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The Application of Geographic Information System for Sustainable Land Use Planning of Central Kalimantan Province, Indonesia

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Abstract
Lands are scarce resources and must be optimally and sustainably utilize to satisfy the growing world population. Not all lands are suitable for agriculture purposes and this can be achieved through agroecological approach with the aid of Geographic Information System. A land use planning study on the basis of agroecological zoning was conducted in Central Kalimantan province of Indonesia. The general methodology in this study was based on land evaluation concept. The expert system called Land Use Program was employed to support land evaluation as general guideline for selection of agriculture system and land utilization. Land resources and climate data were then interpreted by expert system to determine zoning system for forest, perennial and annual crop, and agroforestry. The application of geographic information (GIS) was used as database management system (DBMS) for tabular and spatial reference data as basic information of land use planning. On the basis of land characteristics and climatic data, Central Kalimantan would be geographically divided into 7 main zones and 4 sub-zones with its zoning system within each zone or sub-zone. The Zone I, VI, VII, and sub-zone V.2 with the total area of 4,481,300 hectares or 29.1% of total Central Kalimantan province would be allocated for forest. The Zone II and sub-zone V.1 would be recommended for perennial crop, while zone IV (sub-zone IV1 and IV.2) would be allocated for annual crops. The total area for the perennial crop zones (II and V.1) and annual crop zones (VI) would be 6,708,400 hectares (43.6%) and 2,564,000 hectares (16.7%), respectively. The Zone III with an area of almost 1,509,000 hectares (9.8%) would be recommended for agroforestry. The agroecological zone approach allows efficient, effective, and optimal land utilization but for must be cautiously applied to ensure sustainable future development of Central Kalimantan.
Keywords: GIS, land use planning, agroecological system, Central Kalimantan.

1. Introduction

In land use planning, not all land can be optimally used for agricultural purposes. In order to achieve sustainable agriculture, agriculture development must be oriented to keep the environment and potential natural resources safe and guard. It is therefore necessary to determine areas with agricultural potential and those requiring resource conservation and protection (Altieri, 1992). Sustainable agriculture and land use can be achieved through proper land use and ecologically sound management technologies (Amien, 1998). Proper land use ensures that people can benefit from nature during their lifetime and also ensures the resources can be used for future generations. In addition, the future productivity and profitability of farming will depend increasingly on measures taken from now on to conserve resources and protect the environment (Schaller, 1993).

Sustainable agricultural land use can be achieved through agroecological approach, whereby the group of crops or individual crop can be optimally cultivated in the regions with homogeneous climate and soil based on land suitability and capability (Altieri, 1992). The agroecological zone refers to the division of land into smaller unit which have similar characteristics and homogeneous natural environmental condition (Hamdan *et al.*, 2006). The selection of zoning system with agroecological approach can help to determine systematically the suitable agricultural technology packages based on biophysical condition and agroecology (Bhermana and Massinai, 2003). With agroecological zone approach, each land can be utilized optimally based on its agroecological conditions (Berry and Berry, 1988). It also facilitates areas selection for proper land use and appropriate agricultural system. The application of geographic information system is used as database management system (DBMS) for spatial reference data to provide useful information of land resource as basic information of land use planning. GIS is applied to integrate great quantities of information of land resources and spatial data for land use planning process (Mispan, 2002).

The Central Kalimantan with the total area of almost 15 million hectares is currently alienated into several land utilization types that is forest, dry land agriculture, wet land agriculture, and non agricultural land such as mining and settlement areas (Bhermana *et al.*, 2009). In the year 2008, lands that have been utilized for food crop and horticulture as well as for plantation estate cover about 3,546,867 ha or 23% of total area of

Central Kalimantan province. On the basis of the potentiality of land resources, a large proportion of the land regions of Central Kalimantan have vast opportunity to be developed in the future. The aim of this study was to develop the agroecological zone system with integrated database system consisting of the tabular and spatial data as part of the GIS. The agroecological zone system can then be used as basic information for sustainable land use planning of the Central Kalimantan Province, Indonesia.

2. Materials and Methods

The Central Kalimantan is situated between 0^{O} 47' North latitude - 3^{O} 34' South latitude and 110^{O} 42' - 115^{O} 51' East longitude. The province has an area almost of 15 million hectares is bordered by Java Sea in the south, Kalimantan Barat province in the west and north side, Kalimantan Timur province in the north and east side, and both Kalimantan Timur and Kalimantan Selatan province in the east (Figure 1).

The relevant information considered as a basic data to develop agroecological zone system involved land (soil) resources and climatic data are the land system maps report series for Central Kalimantan area (scale 1: 250.000); agroclimatic map; and other relevant information such as exploratory soil map, general physiographic and elevation data, and land characteristics data. The land system maps as base maps were used because these maps can cover land resources information for the whole area of Central Kalimantan province. Land system concepts assumed that there are close relation between rock type, hydroclimatic, landform, soil, and organism (crop/groups of crop). The same land system anywhere, therefore, would be characterized by the similarity in land potential as well as limiting factors (Suharta, 2007).

The general methodology in this study was based on land evaluation concept through matching process between land and climate characteristics and crop growth requirements that lead to the conclusion about the suitability of land by the crops. The expert system called Land Use program was employed in this study to support land evaluation as general guideline for selection of agriculture system and land utilization. Land resources and climate data were then interpreted by the expert system to determine the zoning system for forest, perennial and annual crop, and agroforestry.

For the land evaluation, the general procedure was to develop an integrated database of unique (homogeneous) polygons. The data inputs, and results in the form of digitized maps, were components of geographical information system (GIS) which facilitated future utilization, updating, improvement, storing and displaying (Eswaran *et al*., 1992; Arshad, 1999). A PC-based GIS called ARC-View and Mapinfo was employed to code, create, store, display, and analyze the spatial data.

In the process of developing the agroecological zone system, land mapping units in land system maps were classified into several unique polygons based on slopes classes and soil types (Amien, 1998). With the aid of expert system, the relevant information on land (soil) and climate were interpreted to provide the specific information of each zone as zoning system for forest, agroforestry, perennial crop plantation and annual crop farming (Table 1). The results of the interpretation also included temperature and moisture regimes as climatic regimes.

3. Result and Discussion

3.1 Background of Study Area

The Central Kalimantan province cover almost 15 million hectare of lands based on its land typology and landform, is divided into wetland and dryland region. The wetland regions that occupy 23% of the Province are made up of tidal swamp land, peat land coastal beaches in the southern part at elevation of 0-50 m.a.s.l with the flat topography. The dryland that occupy almost 77% of the Province are located in central and northern part with an elevation between 150 and 700 m a.s.l and the topography are hillocky plain and mountainous. The soils of the province consisted mainly of Histosols, Entisols, Inceptisols, Mollisols, Spodosols, Ultisols, Alfisols, and Oxisols. The soil temperature regime is isohypertermic with udic moisture regime. (Soil and Agroclimate Research Centre, 2000; 1996; Bhermana, *et al*., 2009).

The Province is geographically a wet equatorial climate with a wet monsoon and a dry monsoon. According to Oldeman climate system, the region falls within the A, B1, B2, C1, and D2 group. This implies that the number of consecutive dry months is 0-1 for B1 and C1, 0-2 for A, and 2-3 for B2 and D2 while the number of consecutive wet months is 10-12 for A, 7-9 for B1 and B2, 5-6 for C1 and D2 (Soil and Agroclimate Research Centre, 1999). The annual rainfall mean is about 2,688 mm. Wet periods start from October to April, while dry periods prevail from June to September. The daily temperature ranges between 25-31^{o}C. Day length varies very little from 12 hours all years round.

For present land use, almost 77% of total area of Central Kalimantan province is still under primary forest, namely tropical rainforest, swamp/peat forest and mangrove forest. Cultivation areas that cover only 3,546,867 hectares or 23% of the Province have been utilized for plantation estate and local agriculture (Bhermana, *et al*., 2009).

The total population of the Province is approximately 2,057,300. Based on the total land area, the population density rate is 13 persons per km^2, is considered to be fairly low density (BPS Statistic of Central Kalimantan Province, 2008). The population comprises the Dayaks, the Malay, and other indigenous group. Like most developing country, the agricultural land use system is not planned by the respective governmental agencies but rather the system grows with time, population boom , and social development. The people traditionally depend on agricultural activities as their source of living.

3.2 GIS Application for Developing Database System of the Agroecological Zone

The Geographic Information System (GIS) is spatial technology information that produces digital data for features of an area (Wirosoedarmo *et al*., 2007). In this study, Geographic Information System (GIS) technology as mapping software was applied to support the capture, management, manipulation, analysis, and displays of spatially referenced data (Chan, 2002). This allowed the linkages and analyzed the conventional tabular information to data in map format within computer environment. The linkage between agroecological zone and GIS enabled computer manipulations of spatially indexed or map data in addition to tabular data (Antoine, 1994). The database system of the agroecological zone in the form of tabular and spatial data as part of GIS was obtained (Figure. 2). Integrated database in the tabular form provided information that included the agricultural system, crop option, soil types (great group), landform, slope classes, elevation, pH, drainage and the climate regime. On the basis of information at reconnaissance level with scale of 1: 250.000, the spatial data developed the agroecological zone in the form of digital map. At this scale, the map was designed for land use planning (Hardjowigeno, 1987) and mapping was carried out to provide resource inventories of large areas (Dent and Young, 1981; Darmawidjaja, 1992).

The process of agroecological zone system was based on slope classes and soil types. Based on land system maps and agroclimatc map, the result of land evaluation and interpretation using expert system (Land Use Program) showed that Central Kalimantan province would be divided into 7 main zones (zone I, II, III, IV, V, VI and VII) and 4 sub zones (IV.1, IV.2, V.1, and V.2) (Table 2).

3.3 Land Use Planning based on the Agroecological Zone System

Based on the agroecological zone system, Central Kalimantan would be divided into 7 main zones and 4 sub-zones. These zones are the land resources mapping unit, defined in terms of climate, landform and soils, and / or land cover, and having a specific range of potentials and constraints for land use. The purpose was to determine the land use allocations. The information provided by the agroecological zone would be considered in all stages of land use planning.

Zone I

The Zone I lands are areas with slope > 40% and would be allocated for forest due to their steep slopes. The most common problem encountered in zone I would be soil erosion. Considering the fragility of the natural environment, this zone should be kept in its natural conditions. The hilly to mountainous topography of zone I would be appropriate for forest lands and these areas are recommended for forest protection and wildlife conservation (Fandeli and Martopo, 1985). Generally, this zone is mainly found in patches of the northern region and covers about 6.1% (945,800 hectares) of total land area of Central Kalimantan (Figure 3).

Zone II

The Zone II lands are hilly areas and dominate arable lands along the central to northern part of the province. It constitutes about 38.2% (5,880,000 hectares) of total land surface. The areas would be allocated for agriculture and the perennial crop plantation is highly recommended (Figure 4). With slope of 15 – 40 %, soil erosion maybe occurs here, particularly on land with long slope but conservation practices can reduce this problem. Von Platen (1985) suggested that perennial crop such as oil palm and rubber planted on sloping land provide good land protection without severe consequences in terms of erosion. Sajjapongse (1996) reported that slope terracing combine with ground cover crops are effective in reducing soil loss and run-off on the sloping lands. Hamdan *et al*. (2000), however, noted that land terracing of slopes expose saprolite to the surface and may have bad effect to plant growth due to saprolite poor physical and chemical properties. For conservation purposes, it would be advisable for the authority to reconsider developing hilly and rugged landscape with slope > 30%. Zone II areas geographically covered vast areas in the remote northern region of the province. For the crop plantations establishment, sufficient infrastructures should be made available to attract workers to such remote areas.

Zone III

The Zone III lands are areas with dominant slope of 8 – 15 % covering about 9.8% (1,509,000 hectares) of the entire land area and are found in the southern and central parts of the province (Figure 5). The system of agriculture design for this area would be agroforestry. In this kind of land use, woody perennial are deliberately used on the same land management unit as annual crops, either sequentially or simultaneously, with the objective of obtaining greater outputs on a sustained basis (Harwood, 1993). Agroforestry is widely practiced by indigenous (Amien, 1990) as the combined cultivation of tree species and agricultural crops have the potential to improve production, to enhance the agroecological sustainability of resource-poor farmers (Harwood, 1993), to contribute to the sustainability of low-input agriculture (Stewart *et.al.*, 1991) and is an appropriate sustainable land use system in fragile tropical environment (Petmak, 1994).

Even though agroforestry is often considered to be the most suitable strategy to restore degraded lands (Sanches *et al.*, 1994), it has been shown to be a suitable approach towards increasing land productivity of both agricultural and forest plantation (Ali and Arshad, 2002). Alley cropping system, for example, where annual crops are cultivated along with perennial trees is often used to manage sloping land (Amien, 1998) because of its effectiveness in managing soil erosion and surface run off (Santoso and Sukristiyonubowo, 1996; Sajjapongse, 1996).

Zone IV

The Zone IV lands are areas with slope <8% would be allocated for the annual crop agriculture. On the basis of soil types, this zone is divided into 2 subzones that is IV.1 and IV.2. The predominant land typology of sub-zone IV.1 is wet lands with poor drainage condition and it is generally located in tidal land areas. Sub-zone IV. 2 areas are mainly found in dry land areas.

Sub-zone IV.1 areas occur in south to central part and occupies 9.9% (1,522,000 hectares) of total province area (Figure 6). The areas are generally located along the rivers, where many settlements exist. Most of these lands have already been cultivated with paddy and other annual crops such as maize, soybean and vegetables. The lands, therefore, have been intensively utilized for agricultural purposes. Although the geographic distribution of these lands are scattered, particularly those in the central region, the development is made possible when both human resources and well-developed infrastructures are available. The recommended annual crop for this zone would be food crop such as wet land rice.

The sub-zone IV.2 lands are dry land typology and are geographically scattered on several parts of Central Kalimantan. They occur mostly in the central region as well as in northern region and occupy about 6.8% (1,042,000 hectares) of total land area (Figure 7). The suitable food crops recommended for these lands would be upland rice, maize, cassava, and soybean.

Zone V

The zone V lands are lowlands composing of organic soil known as peat and muck and are best designated for natural forest. Zone V lands can be divided into 2 sub-zone. The sub-zone V.1 are areas suitable for perennial crops covering about 5.4% (828,400 hectares) (Figure 8), while the sub-zone V.2 are areas best left for natural forest due to deep peat of > 1.5 meters and they cover almost 7.2% (1,114,000 hectares) of the province (Figure 9). Based on the expert system evaluation, peat land with peat depth < 1.5 meters would be allocated for perennial horticultural crops such as fruit crops. Most of the zone V lands are located within the tidal swampland areas with landform comprising of peat basins or peat domes. In such an environment, proper technological agricultural application, especially in soil and water management is required to ensure sustainable development with minimum impact towards the fragile environment (Suriadikarta, 2008).

Zone VI

The zone VI lands are saline soils that contain high salt and sulphate content. These lands are very fragile composing of mangroves and other vegetation such as gelam (*Gelam malacanensis*) and nipah (*Nipa fructicans*) and the best recommendation would be to leave them untouched. The natural forests occur along the coastal beach and swamps, are important to various natural habitats and act as buffer zone to natural hazards. These lands are found along the coastal beach of the southern region and they are estimated to cover only 121,500 hectares or 0.8% of total Central Kalimantan province (Figure 10).

Zone VII

The zone VII lands are lands having poor soil quality (Figure 11). These soils are very sandy, high in quartz sand and have many inherited problems. They are poor in fertility and have poor nutrient and water holding capacity. These lands are only suitable for forest conservation with native vegetation. Total area of zone VII is about 2,300,000 hectares (15.0%).

4. Conclusion

A proper land use system is crucial for a country to ensure sufficient food supply, sustainable development, well managed natural resources, and a sound ecosystem (Hamdan, et al, 2006). In the case of the Central Kalimantan province, Indonesia, the application of GIS and expert system called Land Use Program was engaged to manage and develop land resources database system in the form of tabular and spatial data. The use of GIS as analytic tool of database system to assist land use planning through land use allocation based on the land suitability and agroecological zone system had provided basis for the future sustainable development of the region. On the basis of land characteristics and climatic data, the land of Central Kalimantan would be geographically divided into 7 main zones and 4 sub-zones with its zoning system within each zone or sub-zone.

The lands of zone I, VI, VII, and sub-zone V.2 would be allocated for natural forest due of the limiting factors such as steep slope land and poor soil quality (deep peat land, saline soil and sandy soil). The total areas of these zones are estimated to be about 4,481,300 hectares or 29.1% of total Central Kalimantan province. Land of Zone II and sub-zone V.1 would be recommended for perennial crop, while land of zone IV (sub-zone IV1 and IV.2) would be allocated for annual crops. The total area of land recommended for perennial crop (zone II and V.1) and annual crop (zone VI) would be about 6,708,400 hectares (43.6%) and 2,564,000 hectares (16.7%), respectively. Lands in zone III are recommended for agroforestry and cover almost 1,509,000 hectares (9.8%) of the province. They are about 0.8% of the land areas currently under natural lakes.

Global warming and deforestation of natural forest are current important issues that need to be addressed in any land development program. Currently, about 77% of present land use of Central Kalimantan is under forest (Bhermana, *et al*., 2009). Based on our Agroecological Zone System approach, only about 29.1 % of the province would be left for natural forest. Despite sound land use approach, the decline in the current forest area by 48% may not be acceptable from the ecological point of view. These natural forest areas can be kept back at rational acreage by the following approaches, (i) lands with >30% slope of zone II can remain as forest, (ii) all fragile peat swamp lands of zone V would be designed for forest, and (iii) to leave lands located in the interior regions untouched. With this little effort, land under natural forest can be satisfactorily maintained at 40 to 50% of the total land area. Central Kalimantan at present is under populated (BPS Statistic of Central Kalimantan Province, 2008) and over agricultural development of these areas is seen unnecessary for the time being.

This study have shown that with the agroecological zone system approach, each land can be utilized efficiently, effectively, and optimally based on its agroecological conditions. This system facilitates areas selection for proper land use and appropriate agricultural system. Specific agricultural development programs can then be formulated to provide the most effective support to each zone. This approach, however, must be cautiously applied and major consideration on the global ecological issues must be addressed to ensure sustainable future land use development of Central Kalimantan, Indonesia. For the future study, a thoughtful analysis of the economic implications and long-term impacts of the systems will help us sort out the complexities of resource use and environmental impacts that result from the agroecological zoning approach.

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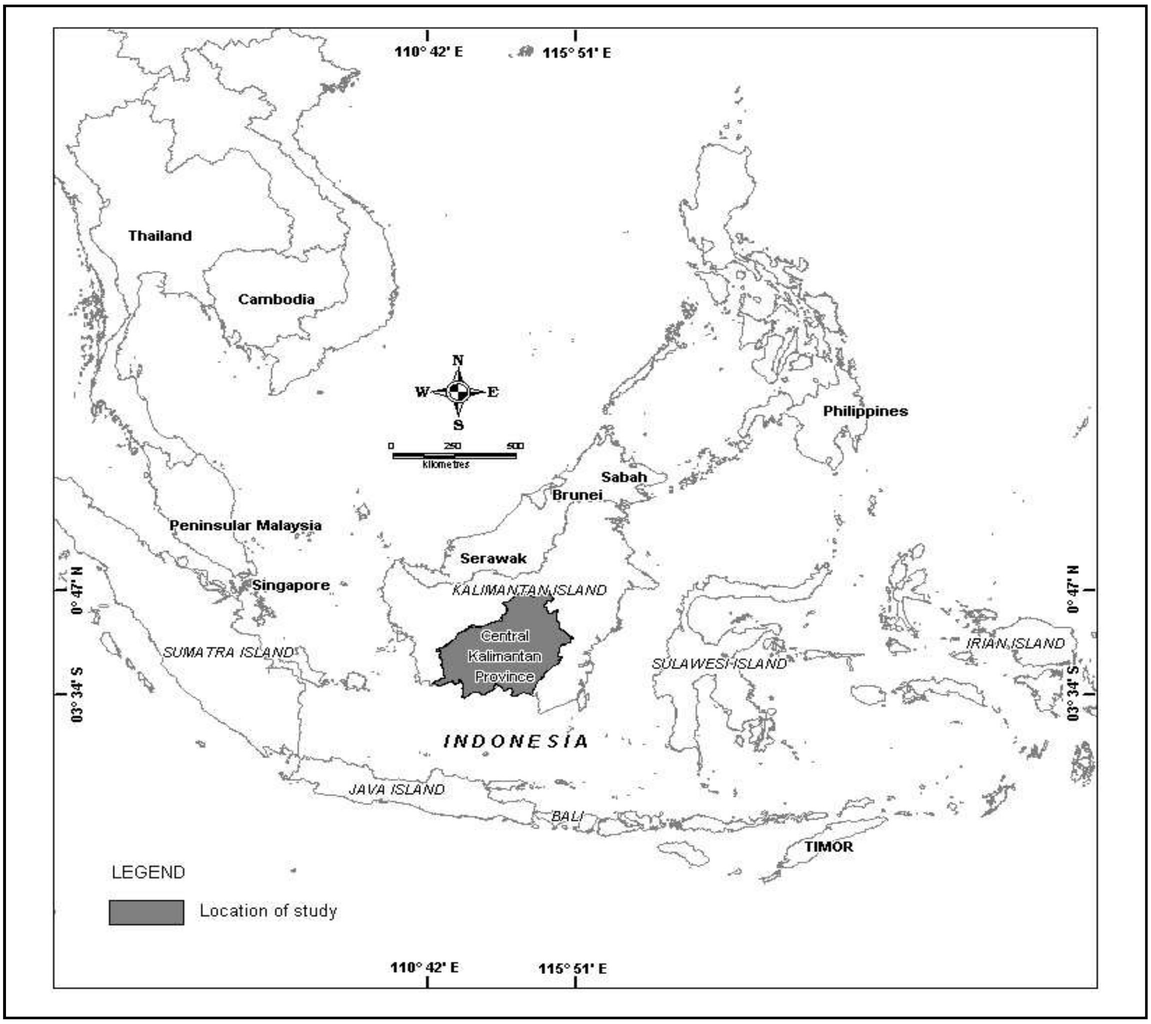

Figure 1. Location of Central Kalimantan Province, Indonesia

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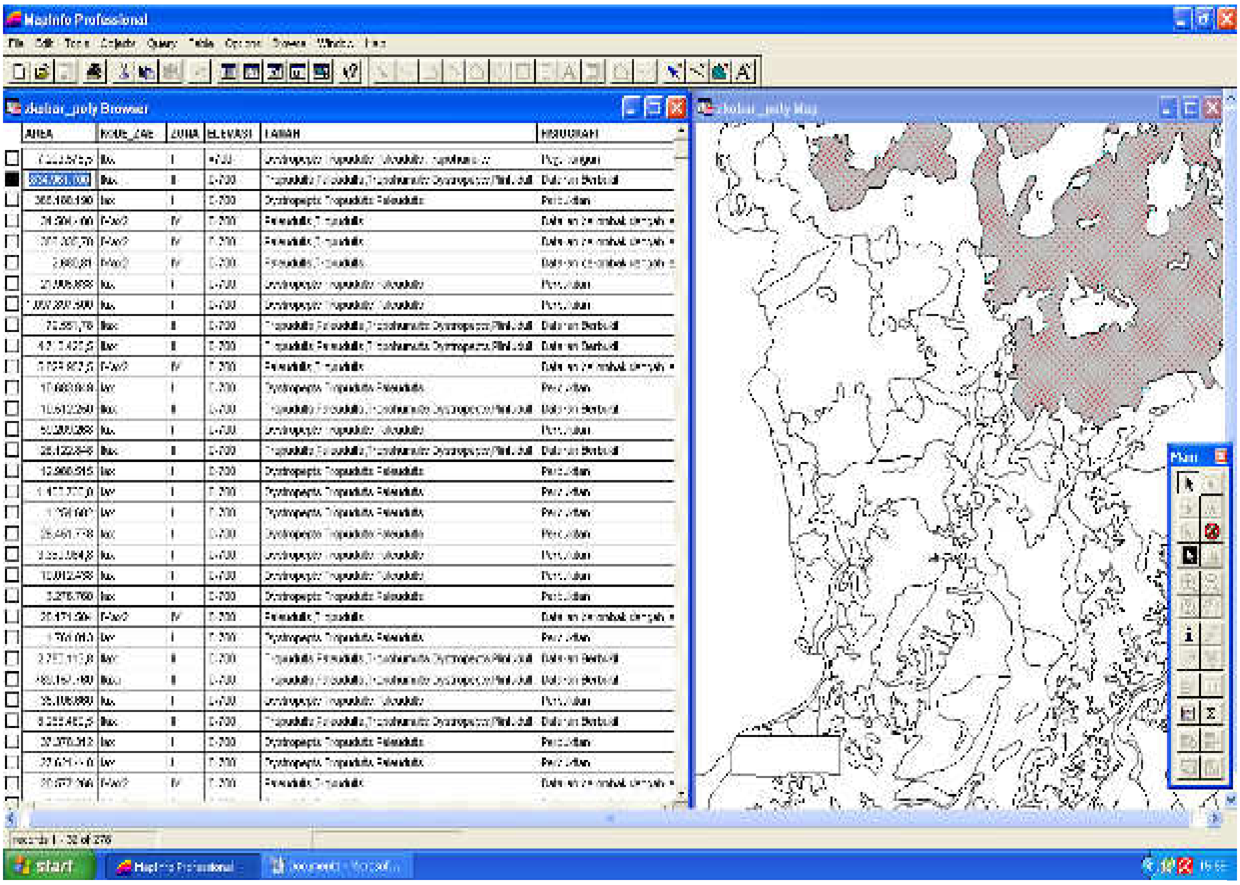

Figure 2. GIS database of the agroecological zone for Central Kalimantan province

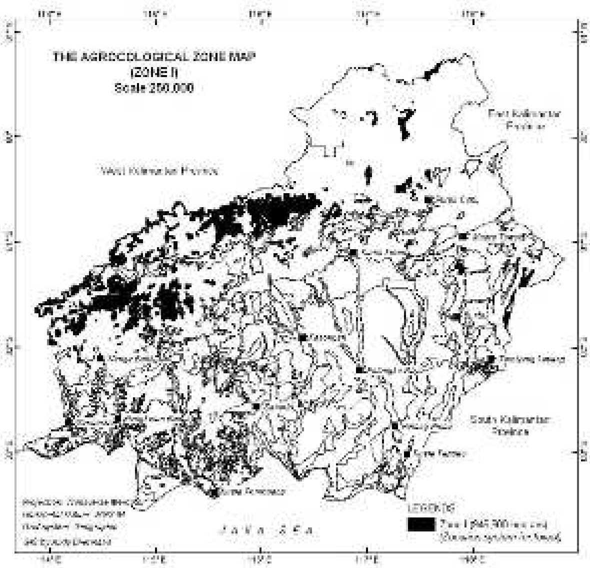

Figure 3. The agroecological zone for zone I

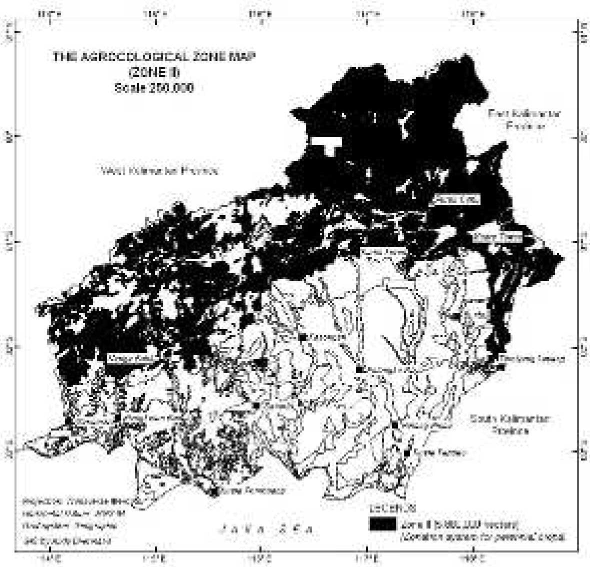

Figure 4. The agroecological zone for zone II

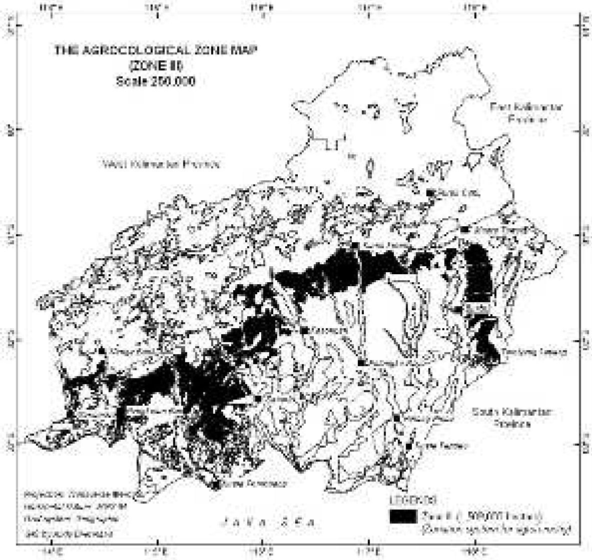

Figure 5. The agroecological zone for zone III

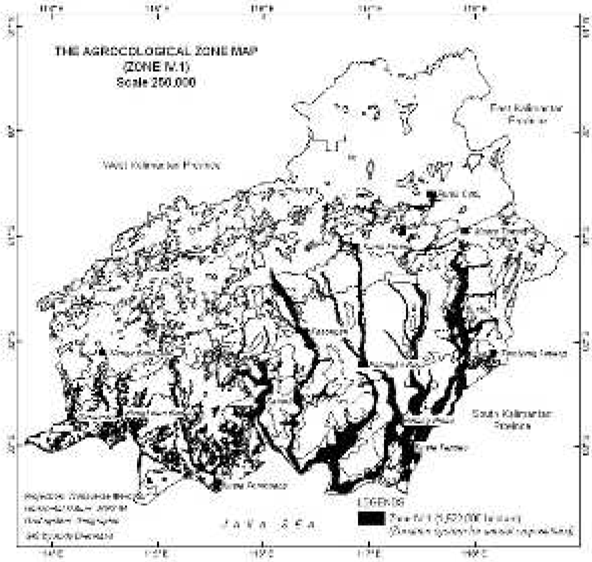

Figure 6. The agroecological zone for zone IV.1

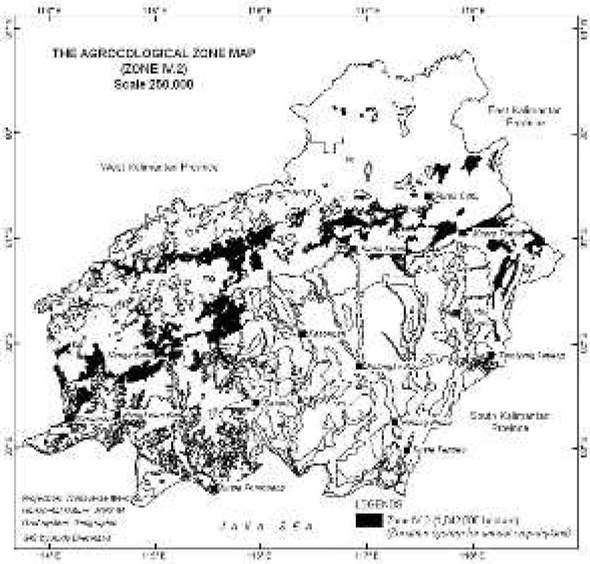

Figure 7. The agroecological zone for zone IV.2

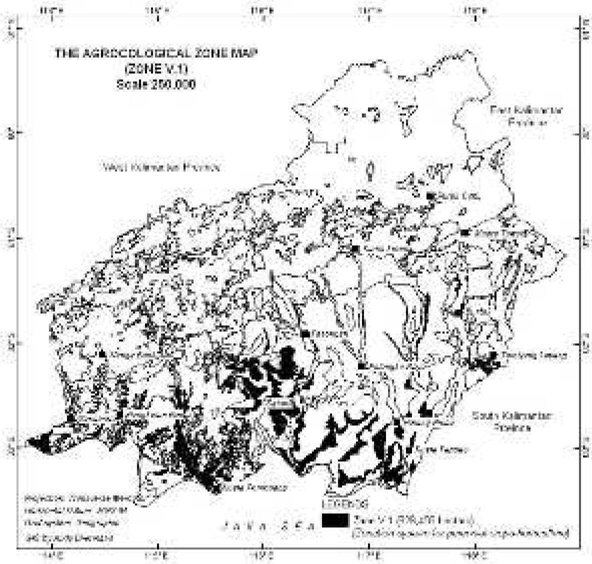

Figure 8. The agroecological zone for zone V.1

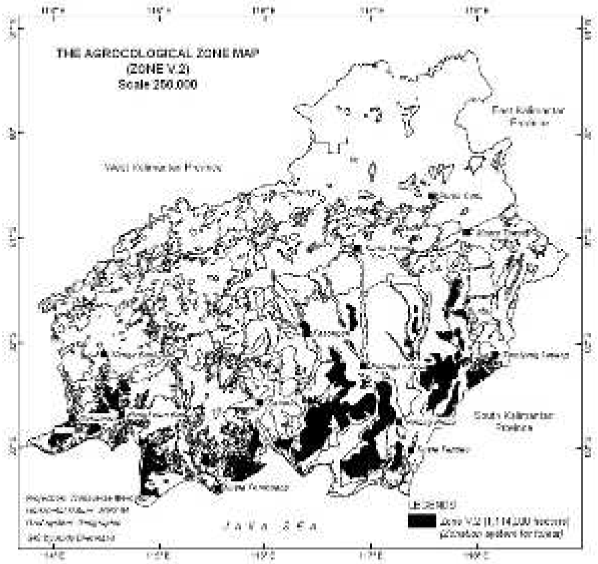

Figure 9. The agroecological zone for zone V.2

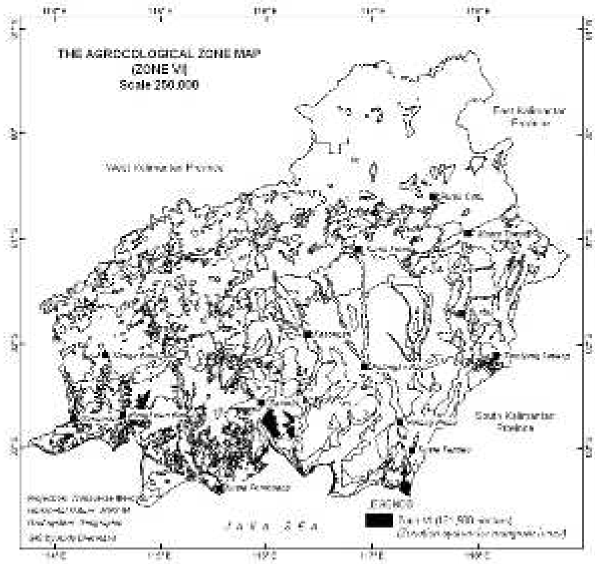

Figure 10. The agroecological zone for zone VI

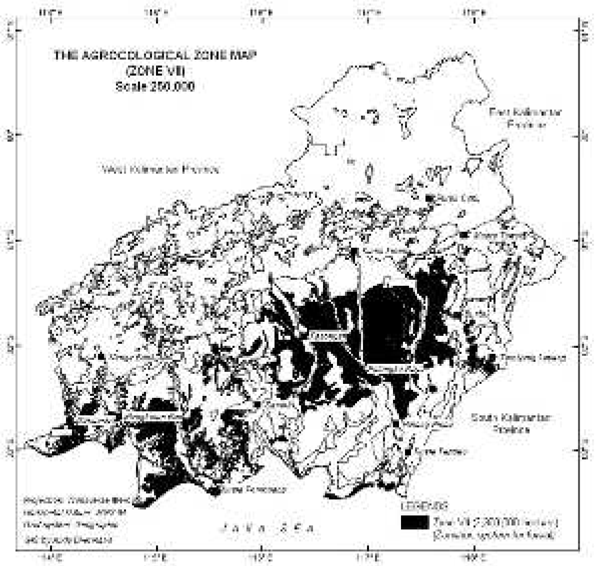

Figure 11. The agroecological zone for zone VII

Table 1. The agroecological zone system

No	Zone		Slope Class (%)	Zonation System	Crop Type
1	**I**		> 40	Forest	Natural vegetation
2	**II**		15-40	Perennial crop/estate	Estate crop
3	**III**		8-15	Agroforestry	Estate crop – food crop
4	**IV**	**IV.1**[1]	2-8	Annual crop	Food crop
5		**IV.2**[2]	2-8	Annual crop	Food crop
6	**V**	**V.1**[3]	2-8	Perennial crop	Horticulture (fruits crop)
7		**V.2**[4]	2-8	Forest	Natural vegetation
8	**VI**		2-8	Mangrove Forest	Natural vegetation
9	**VII**		2-8	Forest	Natural vegetation

[1] Alluvial soil with poor drainage; [2] Mineral soil with well drainage, [3] Peat soil (peat depth < 1.5 meters); [4] Peat soil (peat depth > 1.5 meters)
(Source: Desaunettes, J. R. 1977; Amien, 1998)

Table 2. The agroecological zone system for Central Kalimantan, Indonesia

No	Zone		Zonation System	Soil Type	Acreage (hectare)	Percentage of area (%)
1	**I**		Forest	Dystropepts, Tropudults, Troporthods	945,800	6.1
2	**II**		Perennial crop/estate	Tropudults, Dystropepts, Paleudults	5.880,000	38.2
3	**III**		Agroforestry	Tropudults, Dystropepts	1,509,000	9.8
4	**IV**	**IV.1**[1]	Annual crop	Tropaquepts, Fluvaquents, Tropofluvents	1,522,000	9.9
5		**IV.2**[2]	Annual crop	Paleudults, Tropudult,	1,042,000	6.8
6	**V**	**V.1**[3]	Perennial crop	Tropohemists, Troposaprists, Tropaquents	828,400	5.4
7		**V.2**[4]	Forest	Tropohemists, Tropofibrists	1,114,000	7.2
8	**VI**		Mangrove Forest	Sulfaquents, Hydraquents	121,500	0.8
9	**VII**		Forest	Topopsamments, Quarzipsamments, Placaquods	2,300,000	15.0