3D AGRO-ECOLOGICAL LAND USE PLANNING USING SURFER TOOL FOR SUSTAINABLE LAND MANAGEMENT IN SUMANI WATERSHED, WEST SUMATRA INDONESIA

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8 authors, including:

Aflizar Aflizar
State Polytechnique Payakumbuh for Agriculture

Cornelius Idowu Alarima
University of Agriculture, Abeokuta

Roni Afrizal
Payakumbuh State Agricultural Polytechnic

Husnain Husnain
Indonesian Agency for Agricultural Research and Development

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3D Agro-ecological Land Use Planning Using Surfer Tool for Sustainable Land Management in Sumani Watershed, West Sumatra Indonesia

Aflizar[1], Alarima Cornelius Idowu[2], Roni Afrizal[1], Jamaluddin[1], Edi Syafri[1], Muzakir[1], Husnain[3] and Tsugiyuki Masunaga[2]

[1]State Polytechnic Payakumbuh for Agriculture, Campus Politani PO Box 107, Indonesia, e-mail: aflizar_melafu@yahoo.com; tel/fax +62-752-7750220
[2]Faculty of Life and Environmental Science, Shimane University, Matsue 690-8504, Japan
[3]Indonesia Soil Research Institute, Bogor, Indonesia

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ABSTRACT

Estimation of soil erosion 3D (E3D) provides basic information that can help manage agricultural areas sustainably, which has not been sufficiently conducted in Indonesia. Sumani watershed is main rice production area in West Sumatra which has experienced environmental problem such as soil erosion and production problem in recent years. 3D Agro-ecological land use planning based on soil erosion 3D hazard and economic feasibility analyses consist of production cost and prize data for each crop. Using a kriging method in Surfer tool program, have been developed data base from topographic map, Landsat TM image, climatic data and soil psychochemical properties. Using these data, the Universal Soil Loss Equation was used for spatial map of soil erosion 3D and proposed a 3D agro-ecological land use planning for sustainable land management in Sumani watershed. A 3D Agro-ecological land use planning was planned under which the land use type would not cause more than tolerable soil erosion (*TER*) and would be economically feasible. The study revealed that the annual average soil erosion from Sumani watershed was approximately 76.70 Mg $ha^{-1}yr^{-1}$ in 2011 where more than 100 Mg $ha^{-1}yr^{-1}$ was found on the cultivated sloping lands at agricultural field, which constitutes large portion of soil erosion in the watershed. Modification of land use with high *CP* values to one with lower *CP* values such as erosion control practices by reforestation, combination of mixed garden+beef+chicken (*MBC*), terrace (*TBC*) or contour cropping+beef+chicken (*CBC*) and sawah+buffalo+chicken (*SBC*) could reduce soil erosion rate by 83.2%, from 76.70 to 12.9 Mg ha^{-1} yr^{-1}, with an increase in total profit from agricultural production of about 9.2% in whole Sumani watershed.

Key words: *CP*-values, Erosion 3D, land use, Surfer Tool, *USLE*

INTRODUCTION

No soil phenomenon is more destructive in Indonesia than soil erosion caused by high rainfall and deforestation due to expansion of production fields. Erosion leads to both environmental and socio economic problems, including poverty and unsustainable use of agricultural land (Iwata *et al.* 2003). In recent years, the increasing demand for agricultural product due to population growth and inappropriate land use by farmer through cultivation of land without conservation measure to protect erosion has increased the rate of erosion in Indonesia tremendously. To fulfill the food need for daily life, deforestation, land use change and acceleration of erosion on increase in Indonesia must be checked. Rice is staple food in Indonesia with the rate of consumption growing at a faster rate. In 2000-2005, population growth was 1.2% per year with an addition of 13.74 million people during this period. This increase calls for a need for additional food and other agricultural products and services in Indonesia in addition to meeting the requirement of the existing population of 205 million people in year 2000. Furthermore, 110,000 ha yr^{-1} paddy field was being converted to non agricultural land during the same period (Sarainsong *et al.* 2007). A population projection made for the year 2032 shows an average increase of 50 percent compare to year 2000. The task ahead is how 51.9 million tons rice produced annually as at 2000 will be increased to 79 million ton by the year 2032. Achieving this will require appropriate agriculture techniques that will enhance soil fertility and water conservation with greater attention on reduction of erosion and less land encroachment for non agricultural activities.

In Indonesia, average erosion rate of 6-12 Mg $ha^{-1}yr^{-1}$ on agricultural land has been reported to have caused economic loss of US$ 340-406 million in 1989 which is responsible for nearly 80% of the decline in the productivity of agricultural land. The remaining 20% is due to off-site cost such as siltation of irrigation systems and the loss of reservoir capacity (World Bank 1989; Margareth and Arens 1989). Sumani watershed is a main rice production area in West Sumatra province. All the waters of Sumani watershed flow into Lake Singkarak and is further drained eastward to other watersheds in Riau Province. In general, high soil loss rates occur during frequent intense storms in tropical wet climate in Indonesia. Moreover, intensive cultivation, annual rainfall of more than 2,750 mm, mountainous topography, the transformation of forest to agricultural land and socioeconomic strain for more land have accelerated the rate of soil erosion, especially on sloping lands. If this problem is not fairly approached, not only the well being of the farmers will suffer because of the declining soil fertility, productivity and water availability, but also the functionality of the Singkarak lake as a reservoir and hydroelectric power plant will also be undermined due to siltation and eutrophication.

The Agro Ecological Zones *(AEZ)* and Agro Ecological Land *(AEL)* use planning methodology were developed in 1976 by collaboration between FAO and IIASA (FAO 1993). *AEZ* and *AEL* provide decision support for various problems related to land use appraisal for planning sustainable agricultural development. Before the application in Indonesia (FAO/IIASA 1991), the methodology has been used in land use assessments in Bangladesh, China, Mozambique, Nepal, Nigeria, the Philippines, and Thailand (Agrell *et al*. 2004). The *AEZ* and *AEL* methodology utilizes a land resource inventory to assess, for a given level of input, all feasible agricultural land use options as well as expected production of relevant and agro-ecologically feasible cropping activities. On the basis of this agronomic evaluation and using specific socio-economic data to specify constraints, targets and production options, the attainment of spatial resource allocation objectives can be optimized. The optimization results provide perspectives on the capability of Indonesia land resources, technology, and policy, etc., to improve as well as sustain agricultural production. These perspectives are intended to provide a useful guide to national planning. The plan for the proposed agro ecological land use helps local government, as the management authority, to make agricultural development policies that are more environmentally and socioeconomically oriented (Sarainsong *et al*. 2007).

To assess the present land use condition and its sustainability of the Sumani watershed, there is rising call for a more cost-efficient and timely absorb tabular spatial information for informed land management planning. Significant advanced application of *USLE* model was integrated in Surfer tool for making an agro-ecological land use planning. Models are needed to predict soil erosion rates under different resources and land use conditions for soil conservation planning (Shi *et al*. 2004). Unfortunately, dependable or financially viable means of gauging soil erosion is deficient in the Sumani watershed. This means that much of the soil conservation planning carried out in this area has been based on water conservation (runoff control) with the supposition that soil erosion control will be accomplished by control of the runoff. Many researchers have concluded that this may not be the case forever in the Sumani Watershed (Paranginangin *et al*. 2004). Evaluation of current situation of erosion is very important for improvement of endangered areas, and determining the type of conservation measures to be applied for sustainable management and conservation of the agricultural areas (Irvem *et al*. 2007).

In a previous study (Aflizar *et al*. 2013), we evaluated soil erosion in the Sumani watershed, which is representative of the main rice production area in West Sumatra. The region has faced rapid land use change from forest to agricultural fields and a consequent increase in the rate of soil erosion. The average soil erosion rate in the watershed, estimated by the Universal Soil Loss Equation (*USLE*), increased from 43.13 Mg $ha^{-1}yr^{-1}$ in 1992 (Aflizar *et al*. 2010) to 76.70 Mg ha^{-1} yr^{-1} in 2011, coincident with changes in land use pattern (Aflizar *et al*. 2013). The soil erosion rate exceeded the Tolerable Erosion Rate (*TER*) set for Indonesia, *i.e*. 14 Mg ha^{-1} yr^{-1} for > 52% at the watershed land area. Based on the results of the present study, we recommended an agro ecological land use pattern for the watershed by modifying the land use types to reduce soil erosion to a value less than the *TER*, while maintaining agro-economical production in the watershed. Although, this is a case study, it has never been conducted in Sumatra Island, Indonesia.

MATERIALS AND METHODS

Study Area

Sumani Watershed, covering 58,330 ha, is located in Solok regency (latitude 00° 36' 08" to 10° 44´ 08´´ S, longitude 100° 24´ 11´´ – 101° 15´ 48´´ E) on elevation of 300 m and 2,500 m above sea level and about 50 km east of the Padang city (Figure 1). Outlet of the watershed is Lake Singkarak. It is situated in a tropical zone with a very humid climate.

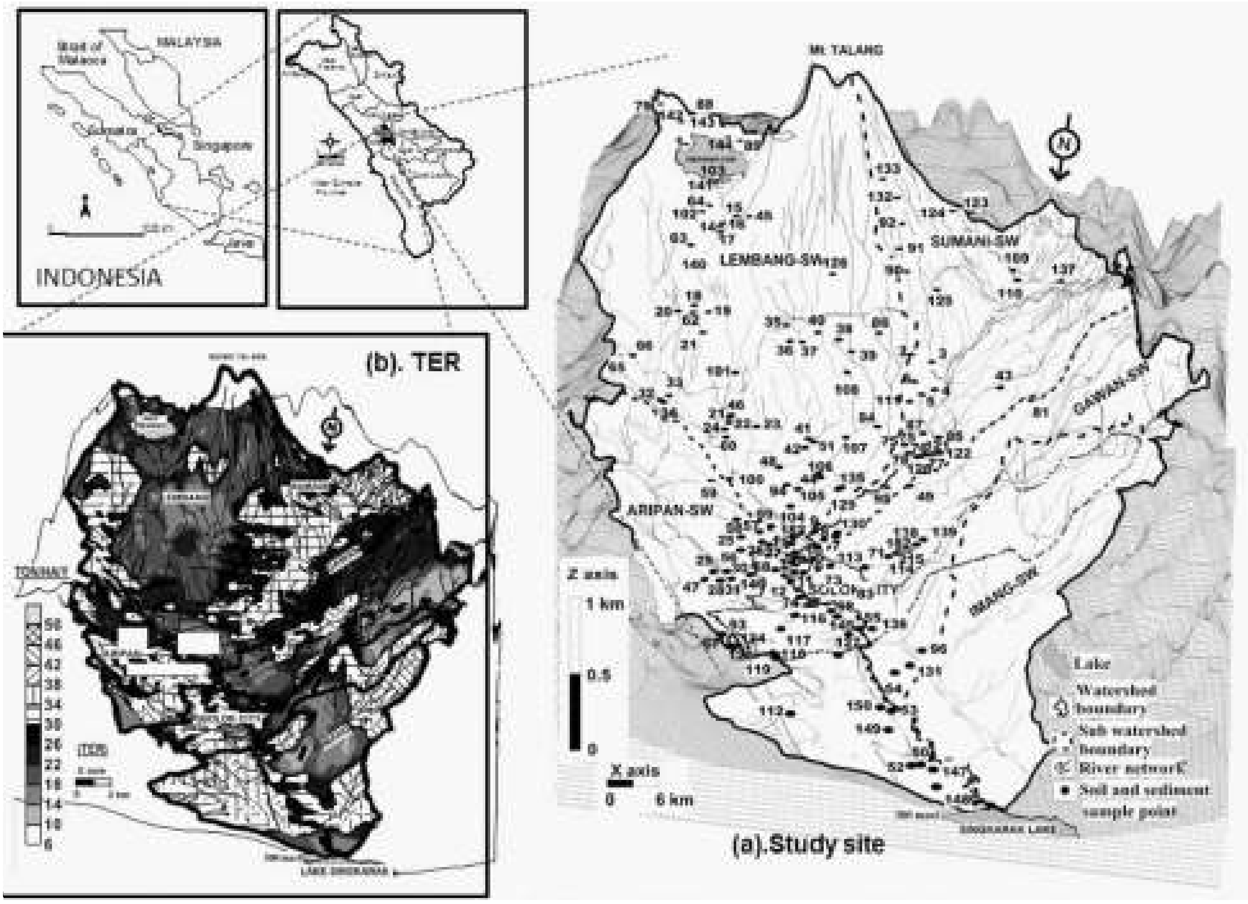

Figure 1. Study site and distribution of soil sampling points sites (a) and TER (b) in Sumani watershed, West Sumatra, coordinates bases on UTM coordinate system WGS 84 Zone 47 Southern Hemispire.

Annual average temperature was 24^{o}C and annual precipitation was averaged 2450 mm, rainfall every month and without clear dry season during 1996 to 2011. These data were collected from the Indonesia Meteorological and Geophysics (BMG). Average humidity was varied from 78.1 to 89.4%. Sumani watershed consists of various land use types, including primary forest, mixed garden (Agroforestry) paddy field and settlement. The term paddy field refer to a levelled and bounded rice field with inlet and outlet for irrigation and drainage (Wakatsuki *et al*. 1998). Mixed garden is practised across the entire area. Mixed garden refers to land where perennial crops, mostly trees such as coconut (*Cocos nucifera*), clove, coffee, sawo, avogado, rubber, cinnamomon, are planted, and under which annual crop are cultivated (Karyono 1990). Vegetables cultivated include chili, onion, soybean (*Glycine max L*), corn (*zea mays L.*) and sweet potato (*Ipomoea batatas* L.). The watershed has six soil orders including six groups, *i.e*. Oxic Hapuldant, Andic Humitropept, Typic Kandiudult, Aeric Tropaquept, Typic Distropept and Typic Eutropept (Soil Survey Staff 1990) which are identified in the watershed. Soil group distribution is dependent on the type of parent material and morphological position. Both Oxic Hapuldant and Andic Humitropept are derived from andesite mount Talang and Welded tuff and are distributed in the upland area of Lembang and Sumani sub-watersheds, close to mount Talang cultivated as vegetable garden, paddy field, mixed garden and forest. Typic Kandiudult is derived from alluvial fan, lime stone, slate and shale, andesite to basalt, undifferentiated volcanic product, and Granite, and is distributed in the lowlands and uplands of the Aripan sub-watershed and in the Lembang sub-watershed cultivated as vegetable garden, paddy field, mixed garden and forest. Aeric Tropaquept is derived from alluvial fan and river alluvium, distributed in the lowlands of the Sumani, Lembang, Aripan, and Gawan dan Imang sub-watersheds used for paddy field and vegetable garden. Typic Distropept is derived from the river alluvium, alluvial fans, undifferentiated volcanic product, and welded tuff and is distributed in the Imang, Gawan and Sumani sub-watersheds used for paddy field, vegetable garden, mixed garden, and forest. Typic Eutropept is derived from lime stone and undifferentiated volcanic product and is distributed only in the Aripan sub-watershed where paddy field and mixed garden are cultivated. Five major rivers, *i.e*. Lembang, Sumani, Bagawan, Ujung Karang and Barus flow in the watershed and finally the river water flows into Lake Singkarak. The Sumani watershed is a representative watershed in West Sumatra, of which natural resources, land use patterns and population densities are typical of the surrounding regions.

Fields Survey and Soil Analytical Methods

Soil survey and sampling at the depth of 0-20 and 20-40 cm were conducted at 103 sites (42 sites in 2002 and 39 sites in 2006 and 22 sites in 2011) as shown in Fig.1 occupying a variety of geomorphic position and land use types. As the land use pattern in Sumani watershed was maintained as almost same during 2002-2007, we assumed the difference in the period of soil survey and sampling did not influence the result of soil physics. Soil structure was recorded during the field survey. Soils were collected using 100 cm^3 core samplers to determine soil water permeability following the protocol of Reeve (1965) and bulk density was determined by volumetric sample (Blake and Hartge 1986). Part of soil samples were air dried and sieved to obtain the fine earth fraction particles less than 2 mm for the physico-chemical analyses. Organic carbon was determined by Walkley and Black type method (IITA 1979). Soil texture was analyzed using pipette method (Gee and Bauder 1986). During the field survey, we also confirm watershed soil, vegetation types and land uses.

Data Processing for Mapping and Erosion 3Dimension (E3D) Modeling Approach

"The overall data processing involving use of *USLE*, was conducted in Surfer® 9 (Golden software 2010) dealing with factors gained from meteorological stations, detail soil surveys, topographic maps, and attendant of other applicable studies. Outline of the mapping procedure is explained as follows. In order to process mapping of *USLE* factors described later and the other data, regionalized variable theory, that has been successfully applied to soil property interpolation for nearly 30 years, was used in the present study. Interpolation is the term a method in Surfer® 9 uses the optimal delaunay triangulation. The algorithm creates triangles by drawing lines between data points. The original points are connected in such a way that no triangle edges are intersected by other triangles. The result is a patchwork of triangular faces over the extent of the grid. This method is an exact interpolator (Golden software 2010). The theory provides a convenient summary of data variability (in the form of a semi-variogram) and an interpolation technique which is kriging method. From a theoretical point of view, kriging method provides the best linear unbiased estimates, a more accurate description of the data spatial structure and valuable information about estimation error distributions (Kravchenko and Bullock 1999). Individual files for respective parameters of *USLE* factors and the others were constructed by grid modeling procedures in Surfer® 9 (Golden software 2010) to calculate soil erosion rate in a spatial domain.A 1:50,000 topographic map, including the Sumani watershed, was input to the Surfer® 9 by manual digitization. This vector elevation map was converted into grid format with a spatial resolution of 125 m × 125 m. Base on kriging in Surfer® 9, an interpolation routine was employed to derive the elevation surface from the rasterized line data. This kriging method and its applicabilities are described in detail by Takata *et al.* (2008). The digital elevation map (DEM) was accustomed as the foundation for other topographic-related analyses. The soil properties, land use types, and other relating attributes were also input to the Surfer® 9 by manual digitization and keyboard entry. Polygons and their attributes were connected with uniform code. Polygon is the command method to draw an irregularly shaped area. These vector maps were also converted into raster, which had the same reference system and resolution as the DEM. The data sources were converted into the grid format. Each defined grid had an exact location in space determined by the grid orientation and grid size and a list of allocate attributes. To predict soil erosion rate in the spatial domain, a map unit was set to the size of 125 m by 125 m, which was the finest resolution size concerning with the available data set and authors` computer facilities. Each grid was assumed as a single slope plane in order to apply for which *USLE* in grid. The watershed was divided by 39316 grids with size of 125m ×125m mesh basic data were allocated or estimated in each grid by means of reading of maps and a Landsat image for land use types and altitude or kriging method for application and soil properties. Base on these data, respective *USLE* factor were calculated in each grid unit. Among the above factors, *C*- and *P*-factors are the ones that we can modify to improve soil erosion and agro-economical conditions in the watershed (Aflizar *et al*. 2013).The overall data processing involving use of *USLE*, was conducted in Surfer® 9 (Golden software 2010) dealing with factors gained from meteorological stations, detail soil surveys, topographic maps, and attendant of other applicable studies. The data sources were converted into the grid format. 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Relief parameter: digital elevation model (*e.g*. interpolated grid from a digitized topographical map, topographic data was used to construct a surface map of the landslide and surrounding Sumani watershed (Aflizar *et al*. 2012). A block diagram showing geomorphic feature and sampling location in watershed was generated by kriging topographic data using Surfer from Golden Software; Golden, CO (Lee *et al*. 2001). (2). Standard soil parameter: particle size distribution of the top soil (four main texture classes) and organic carbon content (%) (Schob 2006). (3). Specific soil parameter: bulk density (kg m^{-3}), soil permeability (cm hr^{-1}), soil structure, effective soil depth. (4). Percentage land slope: digitize map was generated by grid data using Surfer program. (5). Soil sampling polygon, (6). Land use : digital maps e.g. digital topographical maps combined with orthophotos and field mapping with land use boundaries and land use-related information (Schob 2006). (7). Meteorology parameters polygon: Schob (2006) stated that Data recording from tree station in Sumani watershed and polygon map was generated using Surfer 9. Since 1996, the Erosion *3D* model has been integrated into the official agricultural soil conservation programs. Further validation of the Erosion 3D model has been done internationally (Aflizar *et al*. 2013).

USLE Model

In our previous paper (Aflizar *et al*. 2013), we estimated soil erosion rate in Sumani watershed using *USLE* model (Wischmeier and Smith 1978), annual soil loss is expressed as a function of six erosion factors:

$$A = R \times K \times L \times S \times C \times P \qquad (1)$$

Where: A is the estimated soil loss in Mg $ha^{-1}y^{-1}$; R is Rainfall erosivity factor (dimensionless); K is inherent soil erodibility (dimensionless); L is length of the slope factor (dimensionless); S is slope factor (dimensionless); C is crop cover factor (dimensionless); and P is a factor that accounts for the effects of soil conservation practices (dimensionless). In general, rainfall erosivity (R) and soil erodibility (K) are the most important factors that need evaluation based on local conditions for successful application of the model (Chris *et al*. 2002).

The watershed was divided into 39312 grids sized 125 m x 125 m and basic data were allocated and estimated in each grid. Data were obtained by map reading, assessing a Landsat image for land use types and altitude, and use of the kriging method (Golden software 2010) for precipitation and soil properties. Based on these data, each *USLE* factor was calculated in each grid unit. Among the factors, *C*- and *P*-factors can be modified on the field to improve soil erosion and agro-ecological land use planning in the watershed.

Tolerable Erosion Rate (*TER*) for Agricultural Production

Hammer equation (Hammer, 1981) was used to calculate Tolerable Soil Loss (*TER*)

$$TER = \frac{De \times Fd \times BI \times 100}{T} \qquad (3)$$

where *TER* represents Tolerable Erosion Rate (t ha^{-1}), *De* is effective soil depth (cm), *Fd* is soil depth factor, *BI* is soil volume mass (g cm^{-3}), and T is time of use, ranging between 100-500 years, and in this case of Sumani watershed, 250 years was used with consideration that farmer has cultivated paddy field vegetables and mixed garden for 5 generations at 50 years for one generation. Parameters used in the equation were derived from the soil map and soil survey. Estimated soil erosion (from *USLE*) and Tolerable Erosion Rate were then compared to analyze the erosion hazard under the current agricultural land use as an analytical basis for watershed management (Sarainsong *et al*. 2007), where varied *TER* in respective land use were distributed (Table 1 and Figure 1).

Economic Feasibility Analysis

Economic feasibility for different land use types in the watershed was evaluated from its cost-benefit ratio, which was calculated as

$$BC \text{ ratio} = \frac{R - C}{C}$$

where R is revenue, which is calculated as production (kg) x price (US$ kg^{-1}) and C is cost (US$). *BC* ratio is shown as basic data to assess

Table 1. Result of the economic feasibility analyses in the Lembang sub watershed.

Land utilization type	Range of soil erosion rate (t $ha^{-1}yr^{-1}$)	Range of Tolerable soil erosion (t $ha^{-1}yr^{-1}$)	Cost	Revenue (Production x price)	Benefit	Benefit-Cost ratio
			(US$ $ha^{-1}yr^{-1}$)			
Sawah						
Sawah	0.004 – 13.21	13 – 31	770.70	2,055.00	1,284.30	1.7
Sawah+buffalo+duck+fishpond (SBDF)	0.004 – 13.21	13 – 31	1,474.50	6,078.30	4,603.80	3.12
Sawah+buffalo+chicken+fishpond (SBCF)	0.004 – 13.21	13 – 31	1,374.00	4,557.00	3,182.80	2.32
Sawah+chicken+fishpond (SCF)	0.004 – 13.21	13 – 31	763.20	3,677.00	2,913.80	3.82
Average	1.41	19.52	1,095.60	4,091.83	2,996.18	2.73
Vegetables garden						
Red pepper (*Capsicum annum*)	0.4 – 893	14 – 27	3,914.00	90,300.00	86,386.00	21.4
Tomato (*Solonum lycopersicum.syn*)	0.4 – 893	14 – 27	2,666.70	18,204.40	15,537.80	5.83
Carrot (*Daucus carota L.*)	0.4 – 893	14 – 27	22,812.00	33,000.00	10,188.00	0.45
Red onion (*Allium ascalonicum L.*)	0.4 – 893	14 – 27	4,644.50	18,461.7	13,817.2	3.9
Potato (*Solonum tuberosum L.*)	0.4 – 893	14 – 27	19,579.20	44,804.0	25,224.8	0.8
Average	154.98	18.87	10,723.28	40,954.02	30,230.76	2.82
Vegetables +chicken+fishpond (VCF)	18.58	18.87	10,781.30	42,231.00	31,449.8	2.92
Vegetables +terrace+chicken+beef (VTCB)	18.58	18.87	11,245.03	42,567.02	31,322.01	2.79
Vegetables +contour cropping+chicken+beef (VCBC)	18.58	18.87	11,245.03	42,567.02	31,322.01	2.79
Mixed garden						
Duku (*langsium domesticum*)	0.1 – 348.4	17 – 33	204.71	804.71	600.00	2.93
Coconut (*cocos nucifera*)	0.1 – 348.4	17 – 33	245.65	1,304.47	1,058.82	4.31
Coconut (*cocos nucifera*)	0.1 – 348.4	17 – 33	245.65	1,304.47	1,058.82	4.31
Average	84.45	25.53	232.00	1,137.88	905.88	3.90
MGFC+chicken+fishpond (MCF)	25.25	25.53	290	2,414.90	2,124.9	7.3
MGFC+chicken+beef (MCB)	25.25	25.53	753.75	2,750.88	1,997.13	2.65
MGFC+beef (MB)	25.25	25.53	719.75	2,337.88	1,618.13	2.25
Forest		20.68				
Wood fire	0.01 – 2.52	20.68	73.00	730	657	9
Bamboo	0.01 – 2.52	20.68	73	273.75	200.75	2.75
Honey of bee	0.01 – 2.52	20.68	2.40	54	51.6	21.50
Deer hunter	0.01 – 2.52	20.68	12.00	300	288	24
Average	0.41	20.68	40.10	399.44	299.34	7.46
Shrub and Alang alang	32.88	26.99	0	0	0	0
Settlement	235.50	28.41	0	0	0	0

the efficiency of cost investment against the benefit gained from each different agricultural product. The *BC* ratio can be used as a guideline (ranging from 2.6-10.3) to prevent any loss of profit to farmers at each subsequent harvest due to large production costs (Choudhury *et al*. 1995). In order to calculate these parameters, data on costs of labor, fertilizer, pesticide, seed, production and price of agricultural products were derived from a detailed social economic survey 2011, the most recent available data during the study period. Because cost and revenue varied in the watershed, we summarized the results at sub-watershed levels, where varied land uses were distributed (Table 2). Land use types with no cost and revenue such as grasses, alang-alang (land dominated by Imperata cylindrica [Poaceae]) and shrub lands were omitted from the analyses. The average benefit values for paddy field, forest and vegetable and mixed gardens and cattle (beef and buffalo), poultry (chicken and duck), combination of combination of paddy field + buffalo + duck + fishpond (*SBDF*), combination of paddy field + buffalo + chicken + fishpond (S*BCF*), combination of Paddy field + chicken + fishpond (*SCF*), combination of Vegetables + chicken + fishpond (*VCF*), combination of vegetables + terrace + chicken + beef (*VTCF*), combination of Vegetables + contour cropping + chicken + beef (*VCB*), combination of *MGFC* + chicken + fishpond (*MCF*), combination of *MGFC* + chicken + beef (*MCB*) and combination of *MGFC* + beef (*MB*) were calculated as representative values to estimate and compare the total profit of agricultural production in the entire watershed currently and for the agro ecological land use planning.

Agro-Ecological Land Use Planning

Based on the resolute *USLE* factor values of each grid cell, the approximation of the spatial distribution of soil erosion rates under present farming practices in Sumani watershed was established. In order to make agro-ecological land use planning model, we took procedures shown in Fig. 2. We did two analyses and utilized a step by step approach to select the appropriate land use and to plan the proposed suitable land use. We ordered two analyses, on the basis of their importance relative to problem solving in the Sumani watershed. Prevention of soil erosion is basic important problem to solve in the watershed. The use of soil conservation measure that are suitable for Sumani watershed thus preventing watershed function from degradation is the secondary aim. Thus, the planning model is to make decision process that begins with spatial distribution soil erosion 3D analysis (Aflizar *et al*. 2013) as the first filter, followed by economic feasibility analysis.

To establish an agro-ecological land use planning protocol, we followed the procedures depicted in Figure 2. The analyses were conducted in each grid unit. Grids with soil erosion rate were less than the *TER* comprised of grasses, alang-alang

Table 2. K values for different land use type and soil order in Sumani watershed.

Land use type	Soil order	SA	VFS	SI	CL	OM	WSP	SS	K
		(%)				(%)	(cm h^{-1})		values
Forest	Andisol	5.63	4.13	61.24	29.00	6.80	25.39	1, 3, 6	0.230
	Inceptisol	6.15	2.20	62.70	28.95	5.86	9.37	3	0.285
	Ultisol	4.40	8.20	22.40	65.00	4.19	3.63	4	0.137
Mixed garden	Andisol	9.51	2.06	57.99	30.43	6.33	60.42	2, 4	0.227
	Inceptisol	6.97	2.39	44.33	46.32	4.83	39.19	2, 4	0.176
	Ultisol	2.93	0.73	73.10	23.23	5.84	16.32	2,4	0.267
Paddy field	Andisol	8.52	2.60	45.86	43.02	3.28	56.09	1, 2	0.152
	Inceptisol	22.96	2.84	43.28	30.92	3.68	11.00	2, 4	0.200
	Ultisol	6.25	2.00	39.75	52.00	3.88	10.73	2	0.109
Shrub	Andisol	7.92	1.72	65.09	25.26	8.54	17.87	2, 4	0.124
	Inceptisol	7.72	3.09	66.24	22.95	4.90	9.17	2, 4	0.300
	Ultisol	2.94	2.08	28.40	66.58	5.60	4.40	4	0.171
Vegetable fields	Andisol	6.70	1.86	69.72	21.72	6.05	13.81	2, 3, 4	0.250
	Inceptisol	15.96	1.93	50.22	31.89	3.45	14.12	2, 3, 4	0.260

SA, sand; VFS, very fine sand; SI, silt; CL, clay; OM, organic matter; SWP, soil water permeability; SS, soil structure; K, soil erodibility. Soil structure code: 1, very fine granular <1 mm; 2, fine granular 1-2 mm; 3, medium – coarse granular 2 – 10 mm; 4, blocky, platy, massive; Soil permeability code: 1, rapid (>25.4); 2, moderate to rapid (12.7-25.4); 3, moderate (6.3-12.7); 4, moderate to slow (2-6.3); 5, slow (0.5-2); 6, very slow (< 0.5) in cm hr^{-1}.

(land dominated by *Imperata cylindrica*). Vegetable garden generated the highest agro-economic benefit and was maintained in the agro-ecological land use planning. In the case study, all grids with forest, paddy field and tea land use types exhibited soil erosion rates less than the *TER*, and therefore land use was unchanged and we introduced *SBCF, MBC, VBC, VCBC and VTBC*. When the grid soil erosion rate exceeded the *TER*, we calculated *CP*-factors to meet the *TER* by the recommended formula *i.e.CP* = *TER* / (*R x K x LS*) for the respective grids. We subsequently selected a new land use from the lists of suitable land use types. We separated the planning process (Figure 2) for vegetable gardens, and mixed gardens and bush and shrub lands. Benefit among land use types is shown in Table 2, We attempted to maintain vegetable garden land use by applying conservation practices, including contour cropping at *VCBC* and terracing at *VTBC* to reduce soil erosion rates and keep or increase farmers' income. In the case where the recommended *CP*-factor was less than 0.008, we changed the land use to SBCF or SBC or reforestation if water was not available. For mixed garden and bush land use types, full cover crop or reforestation was applied depending on the recommended *CP*-factors. In addition to the planning processes depicted in Figure 2, for the settlement grids located in steep slope areas that exhibited soil erosion rates exceeding the *TER*, soil conservation measures included home gardens with fruit trees and terracing to reduce soil erosion to acceptable levels (Table 3). The agro-ecological land use change processes resulted in 58330 ha of the Sumani watershed modified to reduce soil erosion rates below the *TER*. Change in land usages are summarized in Table 3.

In addition, we provided a simple simulation to evaluate the effects of applying a specific land use type to reduce soil erosion. We took an area with a soil erosion rate exceeding the *TER* under the present land use condition and converted it into a single land use type which possesses relatively low *CP*-factors. Furthermore, areas with the soil erosion rates less than the *TER* were unchanged from the original land use type but introduce *SBC* or *MBC* or *VBC*. Although this was not realistic planning, we addressed the effects of this type of approach.

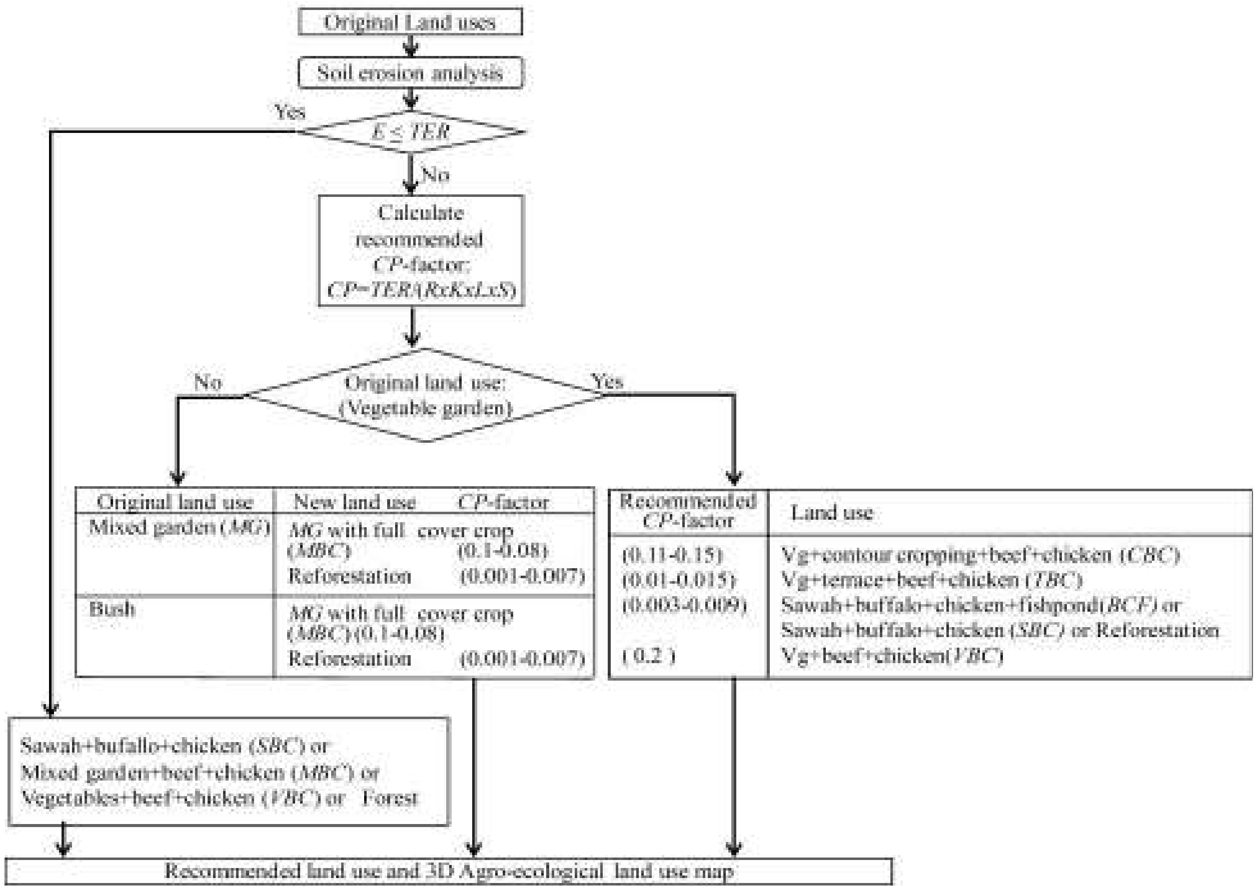

Figure 2. Planning process 3D Agro-ecological land use model: *E*, Estimated soil erosion 3D, *TER*, Soil loss tolerance for economic planning , *CP*-factor: crop factor x protection factor of *USLE*, *Vg*: Vegetable garden, *MG*: Mixed garden, c: chicken or poulty, b: beef of cattle, bf: water bufallo, f: fishpond, *MGFC*: mixed garden with full cover crop.

Table 3. General comparison between current land use and recommended land.

	Current land use	Proposed Agro-ecological land-use
Soil erosion rate		
Average (Ton ha^{-1} y^{-1})	76.7	12.9 (-83.2%)
Range (Ton ha^{-1} y^{-1})	(0.001-1682.09)	(0.00-68.5)
Land use pattern (%)		
Vegetable garden without conservation practices	24.2	0
Mixed garden	14.1	0
Forest	17.2	21.4
Sawah	22.7	0
Settlement	12.1	0
Shrub	6.2	0
Water body	3.9	3.9
Vegetable + beef + chicken (*VBC*)	0	5.6
Vegetable + terrace+beef+chicken (*VTBC*)	0	4.5
Vegetable + counter cropping+beef+chicken (*VCBC*)	0	13.7
Settlement + home garden (*SH*)	0	12.1
Sawah+buffalo+chicken (*SBC*)	0	22.7
Mixed garden with full cover crop+beef+chicken (*MBC*)	0	16
Total	100.0	100.0
Benefit from agricultural production (US $ million y^{-1})	367.2	401.68 (+9.2%)

RESULTS AND DISCUSSION

Properties of the Top Soil in Sumani Watershed

Table 2 shows soil physicochemical properties in Sumani watershed. The results of soil analyses showed high organic matter content in shrub, forest, vegetable and mixed garden. Soil permeability and soil aggregate greatly varied by change in land use type even similar soil order. The soil texture was mainly silty clay loam and silty loam in paddy field, mixed garden, vegetables and other land use types. The entire soil sample collection can be grouped as Inceptisol, Ultisol and Andisol. Base on this parameter we calculated soil erodibility factor (K) at all sampling site. Same land use types have different *K* values in the lower, middle and upper Sumani watershed. Different *K* values assigned for the Inceptisol and Ultisol for lower and middle Sumani watershed. *K* values ranged from 0.001 to 0.48. Thus indicating that *K* factor is greatly affected by varying soil physicochemical characteristics at different topography, land use and soil type in Sumani watershed. Brady and Weil (2008) reported that soils with high rates of soil water permeability commonly have *K* factor of 0.025 or below, while more easily eroded soils with low infiltration have *K*- factor of 0.04 or higher.

Erosion Hazard Analysis

The USLE (Eq. (1)) was run within Surfer tool by simply multiplying R, K, L, S, C and P factors and mapped by kriging procedure. The quantitative output of calculated soil erosion rates for the Sumani watershed available from present farming practices were calculated and categorized into six ordinal classes and presented on the map in Figure 3 of the 58330 ha of Sumani watershed. Erosion greater than 100 Mg $ha^{-1}yr^{-1}$ at steep slope was dominated. About 48.4% had soil erosion rates of < 5 t $ha^{-1}yr^{-1}$ at paddy field, mixed garden and agricultural field at flat slope and forest. 10.3%, 11.6%, 10.5%, 7.1% and 12.1% had low (5-14 Mg $ha^{-1}yr^{-1}$), medium (14-50 Mg $ha^{-1}yr^{-1}$), high (56-100 Mg $ha^{-1}yr^{-1}$), very high (100-200 Mg $ha^{-1}yr^{-1}$) and extremely high (100-200 Mg $ha^{-1}yr^{-1}$) level classes respectively (Figure 3a).

As shown in Figure 3a and Figure 3b, the distribution of soil erosion rate and land use pattern is very similar. Soil erosion rate are very high in vegetable garden and mixed garden at steep slope due to poor management. It means that if we could control land use pattern in vegetable garden, we can control soil erosion rate lower than *TER*. In the case where the current land use type caused significant soil erosion, land conservation measures or improvements and land use type conversion were considered that could reduce soil erosion. In the watershed, stone terrace at paddy field and vegetable garden were found in some upland areas around mount Talang and Lake. A stone embankment around a hillside that interdicts overland flow enhances infiltration, and safely guides runoff off-field, is one of the major recommended engineering

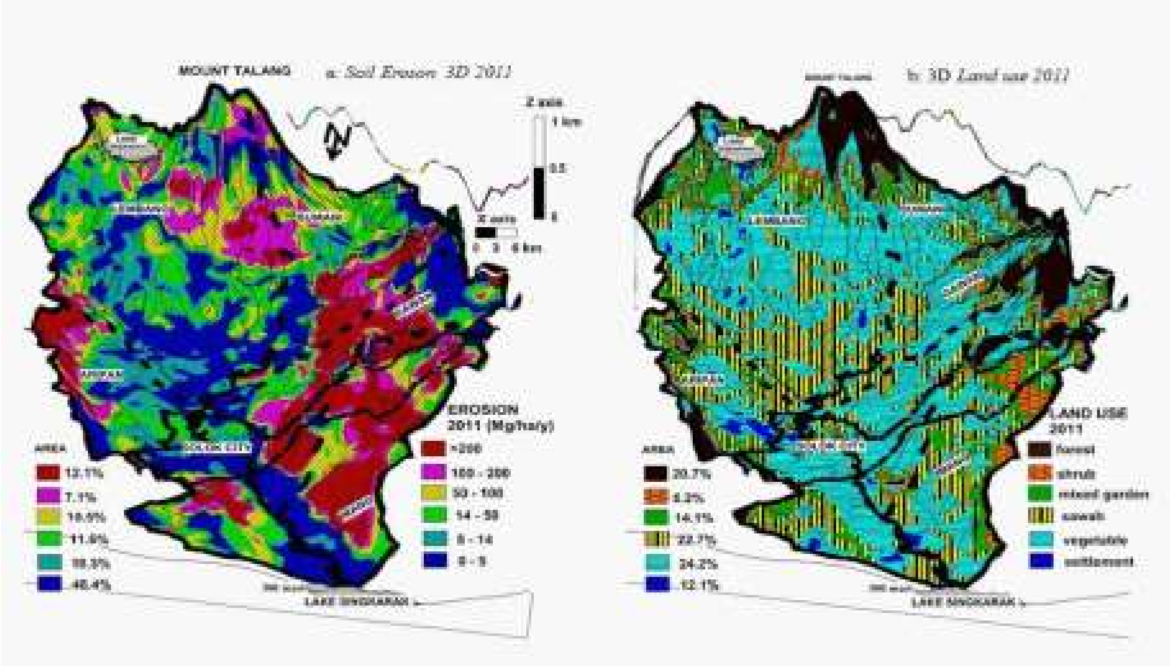

Figure 3. Spatial distribution of estimated soil erosion 3D 2011 and 3D land use 2011 in Sumani watershed. a: Soil Erosion 3D 2011, b: 3D Land use 2011.

structures for controlling soil erosion in the Sumani watershed. However, Shi *et al.* (2004) reported that as slope gradients increase above 10%, the spacing between terraces decreased to such a point that the needed terraces are expensive to construct and lack of investment funds has limited their adoption. Thus, priority is given to the agronomic measures of soil conservation, such as paddy field and mixed garden in the conservation planning. In addition to lower cost, the agronomic gauges are more adapted to the existing farming systems. Terraces should be implemented only if other practices identified with agronomic means are not practicable or are ineffective. In addition, better conservation control practices may be adopted. For instance, an irregular strip planting system should be changed to a contour planting (strip planting across the slope) and mixed garden adopted for its lower cost for erosion control.

Thereafter, we check the factor controlling erosion rate (Figure 3). The data show that soil erosion is higher because of change of land use type from forest to agricultural land in steep slope based on the *C* and *P* factor and *LS* factor. Among these factors, the *S* factor cannot be modified. The *L* (as length of topography), *C* (as crop) and *P* (as conservation measures) can be controlled in erosion management. Base on this relationship, average erosion is presently at a higher level at Sumani watershed due to change in *CP* value by change of forest to agricultural land (Figure 2).

To control and reduce erosion in this watershed, the *USLE* model can be stimulate to find out the appropriate agro-ecological land use planning. Fig. 3 shows that forest and paddy field have lower erosion due to lower *CP* value. To reduce erosion, there is need to have lower *CP* since lower *CP* gives rise to lower soil erosion. On the basis of this analysis, the existing land use types that are suitable were selected from the options of land use types that have passed erosion hazard analysis < *TEP* for the subsequent economic feasibility analysis (Table 2 and Figure 2). The idea of agro-ecological land use planning is to achieve a decrease in *CP* value. Reduce *CP* value may mean to change land use or give conservation measure and for this purpose, economic feasibility analyses are needed to give benefit for both farmers and environment.

Economic Feasibility Analysis

The results of the economic feasibility analysis are shown in Table 2. The benefit was highest in vegetable gardens, combination of vegetables + chicken + fishpond (*VCF*) and combination of vegetables + terrace + beef + chicken (*VTBC*), which was approximately ten to twenty three times greater than paddy field and mixed gardens. Farmers prefer to cultivate vegetables because of the higher economic benefit, however suitable areas to grow vegetable gardens are limited. Vegetable gardens require a cooler climate, which are only located in higher topographical positions. Vegetable gardens occupied approximately 24.2% of the entire watershed area (Figure 3 and Figure 4). Cost-benefit

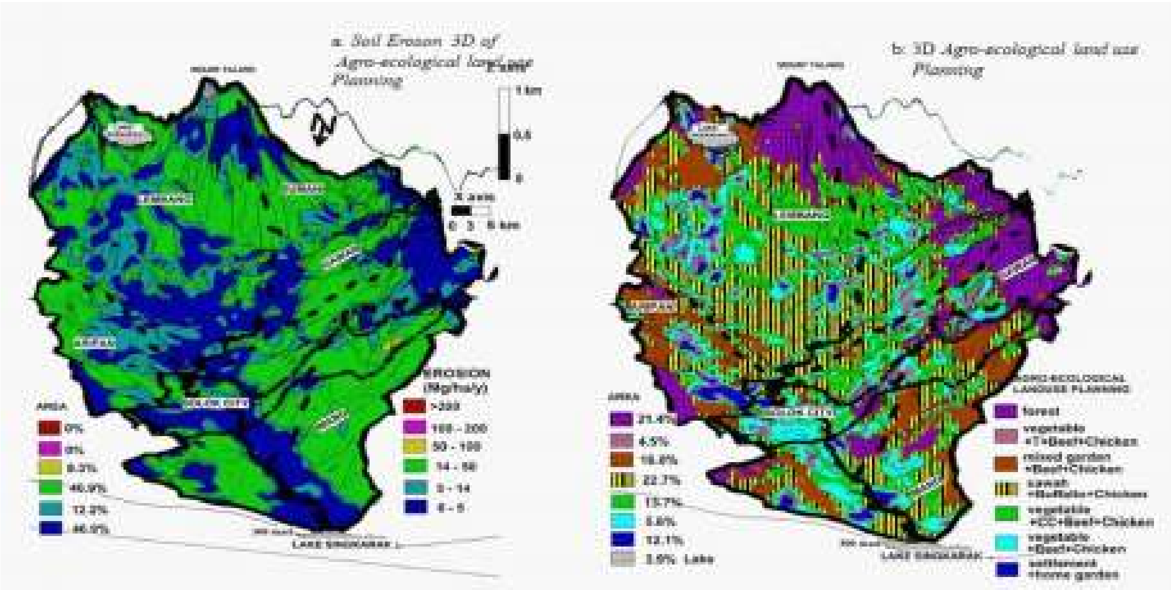

Figure 4. Spatial distribution of Soil Eroson of agro-ecological land use Planning in Sumani watershed. a: Soil Eroson 3D of Agro-ecological land use Planning, b: 3D Agro-ecological land use Planning. CC: contour cropping, T: terrace.

ratio (B/C) ranged from 0.45 to 21.5, which was higher relative to vegetable gardens in the Cianjur watershed (B/C ratio of 1.1) of central West Java (Sarainsong *et al*. 2007). In the Sumani watershed, paddy field in all sub-watersheds exhibited soil erosion rates less than the TER. Rice is only harvested once a year in Sumani sub watershed and Lembang sub watershed, paddy field is located in the middle to upper topographical positions. Sumani sub watershed and Lembang sub watershed rice quality is considered better, likely due to the cooler climate. Therefore, consumers preferred it, resulting in a higher selling price than Gawan sub watershed and Aripan sub watershed lowland rice. Vegetable gardens exhibited very high soil erosion rates, i.e. > 100 Mg ha^{-1} yr^{-1} on average due to locations on watershed slopes. Most vegetable gardens showed values less than the *TER*. Red pepper had high production and prices, resulting in increased *B/C* ratios compared to tomato, carrot, small red onions (*bawang merah* in Indonesian) and potato. In mixed gardens, combination of *MGFC* + chicken + fishpond or combination of *MGFC* + chicken + beef or *MGFC* + beef showed a higher B/C ratio than that of duku and coconut. Our study clearly demonstrates a large difference in the benefit of different land use types. Therefore, we must maintain vegetable gardens to continue generating suitable agricultural profits in the Sumani watershed. Similar considerations must be extended to other watersheds when applying our agro-ecological land use planning.

3D Agro-ecological land use planning

A simulation study was conducted in the watershed in 3D map, with the exception of forest, by converting each of the land use types to different land use type, where none remained under its own “present land use”. The simulation applied a single land use type to simulate control of soil erosion rates on an area where the soil erosion rate exceeded the *TER* (Figure 3). The application of *VBC* was an effective means to reduce the soil erosion rate below the *TER* (5.6%). A 13.7% and 4.5% decrease in soil erosion below the *TER* for the entire watershed was observed when *VCBC* and *VTBC* respectively were adopted as a soil conservation practice. Due to the mountainous topography and high annual rainfall in the Sumani watershed, these conservation practices were not adequate to control soil erosion in agricultural lands. *MBC* and *SBC* were more effective in reducing soil erosion rates in the watershed. This is in agreement with past research conducted in Indonesia, which demonstrated that mixed gardens and paddy field were best suited to reducing soil erosion and increasing crop productivity (Kusumandari and Mitchell 1997). *MBC* and *SBC* were shown to reduce soil erosion rates < *TER* in, approximately 16% and 22.7% of the total watershed area respectively. Mixed gardens and paddy field exhibited a greater potential to control soil erosion due to lower *CP*-factors compared with vegetable gardens. Plants grown in mixed gardens have multilayered canopies. The lowest layer serves as an effective ground cover, protecting the soil surface from disturbance by intense and prolonged rainfall. Paddy field has bunds surrounding the area, which controls soil erosion and run off. As we previously stated, in terms of the greatest economical profit/benefit to the Sumani watershed area, vegetable gardens are the preferred option, followed by paddy field or mixed gardens (Table 2). Reforestation must be applied to slopy areas to control high soil erosion rates in all areas exceeding the *TER*.

The predicted soil erosion rates under watershed Agro-ecological land use planning are shown in Figure 4. Data summarizing soil erosion rates, percent cover of land use types and benefit from agricultural production in the current and agro-ecological land use planning is shown in Table 3. The predicted soil erosion rate under the Agro-ecological land use planning was 12.9 t ha^{-1} yr^{-1}, accounting for a 78.9% reduction in the present land use condition. Zhang *et al*. (2003) reported that terracing vegetable gardens is an effective measure to reduce erosional processes in the Sumani watershed. Terracing is an effective method of soil conservation on steep slopes and has been used extensively to control water erosion in hilly areas by farmers in many countries. By applying the Agro-ecological land use planning to the watershed, we expected a high reduction in the soil erosion rate with low increase in the agro-economic profit i.e. 9.2% from that in the present land use condition. The change was from 367.17 million US$ in current land use condition to 401.68 US$ following the agro-ecological land use planning. In the present study, although we did not consider an option that included a paddy field rotation to increase profitability, it is feasible. It may be most practical and effective to cultivate vegetables during the dry season and rice in the wet season to control soil erosion and ensure that the farmers get the most reliable and profitable income.

Obviously, it is not possible to implement the agro-ecological land use planning at once. Agus *et al*. (1997) and Crasswell *et al*. (1997) report that continued use of appropriate agronomic practices is preferable to reduce soil erosion with low cost whenever possible. Therefore, we should proceed with the application of better watershed management practices step by step. In fact, land use conversion to agro-ecological land use is inevitable for agriculture on very steep slopes. However, the government and/or researchers must not pressurise farmers to take steps to make necessary changes (Svoray *et al*. 2005). This means natural motivation to apply soil conservation practices in the area should be in place. The government and researchers must provide appropriate information and advice farmers and/or the local government regarding appropriate watershed management. The Agro-ecological land use planning in the present study is a practical example of what can be provided.

In this Agro-ecological land use planning, reforestation was applied to sites with bush (grass, shrub and *alang-alang*) and some sites with mixed gardens and vegetables garden on the very steepest slopes. Reforestation is most suitable because these sites are not productive in the present land use condition and tree planting has been a common practice in mixed gardens. In contrast, soil conservation practices such as contour cropping (*VCB*) and terracing (*VTB*) in vegetable gerdens are rather difficult because the approach is costly and requires new skills for farmers. Incentives or subsidies to farmers from the central or local governments and other sectors, such as the National Electricity Agency, which are stakeholders of the Sumani watershed management may be necessary to execute the agro-ecological land use planning. Stevenson and Lee (2001) and Sarainsong *et al*. (2007) report that the strategies and management activities should be discussed and refined by local people, government and other stakeholders before planning implementation.

CONCLUSIONS

This study illustrated that the Erosion 3D with *USLE* (E3D-*USLE*) with appropriate values for each factor and Surfer tool are a useful tool, particularly to pinpoint high-risk areas where soil agro-ecological land use planning and conservation practices are needed. Consideration of high erosion risk areas is of most importance in 3D agro-ecological land use planning. Carrying out soil conservation measures on high-risk areas does not only raise the effectiveness of reducing soil erosion, but also reduce the cost of soil conservation and keep farmer income. Conventional soil and water conservation planning in the Sumani watershed has traditionally been conducted at the farm level. E3D-*USLE* integrated with Surfer tool has potential to permit a much wider scale appraisal at the watershed or regional level. The results of this study, including the land resources-based map, erosion 3D hazard map, and the proposed 3D agro-ecological land-use, could be used to formulate agricultural development strategies. Obtaining detailed information about the distribution of areas that are experiencing low soil loss, those that are experiencing medium soil loss, and those that are experiencing high soil loss helps government to set up proper strategies in accordance with the urgency of the management that needed to be implemented. In the planning of the proposed 3D agro-ecological land-use for the watershed, improvement of land resource management practices under the same land use was revealed to have good potential in helping to overcome soil erosion problems, as well as land use conversion. This study has clarified the application of the erosion 3D information and economic feasibility analysis and Surfer tool approach to 3D agro-ecological land use planning. It provides options for agricultural landscape planning in environments that are experiencing soil erosion problems. One of the most important things to consider is whether the local farmers can get support from outside when making a sustainable planning in the study area. If a great deal of support is available, the Agro-ecological land use planning is suggested since it is favorable in soil erosion control and accepted by the local farmers. The land use modification needs to be carried out gradually. The study therefore recommended that the application of better watershed management practices should be adopted step by step. However, land use conversion is inevitable on very steep slopes, the government and/or researchers must take into account the perception of farmers in making necessary recommendations/changes. This means natural motivation to apply soil conservation practices in the area should be in place. The classification of areas experiencing erosion into three classes – moderate soil loss, high soil loss, and very high soil loss – is intended to provide information more clearly to both farmers and government. Surely all classes except the "no erosion" class require similar but precise action. However, these actions seem difficult to implement simultaneously. Obtaining detailed information about the distribution of areas that are experiencing low soil loss, those that are experiencing medium soil loss, and those that are experiencing high soil loss helps government to set up proper strategies in accordance with the urgency of the management that needs to be implemented. It provides options for agricultural landscape planning in environments that are experiencing soil erosion problems.

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