with strip cropping (Soleh dan Arifin, 2003). Long term conservation technique is considered also in this study, Agro forestry can increase crop productivity of cultivation practices in river basin (Irwanto, 2008).

METHODOLOGY

Model Development

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 combined with Geographical Information System (GIS), AHP was employed for obtaining weighting factor that ware used to formulate optimum land use at the upstream. There are ten conservation alternatives were observed (natural mulch, plastic mulch, strip cropping, crop rotation, cover crops application, plough paralleled with contour, terracering, agro forestry, tree cultivation and replanting) by considering seven criteria's (material availability, farmer knowledge, acceptance level of technology, supporting of institution, suitability of farming system, financial affordability, others criteria).

All analog data were converted into digital form in GIS format, the data analysis employs mainly GIS operators such as overlay, subtract etc. GIS software named Arc View 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.

Fuzzy Multi Attribute Decision Making

Fuzzy Multi Attribute Decision Making (FMADM) was applied in this study in order to formulate optimum land use. 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 land usewith w_i/w_j is important attributes on each criteria w_i on criteria w_j. Assessment criteria of each identified land use consist of environmental, economical and social benefits.

The Membership function of each criteria is described as: $\check{D}=\{(x_i, min(\mu_{cj}(X_i)^{w}{}_{j}))\mid i=1,\ldots,n;j=1,\ldots,m\}$ 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:

$$\check{D}=\{(x_i, min(\mu_{cj}(X_i)^{w}{}_{j}))\mid i=1,\ldots,n;j=1,\ldots,m\}$$

Where x_i, μ is computed using the next step; 5) Setting the x_i, using the highest discordance index of Ď, and determine the optimum alternatives using the scheme described by Saaty; 6) determination of sediment was conducted in order to set the optimum quantity of sediment flow into dam.

In this study, the value of sediment was generated by using geospatial simulation; **7)** Validation. This step was carried out in form of *Focus Group Discussion* (FGD). The obtained land use from the FMADM model is compared with the FGD. In this study, the participant of FGD consists of the community of each represented land use as described above. The conservation alternative includes: natural mulch, plastic mulch, strip cropping, crop rotation, cover crops application, plough paralleled with contour, terracering, agro forestry, tree cultivation and replanting. The vector of *Ď* of each conservation alternative was calculated by using above criteria.

GIS Model for RUSLE Model

Input data for erosion model is realized using an interactive computer software ArcView. The software was 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 & Smith, 1978) as $E= R*K*LS*C*P$.

The erosivity factor *(R)* was calculated using the equation developed by Bols (1976). 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 monograph prepared by Wischmeier & Smith (1978).

The topographic factor is computed following the formula suggested by Williams & Berndt (1972). The land use 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 land use. 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). Land cover factors (C-factors) were modified by using the result of FMADM simulation.

RESULT AND DISCUSSION

The values of weighting factors were determined by using AHP (Analytical Hierarchy Process). It was realized by comparing each criterion that was considered in the analysis. The conservation criteria consist of material availability, farmer knowledge, acceptance level of technology, supporting of institution, suitability of farming system, financial affordability, others criteria. Pair wise comparison was applied in AHP in order to find out the value of weighting factors. The result of the weighting factor is presented below:

Table 1. Weighting factor for powering intersection vector

	Criteria	*Weighting Factor*
1	Material Availability	0.293
2	Farmer Knowledge	0.245
3	Acceptance level of technology	0.150
4	Supporting of Institution	0.102
5	Suitability of Farming System	0.094
6	Financial affordability	0.068
7	Others Criteria	0.048

The value of weighting factor was used for powering of membership function of criteria natural mulch, plastic mulch, strip cropping, crop rotation, cover crops application, plough paralleled with contour, terracering, agro forestry, tree cultivation and replanting. The result of calculation is presented below.

Membership Function of Natural Mulch

The maximum value of membership function of natural mulch was obtained from the criteria of farmer knowledge (0.67). This means that application of natural mulch can be developed if it supported by the increasing of farmer skill. According to Arsyad (2001), that the application of natural mulch can be associated with the source of organic material as well as can protect the soil from rain drops and decreasing of overland velocity during the storms. Application of mulch can maintain stability of soil temperature reach of soil depth 5, 10 & 12 cm. Therefore, decomposition of organic material can be retained.

Membership Function of Synthetic Mulch (Plastic Mulch)

The maximum value of membership function of Synthetic Mulch was obtained from the criteria of farmer knowledge is 0.63. This means that application of synthetic mulch can be developed in case of paralleling with the increasing of farmer skill. According to Mannering and Fenster (1983), that the application of plastic mulch can protect the soil from rain drops and decreasing of overland velocity during the storms. Application of plastic mulch can reduce overland flow and soil erosion (Arsyad, 2001).

Membership Function of Strip Cropping

The maximum value of membership function of strip cropping was obtained from the criteria of farmer knowledge (0.63) and availability of material (0.48). This means that application of strip cropping can be developed in case of paralleling with increasing of farmer skill and availability of conservation material. Strip cropping can be reduce soil erosion of 37 percent, however this value is still below of TSL (*tolerable soil loss)* (Rachman *et. al*, 2008).

Membership Function of Crop Rotation

The maximum value of membership function of crop rotation was obtained from the criteria of farmer knowledge (0.67) and availability of material (0.63). This means that application of crop rotation can be developed in case of paralleling with the increasing of farmer skill and availability of conservation material. Crop rotation can be applied in order to maintain soil conservation (Bowman *et al*., 1999; Schomberg dan Jones, 1999; Vyn *et al*., 2000).

Membership Function of Cover Crop

The maximum value of membership function of cover crop was obtained from the criteria of availability of conservation material (0.74) and farmer skill (0.51). This means that application of cover crops can be developed if it is supported by providing conservation material and increasing of farmer skill.

Membership Function of Plough Parallel with Contour

The maximum value of membership function of plough parallel with contour was obtained from the criteria of farmer knowledge (0.70) and availability of material (0.59). This means that application of plough parallel with contour can be developed if it is supported by the increasing of farmer skill and availability of conservation material. Plough parallel with contour can increase crop production if this practice is applied simultaneously with strip cropping (Soleh dan Arifin, 2003). Application of plough parallel with contour can increase production of 10.63 ton becomes 12.64 ton (Erfandi et al., 2002).

Membership Function of Terracering

The maximum value of membership function of terracering was obtained from the criteria of farmer knowledge (0.56), availability of material (0.70) and affordability of technology (0.22). This means that application of terracering can be developed if it is supported by the increasing of farmer skill in transfer of technology and availability of conservation material. Crop rotation can be applied in order to maintain soil conservation especially in reducing soil erosion. According to Mawardi (2011), that this practices can reduce erosion rate of 8.33 percent and can safe soil erosion of 5.46 ton/ha/year.

Membership Function of Agro Forestry

The maximum value of membership function of *Agro forestry* was obtained from the criteria of farmer knowledge (0.70), availability of material (0.26) and affordability of technology (0.22). This means that application of *Agro forestry* can be developed if it is supported by the increasing of farmer skill in transfer of technology and availability of conservation material. *Agro forestry* could be applied in order to maintain ecological and hydrological function of the catchment (Young in: Suprayogo *et al.,*2003). According to Irwanto, (2008), *Agro forestry* can increase crop productivity of cultivation practices in river basin.

Membership Function of Replanting

The maximum value of membership function of Replanting was obtained from the criteria of farmer knowledge (0.41), availability of material (0.44) and affordability of technology (0.19). This means that application of Agro forestry can be developed if it is supported by the increasing of farmer skill in transfer of technology and availability of conservation material. Replanting can be applied in order to maintain ecological and hydrological function of the catchment. However, this practice is required more financial affordability, therefore, it must be hardly supported by the government institution.

Determination of Weighting Factor (w) and Intersection ($\tilde{D}$)

The fuzzy number of each weighting factor is figured follows fuzzy graph. The weighting factor w_j as described above and obtaining consistency index were realized by using eigenvector method as described by Saaty, calculating the value of $(C_j(x_i))^{w}{}_j$ as presented in Table 2.

Tabel 2. Value of Intersection Factor

Alternatives	*Criteria*						
	Material Availability	*Farmer Knowledge*	*Acceptance Level of Technology*	*Supporting of Institution*	*Suitability of Farming System*	*Financial Affordability*	*Others Criteria*
	A	*B*	*C*	*D*	*E*	*F*	*G*
	Weighting Factor						
	0.293	*0.245*	*0.15*	*0.102*	*0.094*	*0.068*	*0.048*
Natural Mulch	0.873	0.905	0.817	0.625	0.783	0.799	0.854
Plastic Mulch	0.466	0.893	0.817	0.823	0.649	0.928	0.854
Strip Cropping	0.807	0.893	0.751	0.823	0.649	0.878	0.854
Crop Rotation	0.873	0.905	0.916	0.799	0.836	0.946	0.802
Cover Crops Applications	0.916	0.851	0.677	0.714	0.649	0.878	0.912
Plough Paralleled With Contour	0.858	0.918	0.885	0.714	0.911	0.731	0.883
Terracering	0.902	0.866	0.798	0.767	0.892	0.799	0.802
Agro Forestry	0.673	0.918	0.798	0.858	0.649	0.912	0.854
Tree Cultivation	0.725	0.880	0.906	0.871	0.734	0.861	0.802
Replanting)	0.789	0.803	0.776	0.975	0.649	0.838	0.802

The following matrix is obtained by using above criteria: {625, 0.466, 0.649, 0.799, 0.649, 0.714, 0.767, 0.649, 0.725, and 0.649}. From this matrix, the maximum value of Ď is 0,799 occurs on crop rotation and 0.767 occurs on terracering. Increasing of farmer skill becomes the main focus of both nominated conservation alternatives. After generating the value of Ď, the spatial pattern of erosion was calculated by using RUSLE (Wischmeier & Smith, 1978). Erosivity factor (R), soil erodibility factor (K), land use map, C-factor and P-factor were determined by using the procedure as described above. The value of C was generated from the FMADM procedure. It was proved that, from geospatial simulation and FMADM, sedimentation rate can be reduced from 18.43 m^3/km^2/year to 4.63 m^3/km^2/year. Crop rotation can be applied for decreasing of soil erosion and increasing of crop production (Sutrisno dan Nurida, 1995; Hussain et al., 1999).

CONCLUSION

By applying of FMADM, sedimentation rate can be reduced from 18.43 m^3/km^2/year to 4.63 m^3/km^2/year. This can be generated from the value of intersection vector of 0.799 which is attributed to the conservation practice of crop rotation. However, the conservation practices of crop rotation can be involved by increasing of farmer skill and level of technology.

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