EVALUATION OF LAND SUITABILITY FOR SELECTED LAND UTILIZATION TYPES USING GEOGRAPHIC INFORMATION SYSTEM TECHNOLOGY: (Case Study In Bandung Basin West Java)

Evaluasi Kesesuaian Lahan pada Beberapa Tipe Penggunaan Lahan Menggunakan Teknologi Sistem Informasi Geografis : (Studi Kasus di Daerah Aliran Sungai Bandung, Jawa Barat)

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ABSTRAK

Artikel ini membahas tentang pembangunan suatu model pemetaan kesesuaian lahan di suatu wilayah pedesaan dengan menggabungkan prosedur evaluasi lahan dengan pilihan-pilihan pengambilan keputusan dalam suatu sistem informasi geografis (SIG). Studi ini mencakup 5 tahapan : (1) mendisain unit pemetaan lahan, (2), mendiagnosa tipe-tipe penggunaan lahan yang ada dan keperluan-keperluannya, (3) menganalisis kesesuaian lahan melalui "matching" antara unit pemetaan lahan dengan tipe penggunaan lahan, (4) mengintegrasikan data ke basis data relasional (sosial-ekonomi), dan (5) penyajian peta kesesuaian lahan melalui proses "join table" antara hasil kesesuaian lahan dengan unit pemetaan lahan dalam SIG.

Studi ini memperlihatkan bahwa sebagian besar unit pemetaan lahan di areal studi sesuai dengan kesesuaian fisik dari penggunaan lahan (lebih dari 53% termasuk kedalam kelas kesesuaian sedang dan kesesuaian tinggi). Kesesuaian fisik yang diperoleh juga sejalan dengan kesesuaian ekonomi dimana BCR berkisar antara 1,1 sampai dengan 1,38.

INTRODUCTION

Background

Land evaluation is concerned with the assessment of land performance when used for specified purposes. It involves the execution and interpretation of basic surveys of climate, soils, vegetation and other aspects of land in terms of the requirements of alternative forms of land use. To be of the value in planning, the range of land uses considered has to be limited to those, which are relevant within the physical, economic and social context of the area considered. The comparisons must incorporate economic

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considerations. Land evaluation supports land use planning by supplying alternatives for land resource use and providing for each alternative. Land evaluation specialists should be involved in the integration of land evaluation results into this process (Food and Agriculture Organization, 1976).

Over the past decades, land use in developing countries has been subject to an unprecedented pace of change, mainly as a result of the growing demand for crop and livestock products. In many areas, rapid urbanization, mining and deforestation have also greatly affected patterns of land use. Projections for the year 2002 and beyond suggest that, due to population increase and income growth, demand for food and other agricultural products will continue to rise by over 3% annually (Smith, 1989). In most countries the diet is expected to diversify in favor of higher value commodities such as horticultural products. This will have important implications for future land use. Moreover, even where agricultural land use could still be extended, such as in tropical forest areas, this would pose a serious threat to fragile ecosystem (Pierce *et al.*, 1983).

In recent years, sustainability has become a key concept to describe the successful management of resources for agriculture to satisfy changing human needs while maintaining or improvement the quality of the environment and conserving natural resources (Coughlin *et al.*, 1994). Today, one is witnessing a situation of changing demands on land use, of increased needs to deploy efforts in marginal areas and of growing concerns about environmental issues. Under these condition, designing sustainable land use systems capable of meeting qualitatively expanding needs of the population in developing countries, present an enormous challenge to all those concern. Although methods to assess sustainability are still being developed, there is little doubt that intensification of land use at low external input levels is hardly ever sustainable.

Study Objective

The main objective of this study is to assess the suitability of different types of land, for selected and specified land use types. The selected land use types include, forestry land use types in addition to agricultural land use types, particularly when agricultural areas may not be productive, sustainable or socio-economically relevant.

MATERIALS AND METHODS

Times and location of the study area.

This study has been conducted from February until July 2002 at Bandung Basin of West Java Indonesia. The catchment area includes the Saguling Reservoir with an area of approximately 2,283 square km, geographically located between latitude 6° 4′ S and 7° 10′ S, and longitude 107° 15′ E and 107° 45′ E, (see Figure 1).

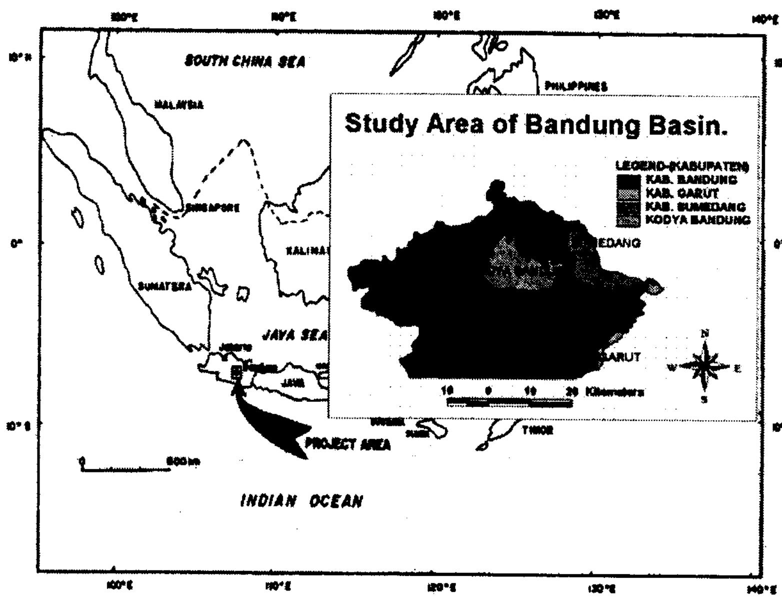

Figure 1. Study area location.

Data Sources

The principle supporting data for this study are the following spatial and non-spatial data available from Center for Soil and Agro-climate Research (Puslittanak) and National Coordinating Agency for Survey and Mapping (Bakosurtanal): (a) Spatial data consisting of thematic maps at scale 1: 100,000 (i.e., topography, geology, soil, slope, elevation and existing land use), (b) climatic data, and (c) non-spatial data consisting of socioeconomic data (i.e., agricultural productions, agricultural price lists, local population conditions). Data were also collected by ground fieldwork checking and observations in the study area.

Hardware and Software

Supporting Hardware and Software required are as follows: a) Hardware; Personal Computer Pentium II having 64.0 MB RAM and 6 GB hard disk, Digitizer, Plotter, Color Printer and Global Positioning System (GPS), b) Software; ArcInfo 3.5, ArcView 3.1 and ALES Version 4.65d.

Methods

The automated land evaluation system (ALES), ArcInfo, and ArcView were used to build the land suitability models. A loose coupling strategy as illustrated in Figure 2 was adopted to integrate these techniques. The methodological approach consisted of five steps: (1) design of land mapping units (LMUs) and their attributes using available thematic maps (i.e., topography, geology, soil, existing land use and elevation) in a GIS environment, (2) diagnostic of proposed land utilizations types (LUTs) and their requirements through land mapping units survey, (3) analysis of land suitability through a matching between land mapping units and land utilizations types assessed by automated land evaluation system, (4) export of output land evaluation (LE) to a spreadsheet program and input into a relational database; and (5) presentation of land suitability maps through joining tables for the output of land suitability analysis and land mapping units within a Geographic Information System (GIS) environment.

Design of Land Mapping Units

Due to this study being at regional level (scale 1: 100,000), physiographic units were considered as the land mapping units, while other thematic data such as geology, soil, slope, elevation were considered as their attributes. Based on physical data analysis (soil, geology, and topography) at scale of 1:100,000, field observations, and the geopedologic classification developed by Zinck (1990), twelve physiographic units and their associated land characteristics were determined in the study area and entered into the digital database via digitizing of the polygons' boundaries. These units comprised: (1) flood plains, (2) alluvio-lacustrine plains, (3) colluvial plains, (4) volcanic plains, (5) alluvio-volcanic fan, (6) volcanic fans, (7) volcanic foot-slopes, (8) lower volcanic ridges, (9) middle volcanic ridges, (10) upper volcanic ridges, (11) hills, and (12) mountains, as shown in Table 4. The characteristics of these land mapping units were recorded from existing data sets using GIS analysis: (1) elevation, (2) average annual rainfall, (3) effective soil depth, (4) soil drainage, (5) available water capacity, (6) soil texture, (7) slope, (8) soil pH, (9) soil cation exchange capacity, (10) soil organic matter, (11) soil base saturation, and (12) soil erodibility.

Diagnostic of Proposed Land Use Types

Seven land utilizations types were considered: 1.Irrigated rice fields, 2.Rain fed rice fields, 3.Dry land arable farming, 4.Mixed gardens, 5.Vegetables, 6.Tea plantations and 7.Forest (Pine plantations). The first and second land utilizations types were proposed to provide food availability. The third, fourth and fifth land utilizations types were proposed to provide cash income and employment. The sixth land utilizations type is thought to provide employment opportunities and export commodities, while controlling soil erosion in a more effective manner. Finally, the seventh land utilizations types was proposed to provide additional employment (i.e., reforestation) and planned to occupy any land mapping unit not suitable for other purposes.

The descriptions of the seven selected land utilizations types are as follows:

a. Land Utilizations Type 1(LUT 1): Irrigated rice field followed by vegetables

- It includes rice (*Oryza sativa LINN*) field and vegetable called 'Kangkung' (*Ipomea spp*) in irrigated areas that support monthly income.

b. Land Utilization Type 2(LUT 2): Rain fed paddy field followed by vegetables

- It includes rice (*Oryza sativa LINN*) field in non-irrigated area, corn (*Zea mays LINN*), Chinese cabbage (*Pisonia sylvetris T & R*), Peanuts (*Arachis hypogaea LINN*) and support monthly income.

c. Land Utilization Type 3(LUT 3): Dry land arable farming with terraces.

- It includes corn (*Zea mays LINN*), Chilly (*Capsicum frutescen LINN* or *Capsicum annum LINN*), paddy (*Oryza sativa LINN*) with terraces and support monthly income.

d. Land Utilization Type 4(LUT 4): Mixed Garden (Banana, Jack fruits, Petai, Bamboo).

- It includes banana (*Musa spp*), Bamboo (*Bambusa vulgaris SCHRAD*) tree, Jack fruit (*Artocarpus integra MEER*), Petai (*Parkia speciosa HASSK*) and support annual income.

e. Land Utilization Type 5(LUT 5): Vegetables.

- It includes corn (*Zea mays LINN*), Chilly (*Capsicum frutescen LINN* or *Capsicum annum LINN*), Chinese cabage (*Pisonia sylvetris* T & R), Tomatoes (*Solanum lycopertsicum LINN*), Cabbage (Brassica oleracea fa cacapitata), Carrot, Potatoes (*Solanum tuberosum LINN*) and support monthly income.

f. Land Utilization Type 6(LUT 6): Tea estates under tree plantation (*Toona sureni*).

- It includes tea (*Thea sinensis LINN*) plantations and sureni (*Toona sureni* MERR) tree plantations.

g. Land Utilization Type 7(LUT 7): Forest (Pine Plantation with King grass).

- It includes Pine (*Pinus merkusii*) plantation with King grass (*Setaria spachelata* or *Pennissetum purpureum*) as ground cover.

Land Characteristics Ratings.

The land characteristics within the study area were classified according to the ratings as shown in Table 1. Based on these ratings, a land suitability analysis was carried out by matching between the land use requirements of selected land utilizations types with the land characteristics of a given land-mapping unit (Food and Agriculture Organization, 1983).

Table 1. Land Characteristics Rating of the Study Area.

Nr	Land Characteristics	Class	Range	Remarks/code
1	Elevation (meter asl)	1	< 700	very low
		2	700-800	low
		3	800-900	moderate
		4	900-1300	high
		5	1300-1500	very high
		6	> 1500	extremely high
2	Average annual rainfall (mm)	1	< 800	very low
		2	800-1200	low
		3	1200-1800	moderately low
		4	1800-2500	moderate
		5	2500-4000	high
		6	> 4000	very high
3	Effective soil depth (cm)	1	< 15	very shallow
		2	15-35	shallow
		3	35-60	moderately deep
		4	60-120	deep
		5	> 120	very deep
4	Soil drainage	1	poor	pd
		2	imperfect	id
		3	moderate	mwd
		4	well	wd
		5	somewhat excessive	sed
		6	excessive	ed
5	Available water capacity (cm)	1	< 5	very low
		2	5-10.	low
		3	10-15.	moderate
		4	15-20.	high
		5	> 20	very high
6	Soil texture	1	sapric material	a
		2	clay	c
		3	clayloam	cl
		4	hemic material	e
		5	fibric material	f
		6	loam	l
		7	loamy sand	ls
		8	sand	s
		9	sandy clay	sc
		10	sandy clay loam	scl
		11	silt	si
		12	silty clay	sic
		13	silty clay loam	scl
		14	silt loam	sil
		15	sandy loam	sl

Nr	Land Characteristics	Class	Range	Remarks
7	Topography (%)	1	< 1	flat
		2	1 - 3.	nearly flat
		3	3 - 8.	undulating
		4	8 - 15.	rolling
		5	15 - 30	hillocky
		6	30 - 50	hilly
		7	> 50	mountainous
8	Soil pH	1	< 3.5	ultra acid
		2	3.5 - 4.5	extremely acid
		3	4.5 - 5	very strongly acid
		4	5 - 5.5	strongly acid
		5	5.5 - 6	moderately acid
		6	6 - 6.5	slightly acid
		7	6.5 - 7.3	neutral
		8	7.3 - 7.8	slightly alkaline
		9	7.8 - 8.4	moderately alkaline
		10	8.4 - 9	strongly alkaline
		11	9 - 14.	very strongly alkaline
9	Soil cation exchange capacity (cmol/kg)	1	< 8	extremely low
		2	8 - 12.	low
		3	12 - 16.	moderate
		4	16 - 24	high
		5	24 - 60	very high
		6	> 60	extremely high
10	Soil organic matter (kg/m2)	1	< 1	very low
		2	1 - 3.	low
		3	3 - 8.	moderate
		4	8 - 12.	moderately high
		5	12 - 50.	high
11	Soil base saturation	1	< 5	extremely low
		2	5 - 10.	very low
		3	10 - 20.	low
		4	20 - 35	moderate
		5	35 - 75	high
		6	> 75	very high
12	Soil erodibility	1	< 0.10	very low
		2	0.10 - 0.17	low
		3	0.17 - 0.28	moderate
		4	0.28 - 0.43	high
		5	> 0.43	very high

Matching between land mapping units and land utilizations types assessed by automated land evaluation system.

In order to provide a land suitability analysis of the study area using automated land evaluation system (ALES) program, the following steps need to be carried out: (1) determine the land characteristics data belonging to land mapping units pre-defined and classify them in to a given class; (2) identify the land use requirements for each of the land utilizations type considered; (3) identify the input and output economic parameters for each land utilizations type, (4) select land mapping unit (e.g. *alluvio-lacustrine plains*), and classify each of the land characteristics belonging to the land mapping unit(LMU); (5) specify the description of the land utilizations types(e.g., irrigated rice fields), length of planning horizons (i.e., 32 years for tea estates), economic parameters (i.e., discount rate: 15 %), inputs annual (i.e., manpower), and input by year (i.e., land tax) for each land utilizations types being considered; (6) specify the land use requirements of each land utilizations type(LUT); (7) decide which land characteristics are dominant for each land utilizations type; (8) For each land utilizations type select an optimum yield, the number of years for which planning is computed; and (9) evaluate all the land mapping units and their corresponding land utilizations type according to their physical and economical suitability using the parameters selected in the previous.

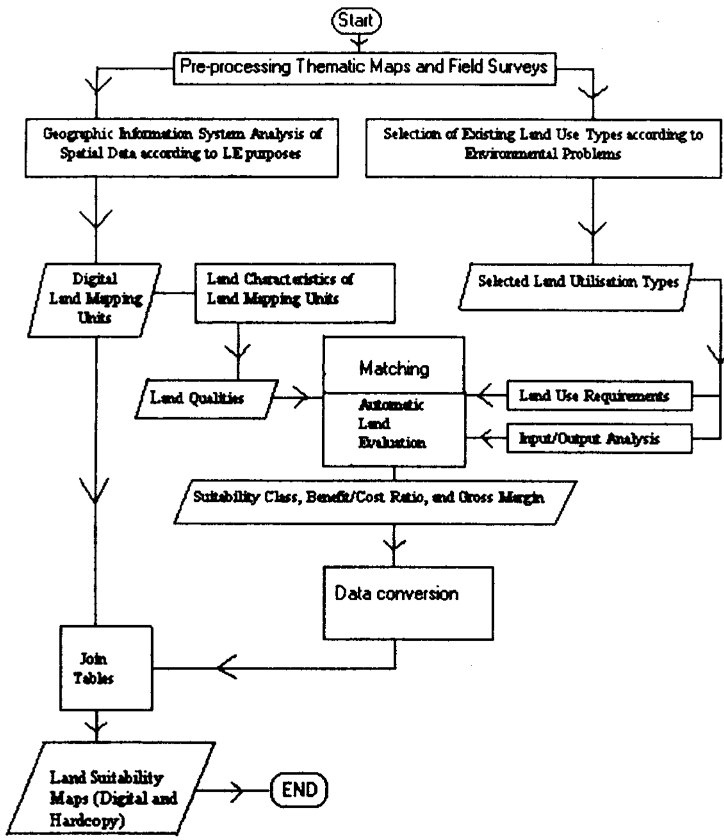

Figure 2. Flow diagram of the Automated land evaluation and geographic information systems for evaluating land suitability

Land Evaluation to a spreadsheet.

In order to present land suitability maps in a GIS environment, the outputs of land suitability analysis (i.e., land suitability class, benefit/cost ratio, and gross-margin) were exported to a spreadsheet program (Excel) and input to a relational database. Finally, the visual display of the land suitability maps required is by importing the land mapping units and the land suitability class tables derived in automated land evaluation system into

ArcView. These tables were further joined, the legend edited and the final cartographic layout designed to generate digital land suitability maps.

Presentation of the Land Suitability Maps.

ArcView was used to present the digital land suitability maps through joining the tables of the land suitability outputs produced by automated land evaluation system and the digital land-mapping units generated using ArcInfo. Several commands within ArcView, such as edit legend, layout, and print were used respectively for designing and generating digital land suitability maps as well as printing hardcopy maps.

RESULTS AND DISCUSSIONS

Digital Land Mapping Units and Analysis of Existing Land Use Types.

Spatial analysis was performed within ArcInfo and ArcView to obtain the main characteristics of a given land-mapping unit composing the study area, are tabulated in Table 2. This table indicates the total surface area of the study area is approximately 208,191.53 hectares. Seven dominant physiographic units were identified: lower volcanic ridges (21.41 %), alluvio-lacustrine plains (19.30 %), hills (15.01 %), middle volcanic ridges (10.47 %), upper volcanic ridges (10.34 %), flood plains (8.02 %) and volcanic foot-slopes (5.02 %). The majority of the land-mapping units (62%), present slopes between 1 to 30 %, being therefore suitable for agricultural activities.

Table 2. Land Characteristics of the Land Mapping Units

				Land Characteristics of the Land Mapping Units.											
Number	Physiographic Units	Area (ha)	(%)	Elevation (m above sea level)	Annual Rainfall (mm)	Effective Soil Depth (cm)	Soil Drainage Conditions	AWC-100 cm	Soil Texture	Slope Steepness (%)	pH_50 cm (index)	Soil Organic Matter (kg/m2)	CEC_50 cm (cmol/kg)	Base Saturation (%)	Soil Erodibility (Index)
1	Flood Plains	16,688.66	8.02	694	1,568	98	Poor	20.6	sc	1-3	6.2	3.61	22.4	81	0.36
2	Alluvio-Lacustrine Plains	40,174.15	19.30	684	1,493	146	Mod. Well	22.6	c	1-5	6.8	2.24	50.8	82	0.24
3	Colluvial Plains	6,031.72	2.90	800	1,493	132	Poor	17	sicl	1-5	5.8	4.68	30.3	86	0.19
4	Volcanic Plains	2,295.00	1.10	1,313	1,835	140	Mod. Well	19.5	ls	1-15	5.4	2.99	95.8	73	0.21
5	Alluvio-Volcanic Fan	2,321.44	1.12	707	1,717	153	Poor	21.3	ls	3-7	6	3.9	40	80	0.19
6	Volcanic Fans	6,389.59	3.07	880	2,162	102	Well	22	cl	3-8	5.3	3.34	32.8	81	0.29
7	Volcanic Foot Slopes	10,451.81	5.02	905	1,857	144	Well	19.5	cl	3-8	6.5	1.89	40	61	0.38
8	Lower Volcanic Ridges	44,578.27	21.41	728	1,548	132	Well	19.5	sicl	3-30	5.8	1.67	28.5	54	0.23
9	Middle Volcanic Ridges	21,788.17	10.47	1,352	1,676	139	Well	19.8	cl	8-50	5.3	2.64	20.9	58	0.25
10	Upper Volcanic Ridges	21,531.35	10.34	1,437	1,842	107	Well	16.8	cl	>50	5.4	2.75	23.1	54	0.28
11	Hills	31,256.20	15.01	1300	2,162	126	Well	18.5	cl	15-50	5.6	1.28	20.2	64	0.18
12	Mountains	4,685.17	2.25	1,400	2,162	98	Well	19.7	cl	>50	5	1.3	17.7	30	0.16
	Total area (ha)	208,191.53	100.00	-	-	-	-	-	-	-	-	-	-	-	-

Table 3. Existing Land Utilization Types within Physiographic Units (in hectare)

Land Mapping Unit Number	Physiographic units	Area of physiographic units (ha)	Existing Land Utilization Types in Hectares.											
			LUT 1. Irrigated rice fields	LUT 2. Rain fed rice fields	LUT 3. Dry Land Arable farming	LUT 4. Mixed Garden	LUT 5. Vegetables	Toona Sureni Plantations	Quinine Plantations	LUT 6. Tea Plantations	LUT 7. Production Forest (Pine Plantations)	Primary Forest	Secondary Forest	Settlements
1	Flood Plains	16,688.66	9059.8	797.2	1412.2	1959.9	903.2	-	9.6	-	323.8	150.7	-	2072.3
2	Alluvio-Lacustrine Plains	40,174.15	30364.3	2039.1	1265.8	1599.4	-	-	-	-	-	-	-	4905.7
3	Colluvial Plains	6,031.72	2898.9	1785.0	102.9	883.1	-	-	-	-	-	9.5	122.8	309.5
4	Volcanic Plains	2,295.80	142.9	-	-	25.7	1699.3	-	-	-	11.7	-	-	415.4
5	Alluvio-Volcanic Fan	2,321.44	2046.6	-	5.6	54.0	-	-	-	-	-	-	-	215.2
6	Volcanic Fans	6,389.59	2853.0	154.7	834.1	795.3	323.8	-	-	437.5	452.1	335.8	-	203.5
7	Volcanic Foot Slopes	10,451.81	1664.2	229.6	186.8	14.0		-	-	-	-	-	-	8357.2
8	Lower Volcanic Ridges	44,578.27	17521.7	1106.5	9023.4	7997.2	1747.4	-	-	424.7	1132.1	1231.8	1531.7	2588.7
9	Middle Volcanic Ridges	21,788.17	2000.5	-	4549.4	1392.9	618.8	273.0	876.9	69.3	6369.5	4947.8	954.6	8.0
10	Upper Volcanic Ridges	21,531.35	937.6	130.3	4602.0	846.3	252.3	0.2	278.2	-	8958.9	5524.2	1.6	-
11	Hills	31,256.20	7547.9	1640.1	3724.6	11632.7	62.3	-	-	1.1	1543.0	4021.3	918.0	165.1
12	Mountains	4,685.17	961.5	57.7	344.6	1188.6	-	-	-	589.3	1050.5	-	479.5	13.5
	Total area (ha)	208,191.53	77998.9	7940.2	26051.4	28309.1	5607.1	273.2	1164.7	1521.9	19841.6	16221.1	4008.2	19254.1

Likewise, a cartographic overlay was constructed between land mapping units and the existing land use types. The results are presented in Table 3. From Table 3, six dominant existing land use types are identified: irrigated rice fields (77,988.9 ha), mixed gardens (28,309.1 ha), dry land arable farming (26,051.7 ha), settlements (19,254.1 ha) and primary forest (1,6221.1 ha), and pine plantations (19,841.6 ha).

Based on the observations, it is known that irrigated rice fields and rain fed rice fields support food availability; dry land arable farming and vegetables support monthly income and food availability, mixed gardens supports annual income; crop plantations provide rural employment and export commodities and soil erosion control; and pine plantations (production forest) provide additional rural employment and soil erosion control. The tea estates for example, have three main advantages for sustainable rural development in the study area: provides a commodity for export, employment for local population, while controlling soil erosion. Therefore, these land utilizations types were selected as proposed land use types to solve environmental and economic problems in the area and analyzed for their requirements.

A joint analysis of Tables 2 and 3 shows that the highest soil erodibility values occur in the volcanic foot slopes (0.38) mostly used for settlements. Likewise, soil erodibility values of 0.36 are recorded in the flood plains where the dominant land use types are: irrigated rice fields (9,059.8 ha), settlements (2,072.3 ha), mixed gardens (1,959.9 ha), dry land arable farming (1,412.26 ha), vegetables (903.2 ha), rain fed rice field (797.2 ha), pine plantations (323.8 ha), and primary forest ((150.7 ha). The lowest soil erodibility values occur in the mountains (0.16) and hills (0.18) mostly used for mixed gardens, irrigated rice fields, dry land arable farming, rain fed rice fields, and pine plantations.

Table 4. The Land Suitability Output of Selected and Existing Land Utilization Types (ha. and percentage) for each Physiographic Unit in Bandung Basin.

No.	Physiographic units	Area (ha)	Land Suitability Sub Class of Selected Land Utilization Types (Land Suitability Rating/Hectares)						
			LUT 1. Irrigated Rice Fields	LUT 2. Rain fed Rice Fields	LUT 3. Arable Farming	LUT 4. Mixed Gardens	LUT 5. Vegetables	LUT 6. Tea Plantations	LUT 7. Forest (Pine Plantations)
1	Flood Plains	16,688.66	S1 9,059.8 (11.6%)	S2na/rc 797.2 (10.0%)	S3tc 1,412.2 (5.4%)	S2rc 1,959.9 (6.9%)	S3tc 903.2 (16.1%)	-	S2rc 323.8 (1.6%)
2	Alluvio-Lacustrine Plains	40,174.15	S1 30,364.3 (38.9%)	S2na/rc 2039.1 (25.7%)	S3tc 1,285.8 (4.9%)	S2rc 1,599.4 (5.6%)	-	-	-
3	Colluvial Plains	6,031.72	S2na/tc 2,898.9 (3.7%)	S2na 1,785.0 (22.5%)	S2tc 102.9 (0.4%)	S1 803.1 (2.8%)	-	-	-
4	Volcanic Plains	2,295.00	S3tc 142.9 (0.2%)	-	-	S2rc/wa 25.7 (0.1%)	S3rc 1,699.3 (30.3%)	-	S1 11.7 (0.1%)
5	Alluvio-Volcanic Fan	2,321.44	S2tc 2,046.6 (2.6%)	-	S2tc 5.6 (0.02%)	S1 54.0 (0.2%)	-	-	-
6	Volcanic Fans	6,389.59	S2tc 2,853.0 (3.7%)	S2na/tc 1,54.7 (1.9%)	S1 834.1 (3.2%)	S1 795.3 (2.8%)	S1 323.8 (5.8%)	S2tc 437.5 (28.7%)	S1 452.1 (2.3%)
7	Volcanic Foot Slopes	10,451.81	S3tc 1,664.2 (2.1%)	S3tc 229.6 (2.9%)	S1 186.8 (0.7%)	S2wa 14.0 (0.05%)	-	-	-
8	Lower Volcanic Ridges	44,578.27	S3na 17,521.7 (22.5%)	S3na 1,106.5 (13.9%)	S2tc 9,023.4 (34.6%)	S1 7,997.2 (28.2%)	S2tc 1,747.4 (31.2%)	S2tc 424.7 (27.9%)	S1 1,132.1 (5.7%)
9	Middle Volcanic Ridges	21,788.17	S3tc 2,000.5 (2.6%)	-	S2tc 4,549.4 (17.5%)	S2tc 1,392.9 (4.9%)	S1 618.8 (11.0%)	S1 69.3 (4.6%)	S1 6,369.5 (32.1%)
10	Upper Volcanic Ridges	21,531.35	S3tc 937.6 (1.2%)	S3tc 130.3 (1.6%)	S2tc 4,602.0 (17.7%)	S2rc/tc 846.3 (3.0%)	S1 252.3 (4.5%)	-	S2rc 8,958.9 (46.2%)
11	Hills	31,256.20	S3tc 7,547.9 (9.7%)	S3tc 1,640.1 (20.7%)	S1 3,724.6 (14.3%)	S1 11,632.7 (41.1%)	S1 62.3 (1.1%)	S1 1.1 (0.07%)	S1 1,543.0 (7.8%)
12	Mountains	4,685.17	S3tc 961.5 (1.2%)	S3tc 57.7 (0.7%)	S1 344.6 (1.3%)	S2rc 1,188.6 (4.2%)	-	S1 589.3 (38.7%)	S2rc 1,050.5 (5.3%)
	Total area (ha)	208,191.53	77,998.9	7,940.2	26,051.4	28,309.1	5,607.1	1,521.9	19,841.6

Note:
S1 = Highly Suitable, **S2** = Moderately Suitable, **S3** = Marginally Suitable, **N** = Not Suitable
tc = Temperature condition for growth as a limiting factor.
na = Nutrient availability for growth as limiting factor.
rc = Root condition for growth as limiting factor.
wa = Water availability for growth as limiting factor.

Land Suitability Analysis.

Based on the integration of land evaluation and GIS for mapping land suitability, the outputs of land suitability analysis is shown in Table 4. It is shown that most of the land mapping units meet the requirements to cultivate the land utilizations types identified, to resolve the main environmental and economic problems in the area. The highest limiting factor is temperature conditions. Each land mapping unit is particularly suitable for certain land utilizations types such as: flood plains and alluvio-lacustrine plains are highly suitable for irrigated rice fields. Examples of land suitability maps for LUT-1 end LUT-7 are respectively shown in Figures 3 and 4.

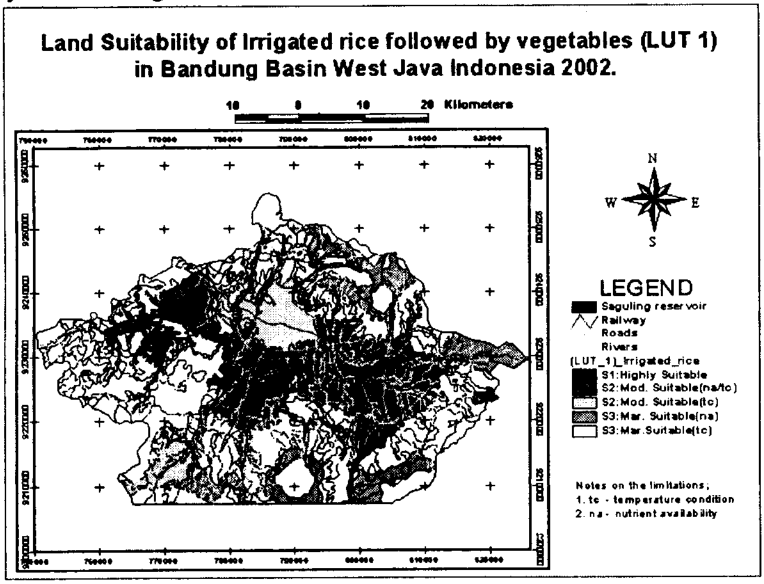

Figure 3. Land Suitability Map of LUT 1:Irrigated Rice Fields followed by Kangkung.

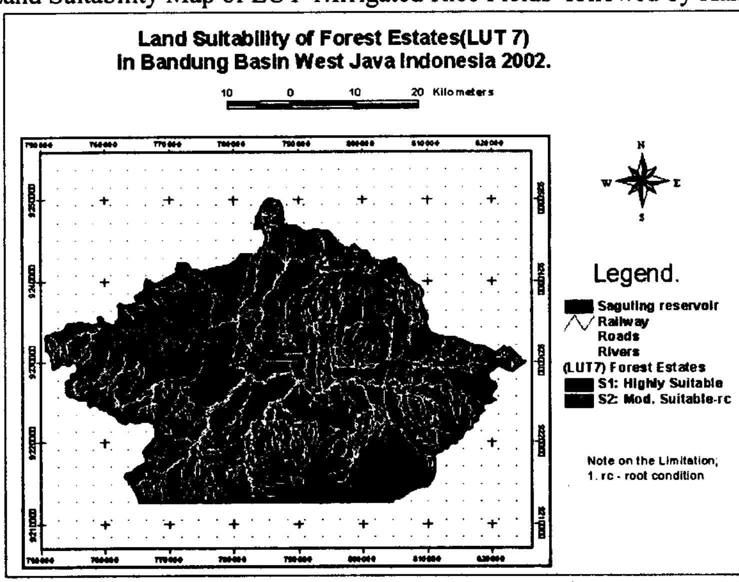

Figure 4. Land Suitability Map of LUT 7: Forest Estates (Forest including Pine plantations and King grass)

Benefit/Cost Ratio (BCR) and Gross Margin (GM)

Table 4 also shows that most land utilizations types are competing with each other. To select which one is the best for investment, gross margin and a benefit/cost ratio analysis of these land utilizations types within a given land-mapping unit should be undertaken, as shown in Tables 5 and 6. Gross Margin analysis is selected because it is satisfactory for analyzing land utilization types with no capital improvements and only recurring costs and outputs. Further more, Gross Margin is not susceptible to errors due to incorrect assumptions about discount rate. The Benefit/Cost Ratio expresses the Net Present Value in terms of the leverage of each unit of currency invested. The higher the Benefit/Cost Ratio, the more return is expected for each unit currency invested. Also, the higher Benefit/Cost Ratio, the less risky the land utilization types, because a lower-than-expected benefit, or higher-than-expected cost, will still leave the Benefit/Cost Ratio greater than one. The Benefit/Cost Ratio is dimensionless and reflects the leverage of investing a unit sum of money into the project.

Table 5 shows that vegetables allocated to volcanic fans, middle volcanic ridges, upper volcanic ridges and hills have the highest benefit/cost ratio that is 8.31. Existing tea estate of Bandung Basin, have benefit/cost ratio ranging from 1.1 to 1.38. In term of investment, a benefit cost ratio of more than one is still considered a benefit, because additional factors such as stable market and rural employment availability, ground water recharge and soil erosion control, food self sufficiency should also be taken into account.

Table 5. The Benefit/Cost Ratio (BCR) of the selected land utilizations type (LUT) in a given Land Mapping Unit.

No.	Physiographic units	Area (ha)	Benefit/Cost Ratio (BCR) of Selected Land Utilization Types.						
			LUT 1.	LUT 2.	LUT 3.	LUT 4.	LUT 5.	LUT 6.	LUT 7.
1	Flood Plains	16,688.66	2.98	3.42	2.28	1.92	4.99	-	2.47
2	Alluvio-Lacustrine Plains	40,174.15	2.98	3.42	2.28	1.92	4.99	-	2.47
3	Colluvial Plains	6,031.72	2.65	3.42	3.02	2.39	6.65	1.1	3.08
4	Volcanic Plains	2,295.00	2.31	2.56	2.28	1.92	4.99	0.83	3.08
5	Alluvio-Volcanic Fan	2,321.44	2.65	3.42	3.02	2.39	6.65	1.1	3.08
6	Volcanic Fans	6,389.59	2.65	3.42	3.77	2.39	8.31	1.1	3.08
7	Volcanic Foot Slopes	10,451.81	2.31	2.56	3.77	1.92	6.65	1.38	3.08
8	Lower Volcanic Ridges	44,578.27	2.31	2.56	3.02	2.39	6.65	1.1	3.08
9	Middle Volcanic Ridges	21,788.17	2.31	2.56	3.02	1.92	8.31	1.38	3.08
10	Upper Volcanic Ridges	21,531.35	2.31	2.56	3.02	1.92	8.31	1.38	2.47
11	Hills	31,256.20	2.31	2.56	3.77	2.39	8.31	1.38	3.08
12	Mountains	4,685.17	2.31	2.56	3.77	1.92	8.31	1.38	2.47
	Total area (ha)	208,191.53							

Table 6 shows that for the conditions of the study area, vegetables provide the highest gross margin over of planning horizon of five years ranging from $US 13,320.86 to $US 17,151.25 per ha per year while mixed garden provide the lowest return around $US 391.68 to $US 545.75 per ha per year.

Table 6. Gross Margin of the Selected Land Utilizations Type (LUT) in a given land mapping units.

No.	Physiographic units	Area (ha)	The Gross Margin of Selected Land Utilization Types ($US/ha/yr).						
			LUT 1.	LUT 2.	LUT 3.	LUT 4	LUT 5.	LUT 6.	LUT 7.
1	Flood Plains	16,688.66	1,722.00	2,168.25	1,521.85	391.68	9,490.05	-	1,303.16
2	Alluvio-Lacustrine Plains	40,174.15	1,722.00	2,168.25	1,521.85	391.68	9,490.05	-	1,303.16
3	Colluvial Plains	6,031.72	1,446.00	2,168.25	2,374.25	546.75	13,320.65	1,326.86	1,697.16
4	Volcanic Plains	2,295.00	1,170.00	1,441.25	1,521.85	391.68	9,490.05	764.4	1,697.16
5	Alluvio-Volcanic Fan	2,321.44	1,446.00	2,168.25	2,374.25	546.75	13,320.65	1,326.86	1,697.16
6	Volcanic Fans	6,389.59	1,446.00	2,168.25	3,226.65	546.75	17,151.25	1,326.86	1,697.16
7	Volcanic Foot Slopes	10,451.81	1,170.00	1,441.25	3,226.65	391.68	13,320.65	1,889.33	1,697.16
8	Lower Volcanic Ridges	44,578.27	1,170.00	1,441.25	2,374.25	546.75	13,320.65	1,326.86	1,697.16
9	Middle Volcanic Ridges	21,788.17	1,170.00	1,441.25	2,374.25	391.68	17,151.25	1,889.33	1,697.16
10	Upper Volcanic Ridges	21,531.35	1,170.00	1,441.25	2,374.25	391.68	17,151.25	1,889.33	1,303.16
11	Hills	31,256.20	1,170.00	1,441.25	3,226.65	546.75	17,151.25	1,889.33	1,697.16
12	Mountains	4,685.17	1,170.00	1,441.25	3,226.65	391.68	17,151.25	1,889.33	1,303.16
	Total area (ha)	208,191.53							

Table 7 shows a joint analysis, which summarize the condition of land suitability of seven selected land utilization types existing in Bandung Basin. The highly suitable areas consist of irrigated rice fields (39,424.1 ha -that is 50.5 % of the total area of irrigated rice fields), followed by mixed garden (21,282.3 ha -that is 75.1 % of the total area of mixed garden), forest-pine production (9,508.4 ha -that is 48 % of the total area of forest-pine production), dry land arable farming (5,090.1ha -that is 19.5 % of the total area of arable farming), vegetables (1,257.2 ha -that is 43.4 % of the total area of vegetables) and tea plantations (659.7 ha -that is 48 % of the total area of tea plantations).

Table 7. Economic and physical suitability of the selected land utilization types (LUTs) within the existing area of Bandung Basin.

Economic and Physical Suitability	**LUT 1: Irrigated rice fields**	**LUT 2: Rain fed rice fields**	**LUT 3: Dry land arable farming**	**LUT 4: Mixed Garden**	**LUT 5: Vegetables**	**LUT 6: Tea Plantations**	**LUT 7: Forest Pine Plantations**
Highly suitable	S1	-	S1	S1	S1	S1	S1
BCR	2.98	-	3.77	2.39	8.31	1.38	3.08
GM ($US/ha/yr)	1,722.00	-	3,226.65	545.75	17,151.25	1,889.33	1,697.16
Percentage (%)	50.5	-	19.5	75.1	22.4	43.4	48.0
Area (ha)	**39,424.1**	-	**5,090.1**	**21,282.3**	**1,257.2**	**659.7**	**9,508.4**
Moderately suitable	S2	S2	S2	S2	S2	S2	S2
BCR	2.65	3.42	3.02	1.92	6.65	1.1	2.47
GM ($US/ha/yr)	1,446.00	2,168.25	2,374.25	391.68	13,320.55	1,326.86	1,303.16
Percentage (%)	10	60	70.2	24.9	31.2	56.4	52
Area (ha)	**25,320.2**	**5,882.5**	**18,283.3**	**7,026.8**	**1,747.4**	**862.2**	**10,333.2**
Marginally suitable	S3	S3	S3	-	S3	-	-
BCR	2.31	2.56	2.26	-	4.99	-	-
GM ($US/ha/yr)	1,170.00	1,441.25	1,521.85	-	9,490.05	-	-
Percentage (%)	39.5	40	10.3	-	46.4	-	-
Area (ha)	**13,254.6**	**2,057.7**	**2,678**	-	**2,602.5**	-	-

Notes:

S1-Highly suitable BCR -Benefit cost ratio
S2-Moderately suitable GM -Gross margin
S3-Marginally suitable LUT -Land utilization type

%: The percentage from total area of each land utilization type (LUT) in Bandung Basin.

CONCLUSIONS AND RECOMMENDATION

Conclusions

From the foregoing discussions, the following unclusions are derived :

Physical land suitability of selected land utilization types (LUT).

Land Utilizations Type 1(LUT 1)-Irrigated rice fields; 50.5 % are highly suitable (S1); 10 % are moderately suitable (S2) because temperature and nutrient conditions for growth as moderate limiting factors and 39.5 % are marginally suitable (S3) because temperature and nutrient conditions for growth as serious limiting factors.

Land Utilizations Type 2 (LUT 2)-Rain fed rice; 60 % are moderately suitable (S2) due to nutrient availability and root condition for growth as moderate limiting factors and 40 % are marginally suitable (S3) due to nutrient availability and temperature condition for growth as serious limiting factors.

Land Utilizations Type 3 (LUT 3)-Dry land arable farming; 19.5 % are highly suitable (S1); 70.2 % are moderately suitable (S2) because temperature condition for growth as a moderate limiting factor and 10.3 % are marginally suitable (S3) because temperature condition for growth as a serious limiting factor.

Land Utilizations Type 4 (LUT 4)-Mixed gardens; 75.1 % are highly suitable (S1) and 24.9 % are moderately suitable (S2) because root condition and water availability for growth as moderate limiting factors.

Land Utilizations Type 5 (LUT 5)-Vegetables; 22.4 % are highly suitable (S1); 31.2 % moderately suitable (S2) because of temperature condition for growth as a limiting factor and 46.4 % marginally suitable (S3) because temperature and root condition for growth as serious limiting factors.

Land Utilizations Type 6 (LUT 6)-Tea plantations; 43.4 % are highly suitable (S1) and 56.6 % are moderately suitable (S2) because of root condition for growth as a limiting factor.

Land Utilizations Type 7 (LUT 7)-Forest (Pine plantations); 48 % are highly suitable (S1) and 52 % are moderately suitable (S2) because of root condition for growth as a limiting factor.

Area of Physiographic Unit in Bandung Basin.

The total area of the physiographic (land mapping) unit in Bandung Basin is 208,191.5 hectares and consist of Flood Plains (16,688.7 ha), Alluvio-Lacustrine Plains (40,174.2 ha), Colluvial Plains (6,031.7 ha), Volcanic Plains (2,295.0 ha), Alluvio-Volcanic Fan (2,321.4 ha), Volcanic Fans (6,389.6 ha), Volcanic Foot Slopes (10,451.8 ha), Lower Volcanic Ridges (44,578.3 ha), Middle Volcanic Ridges (21,788.2 ha), Upper Volcanic Ridges (21,531.4 ha), Hills (31,256.2 ha) and Mountains (4,685.2 ha).

Soil erodibility.

The highest soil erodibility values occur in the volcanic foot slopes (0.38) mostly used for settlements. Likewise, soil erodibility values of 0.36(high) are recorded in the flood plains where the dominant land use types are: irrigated rice fields (9,059.8 ha), settlements (2,072.3 ha), mixed gardens (1,959.9 ha), dry land arable farming (1,412.26 ha), vegetables (903.2 ha), rain fed rice field (797.2 ha), pine plantations (323.8 ha), and primary forest ((150.7 ha). The lowest soil erodibility values occur in the mountains with value of 0.16(low) and hills with value of 0.18(moderate) mostly used for mixed gardens, irrigated rice fields, dry land arable framing, rain fed rice fields, and pine plantations.

Economic Suitability

Vegetables allocated to Middle Volcanic Ridges, Volcanic Fans, Hills, Mountains and Upper Volcanic Ridges have the highest Benefit/Cost Ratio that is 8.31. The lowest is from existing tea estates of Bandung Basin, ranging from 1.1 to 1.38. Vegetables provide the highest gross margin over of planning horizon of five years ranging from $US 9,490.05 to $US 17,151.25 per ha per year, while mixed garden provide the lowest return around $US 391.68 to $US 545.75 per ha per year.

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