GIS Application in Evaluating Land Use-Land Cover change and its Impact on Hydrological Regime in Langat River Basin, Malaysia*

Noorazuan M. H
School of Social, Development & Environment, UKM Bangi
(now on study leave at School of Geography, University of Manchester, UK)

Ruslan Rainis
Geoinformatic Unit, Geography Section, School of Humanities
Universiti Sains Malaysia, 11800 Penang. E-mail: rruslan@usm.my

Hafizan Juahir, Sharifuddin, M.Zain
Department of Chemistry, Universiti Malaya, KL

Nazari Jaafar
Department of Geography, Universiti Malaya, KL

Abstract

GIS-based multi-temporal land use data provides a historical vehicle for determining and evaluating long term changes of land use due to urbanization. Along with the concurrent daily streamflow and precipitation records, the impact of land use change on the rainfall-runoff relationships has been explored in Langat River Basin. The basin is located at southern of the heart of Malaysia i.e. Kuala Lumpur, mentioned to be the most rapid semi-urban basin that experienced land use and land cover changes due to the onslaught of development. This article will highlights the evaluation of land use change result and how this outcome could affects the rainfall-runoff relationships. The study revealed that the landscape diversity of Langat significantly change after 1980s and as the result, the changes also altered the Langat's streamflow response. Surface runoff has increased from 20.35% in 1983-88 to about 31.4% of the 1988-94 events. Evidence from this research suggests that urbanisation and changes in urban-related landuse-landcover (LULC) could affect the streamflow behaviour or characteristics. The application of GIS succeed to shows the landscape diversity and spatial analysis of Langat basin.

Keywords: GIS, land use change, rainfall-runoff, runoff ratio

*This paper will be presented in the oral session of the 2nd Annual Asian Conference of Map Asia 2003, 14-15 October, PWTC Kuala Lumpur, organised by the Malaysian Remote Sensing Center (MACRES).

INTRODUCTION

Urban expansion has increased the exploitation of natural resources and has changed land use and land cover patterns. In 1900, only 15 percent of the world's population lived in the cities, however now more than 50% do so, with the United Nations forecasting that between 1990 and 2050, the urban population will rise to over 5 billions (Maksimovic & Tucci, 2001). In Malaysia, for example, the total urban population has increased to 58.8 per cent in the year 2000 (Samad Hadi, 2000) and some of the states in the Peninsular has achieved the urbanisation level of developed countries i.e. 80 percent of the total population. Foreign and local investment in the agricultural, commercial and mining sectors were the main factors leading to the growth of the urban population in Malaysia.

Most urban areas in developing countries are located on the coast or on major rivers as in Malaysia. The uncontrolled growth of urban development has adversely affected Malaysian river basin ecosystems (Jamaluddin Jahi & Nordin Hassan, 1996) especially their capacity to regulate streamflow. About 2.5 million urban dwellers in Malaysia are exposed to flood hazards due to their settlements in the flood plain (Mohd Ekhwan, 2000). According to Chan, N.W (1996), the flood risks and community vulnerability have increased since 1985 due to the onslaught of urban development in river corridors.

The increase in urban population density and built up areas (Hall, 1984) directly or indirectly affects hydrological processes, through : a) Change in total runoff or streamflow b) Alteration of peak flow characteristics, c) Decline in water quality and d) Changes in river's amenities. Basically, urbanisation could lead the alteration in streamflow characteristics by the expansion of built up areas, modification of natural channel through channelisation processes and the interferences from the artificial drainage or sewer system to the natural drainage system. The information of the changing LULC within a watershed is vital for evaluating the current ecosystem health. The impact of LULC change on hydraulic and stream stability, with special reference to the urban built-up areas (including impervious surfaces) has been discussed widely in academic literatures. The recent results regarding impact of LULC on hydrological regime has been discussed in Jennings & Jarnagin (2002), De Roo et.al (2001), Lahmer, et.al (2001) and Acreman (2000).

The application of computer systems and information technology in handling geographic and spatial data is a necessity. Thus, the Geographic Information systems (GIS) and coupling with the deterministic or stochastic process models will accelerate the field of research and development in spatial science. The application of GIS will facilitates new avenues of exploratory spatial data analysis that were previously not feasible and also enables the integration of data collected by different media thereby substantially increasing the communications capabilities of those involved in urban management (Masser, 2001).

Using the Arc-View Spatial Analyst with the Patch Analysis extension, the assesment of spatial landscape diversity and land use changes in watershed could be more easier and faster (Whelan, F. 1999). Some of the researchers coupled their efforts in hydrological analysis with GIS and other hydrological model that available. As such, the coupling of GIS and hydrological modelling can be seen in Brun and Band (2000), Nelson and Jones (1996) and Saunders and Maidments (1996), Campana and Tucci (2001) in very recent research.

The objective of this study were (1) to identify spatial patterns of Langat Basin within 1984 and 1997 and, (2) to analyse the change in flow behaviour due to the impact of urbanisation. In this study, we related the impact of urban LULC change, especially the built-up areas upon the daily streamflow discharge, and focusses in detail of the changing pattern in surface runoff and streamflow responses.

STUDY AREA

The area of interest for this study is Langat River Basin, that has a total catchment area of 2271km^2. Fig 1 shows the diversity of Langat's LULC for 1984, 1990,1995 and 1997. This river basin located at southern part of Klang Valley, which is the most urbanised river basin in Malaysia, and it is believed that the Langat will compensate the virtue of 'spill-over' development from Klang Valley. Hydrometeorologically, the basin experienced two types of monsoons, i.e. the North East (November to March) and the Southwest (May to September). The average rainfall is about 2400mm, and the highest months (April and November) show rainfall amount above 250mm, while the lowest is in June, about the average of 100mm (Noorazuan, 2001). Topographically, Langat basin can be divided into three geographic regions, i.e. the mountainous area of the north, the undulating land in the centre of the basin and the flat flood plain at the downstream of Langat river. A wide range of landforms and an equally wide diversity of surface features and cover are found in the basin.

METHODS

This study makes use of the digitally GIS-based land use maps of 1984, 1990, 1995 and 1997 (Figure 2a to d). The study of landscape patterns and spatial statistics were carried out using GIS ArcView 3.1 with Patch Analysis extension, and SPSS 11.0. In this study, the urban built-up component shall be highlighted and its relationship to hydrological impact. The Langat land cover diversity index will be analysed by using the Patch Analyst extension. Among the spatial statistic of landscape and classes levels involved are Shannon's Diversity Index (SDI), patch density and edge density. SDI is a index to measure the relative patch diversity within a watershed. Historical mean hourly and daily streamflow data from the Department of Irrigation and Drainage (DID) stream gauge 2816441, of Dengkil station, were obtained for each year from 1984 to 1997. The reason is to study the change of the flow behaviour within the years of land use is mapped.

The hourly and daily rainfall records coincident with streamflow records were acquired from DID rainfall station at Kajang, station number 2917001. For the built–up and streamflow relationship study, only the urban areas above the gauging station will be used in the analysis, which comprises area of 1549km^2. Among the analyses that will be used to test the relationship between streamflow and built-up were the surface runoff and streamflow response value. The streamflow response value is a conceptual tool for analysing the rainfall-runoff relationships (Bedient & Huber, 1988).

LANGAT'S LANDSCAPE STRUCTURE ANALYSIS

Fig 3 shows the spatial pattern of each LULC types of Langat for 1984, 1990, 1995 and 1997. Among landscape structure statistical analysis involved in this study were the number of patches, patch size coefficient of variance, edge density and Shannon's Diversity Index (SDI). The formulation of these GIS spatial metrics can be review in McGarigal & Marks (1994) and Patch Analyst 2.2 Reference Guide (1999).

Table 1: Overall landscape structure analysis

Patch Statistic	1984	1990	1995	1997
Number of Patches (NumP)	327	275	3781	3997
Patch size coefficient of variance (PSCoV)	610	451	1070	891
Edge Density (ED)	16.21	17.89	52.0	54.0
Shannon's Diversity Index (SDI)	2.066	2.132	2.62	2.63

Based on the overall spatial landscape structure analysis (Table 1), there is a significant different of NumP, PSCoV, ED and SDI values between period of 1984-1990 and 1995-1997. we can easily grouped these value into two main groups based on the period. It reveals that there is a significant impact of human activities on the landscape of Langat basin, especially to the period of 1995-1997. Among the major LULC change occurs in the period was the development of Kuala Lumpur International Airport near Sepang as well as the Cyberjaya-Putrajaya development projects (Noorazuan, 2001). The SDI value indicates that 1995-97 LULC diversity in Langat basin was significantly different from the period of 1984-1990. Thus, from this argument we will divided the further analysis based on this two periods, i.e. 1984-1990 and 1995-97.

Table 2 : Spatial statistic based on selected urban built up-related land use classes for Langat

Class(1984)	**Class Area (CA)**	**Number of Patches (NumP)**	**Patch Size Standard Deviation (PSSD)**	**Edge Density (ED)**	**Mean Perimeter – Area Ratio (MPAR)**
Newly cleared land	1459.87	17	86.39	0.28	2602.81
Urban area	2343.58	14	198.55	0.34	112.89
CLASS(1990)					
Urban area	8563.17	26.00	479.14	1.062	756.185
Newly cleared land	371.13	4.00	38.61	0.090	73.400
Class_(1995)					
Newly cleared land	4926.368819	270	95.83	1.82	223.28
Urban area	10961.75659	246	156.37	3.01	414.68
Agricultural buildings	810.2607593	137	6.88	0.63	239.64
Transmission routes	1162.773443	42	30.05	1.40	291.99
Recreational area	973.2692169	14	50.06	0.22	100.82
Cemetary	131.3230042	10	16.50	0.06	195.61
Highways	792.0907781	17	57.75	1.18	347.17
Railways	363.1319486	4	36.98	0.42	285.45
Class_(1997)					
Urban area	13886.19	272	164.25	3.58	400.42
Newly cleared land	8703.68	312	167.53	2.63	424.06
Highways	1600.13	52	56.06	1.93	1139.17
Transmission routes	1339.47	48	34.21	1.56	1089.56
Agricultural buildings	716.1	119	6.99	0.55	230.93
Railways	347.77	8	39.11	0.41	302.70

Cemetary	88.91	6	20.36	0.04	166.35
Recreational area	194.99	3	55.60	0.04	103.27

Table 2 shows detail statistics of spatial analysis based on urban-related land use classes in Langat for 1984, 1990, 1995 and 1997. The overall built up or urban-related land uses within the basin has markly change during the period (Fig 3).

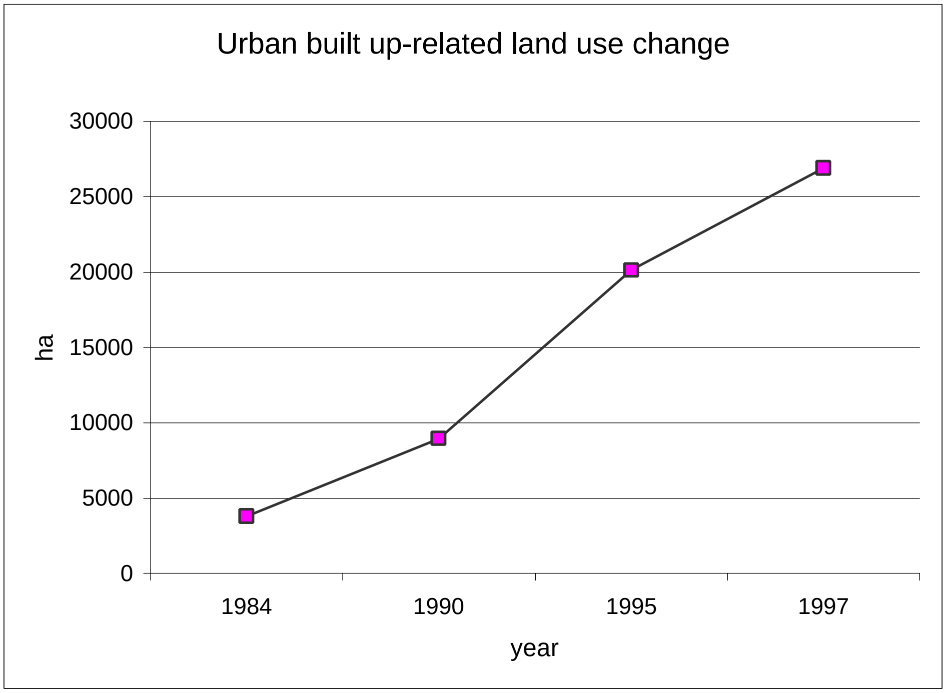

Fig 3: Overall urban built up-related land use change in Langat within 1984 and 1997.

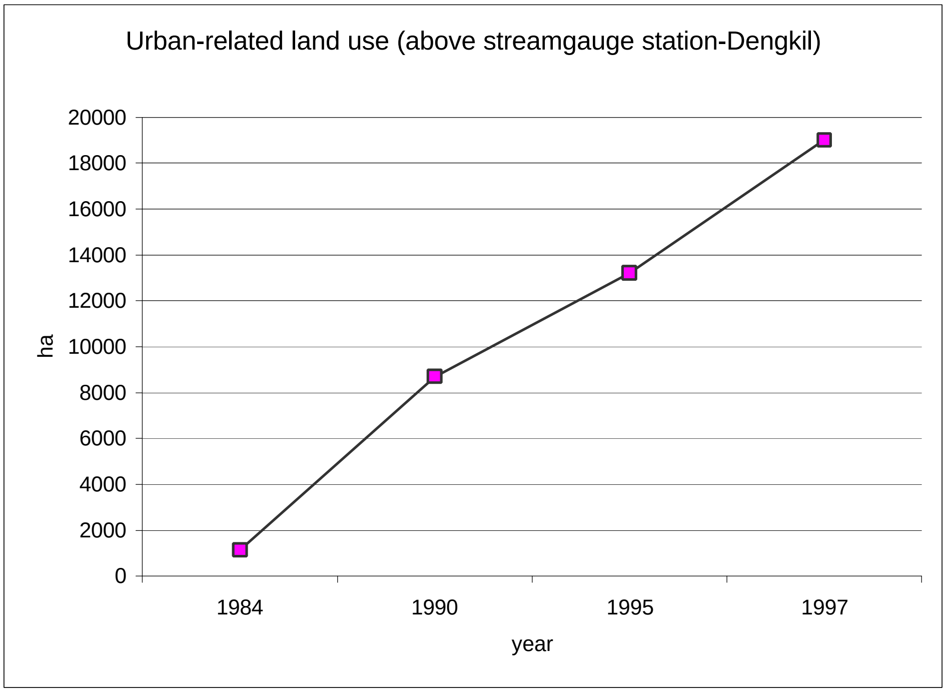

Fig 4: Urban built up-related land use change above streamgauge at Dengkil.

Fig 4 shows the changes in urban-related land use classes in Langat within 1984 and 1997, for catchment above the stream gauging station at Dengkil (1549km^2).

FLOW ANALYSIS OF LANGAT RIVER AT DENGKIL STATION (Ref: 2816441)

Theoritically, urban built-up especially the impervious surfaces could affect the flow behaviour within a catchment. According to Brun & Band (2000), a threshold percent of impervious cover, i.e. 20 percent of the basin's area, above which could dramatically change the value of sreamflow responses. The increment of built-up areas also has proved affected the water quality through its pollutant loads (David et.al, 1989; Barrett et.al , 1995). In this study, we try to relate how much effects of the LULC could alter the flow behaviour, i.e. the Langat River. For the hydrograph separation analysis, we applied a very recent ISEP-hydrograph separation model., developed by Dr. K.J. Lim (2003) from University of Purdue.

Table 2 shows the rainfall and flow analysis of Langat within 1983 to 1994. Due to missing information of daily and hourly data, although no interpolation was done to this, we manage to study the flow responses only for 12 years period (1983-1994). The result shows that the total surface runoff has increased especially after the period of 1989-91 and contributes significant change of streamflow response (Table 3).

Table 2: Rainfall and streamflow study of Langat River at Dengkil station

Year	Flow			
	Total Rainfall (mm)	Total Flow (cumecs)	Total Surface runoff (cumecs / mm)	Total Baseflow (cumecs)
1983-85	6236.6	93,638	20500 / 1143	73,138
1986-88	6709.3	74,974	14205 / 792	60,768
1989-91	NA*	92,017	26843 / 1497	65,174
1992-94	6473.3	81,918	27491 / 1533	54,419

* incomplete information of rainfall record

Table 3 : Urban-related land use change and flow response analysis of Langat River at Dengkil

		Flow responses		
Year	Urban-related land uses (ha)	Surface Runoff per Total Runoff (%)	Baseflow per Total Runoff (%)	Runoff Coefficient (%)
1983-85	1135	21.8	78.2	18.3
1986-88	8700	18.9	81.1	11.8
1989-91	13214	29.2	70.8	NA
1992-94	18992	33.5	66.5	23.7

Except the period of 1986-88, this study reveals that the surface runoff has increased, with the positive relationship with the urban-related land uses increment (r = 0.82). Within the period of study (1983-1994), we also manage to analyse the change in runoff coefficient, i.e. from 15.5 % (average between 1983-1988) to about 23.7% of the 1992-94 period. As mentioned in various sources of research elsewhere, the higher runoff coefficient is due to the increase amount of imperviuos surfaces of the urban-related land uses (Barnes, Morgan & Roberge, 2001; NEMO, 2000; EPA, 1997; Zandbergen, 1998). Urban imperviousness is the most important parameter in modelling the change of hydrograph volumes (Bedient & Huber, 1998).

CONCLUSION

Evidence from this research suggests that urbanisation and changes in urban-related LULC could affect the streamflow behaviour or characteristics. The application of GIS succeed to shows the landscape diversity and spatial analysis of Langat basin. Using the GIS Arcview with Patch Analyst, the assessment of hydrologic properties as well as the land use change in Langat could be more precise and even faster. However, due to limitation of financial back up, this research excluded the use of urban impervious surfaces that can be derived from remote sensing data such as aerial photo or satellite imageries.

REFERENCES

Acreman, M (ed). 2000. The hydrology of the UK. A study of change. Routledge. London.

Barrett, M, Malina, J. , Charbeneau, R. & Ward,G. 1995. Water quality and quantity impacts of highway construction and operation: summary and conclusions. Technical report CRWR 266. Nov 1995. Austin (unpublished report).

Barnes, K., Morgan, J. & Roberge, M. 2001. Impervious surfaces and the quality of natural and built environment. Paper presented in ASPRS 2001 Annual Convention, St Louis, MO, April 23-27, 2001.

Bedient, P. & Huber, W. 1988. Hydrology and floodplain analysis. Addison-Wesley Publ.

Brun, S.E. and Band, L.E. 2000. Simulating runoff behaviour in an urbanizing watershed. Computers, Environment and Urban Systems. 24. (2000). 5-22.

Campana, N.A and Tucci, C.E.M. 2001. Predicting floods from urban development scenarios: case study of the Diluvio Basin, Porto Alegre, Brazil. Urban Water. 3 (2001) 113-124.

Chan, N.W. 1996. Socio-economic aspects related to flood hazard in Peninsular Malaysia. National *Prosiding of Social Science Study.,IRPA - Universiti Malaya.* (ms : 294-311) (in Malay).

De Roo, A. , Odijk, M., Schmuck, G., Koster, E and Lucieer, A. 2001. Assesing the effects of land use changes on floods in the Meuse and Oder Catchment. Phys. Chem.Earth (B), Vol 26, No 7-8. pp 593-599.

EPA. 1997. Urbanization and streams : studies of hydrologic impacts. Office of Water. Washington. Report No. 641-R-97-009.

K.J. Lim. 2003. Personal. Communication.

Jamaluddin Jahi & Nordin Hasan. 1996. Federal-State relationships in environmental management in Malaysia. Workshop on "Federal-State Relationships in Environmnetal Management' Organised by ISIS Malaysia and MOSTE. 22-23 August 1996.

Jennings, D.B and Jarnagin, S.T. 2000. Using GIS and aerial photography to determine a historical impervious surface/streamflow relationship. Paper presented in ESRI Conference (via internet).

Lahmer, W., Pfutzner, B., and Becker, A. 2001. assesment of land use and climate change impacts on the Mesoscale. Phys. Chem.Earth (B), Vol 26, No 7-8. pp 565-575.

Maksimovic, C and Tucci, C (eds). 2001. Urban drainage in specific climates. IHP-V. Technical documents in Hydrology. No 40, Vol 1. UNESCO Paris.

Masser, I. 2001. Managing our urban future : the role of remote sensing and geographic information systems. Habitat International. 25. (2001). 503-512.

Mohd Ekhwan. 2000. Flood as hazard: Issue and its challenges in Malaysia. In. Jamaluddin Md Jahi (eds). *Environmental Management in MAlaysia*. Bangi. Universiti Kebangsaan Malaysia (ms127-147) (in Malay).

Nelson, E.J. and Jones, N.L. 1996. Utilizing the ArcInfo data model to build conceptual models for environmental/hydraulic/hydrologic simulations. Paper presented in ESRI Conference (via internet).

NEMO. 2000. Methods for deriving impervious cover information. Nonpoint education for Municipal Officials Project. Haddam, Connecticut.

Noorazuan, M.H. 2001. Urbanisation and water industry growth in Malaysia: Issues and challenges in the new millennium. International Proceedings of Frontiers in urban water management: Deadlock or hope? IHP-UNESCO Paris. CD-ROM Series No 2.

Noorazuan, M.H. 2002. The impact of urban development on the vulnerable community. University Research Highlights 2001. National University of Malaysia. Bangi.

Saunders, W.K. and Maidment, D.R. 1996. A GIS assessment of nonpoint source pollution in the San Antonio-Nueces Coastal Basin. CRWR Online report 96-1. Bureau of Engineering research. Austin, Texas.

Samad Hadi, 2000. Malaysian urbanisation and the environment. Sustainable urbanisation in the new millennium. Environmental management programme. Bangi. 76 pp.

Whelan, F. 1999. Assessment of hydrologic properties and land use /land cover in Pasific Northwest watersheds through hydrologic modelling utilizing GIS. Paper presented in ESRI Conference (via internet).

Zandbergen, P. 1998. Urban watershed ecological risk assessment using GIS : A case study of the Brunette River watershed in British Columbia, Canada. Journal of Hazardous materials. 61. (1998). 163-173.

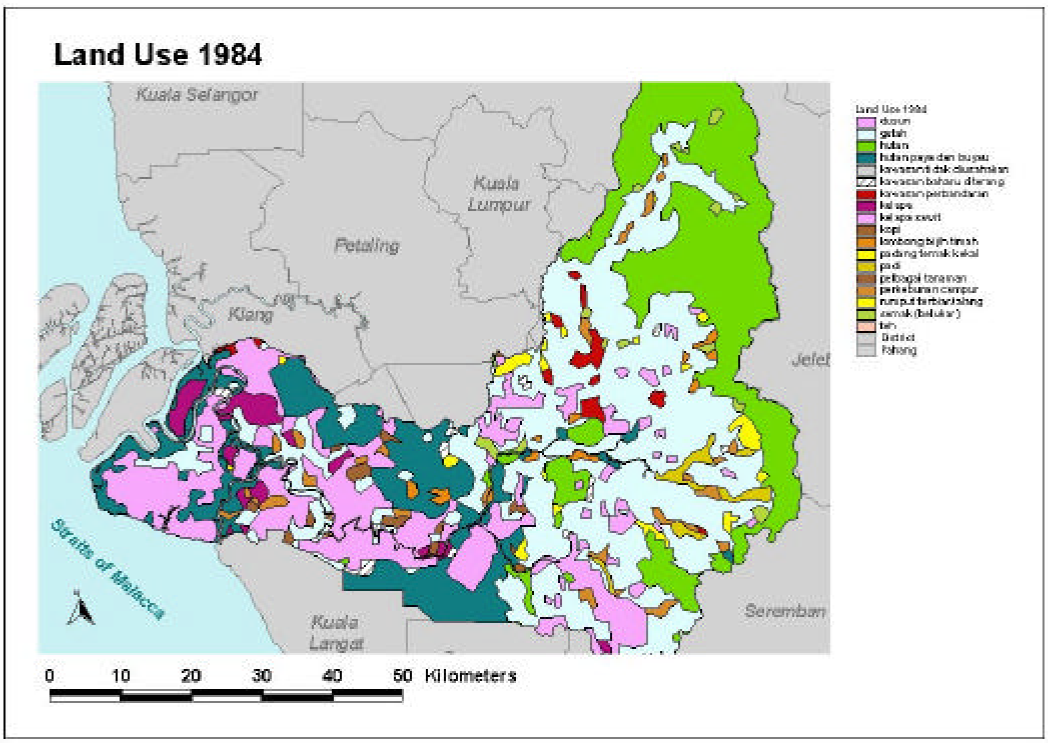

Figure 2a: Land use of the study area, 1984.

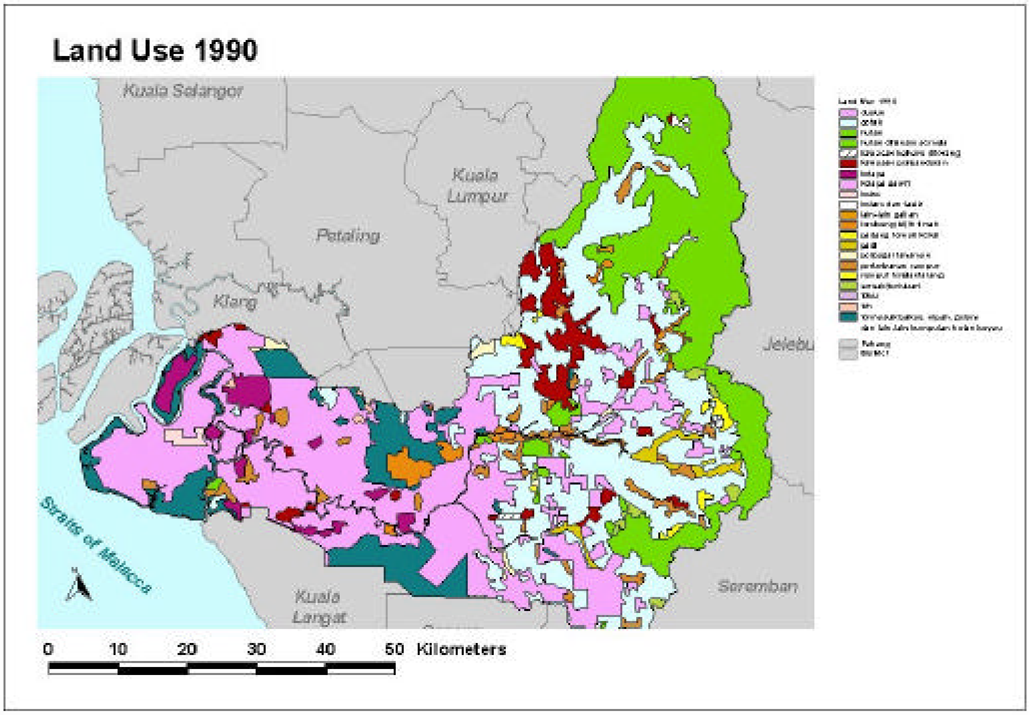

Figure 2b: Land use of the study area, 1990.

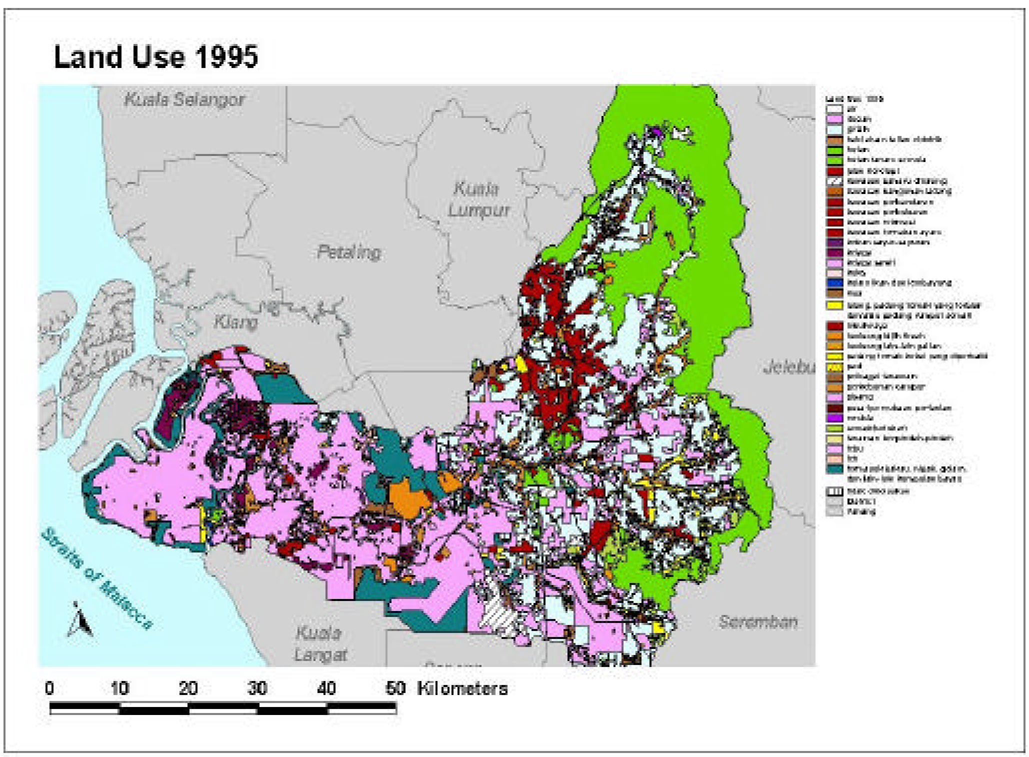

Figure 2c: Land use of the study area, 1995.

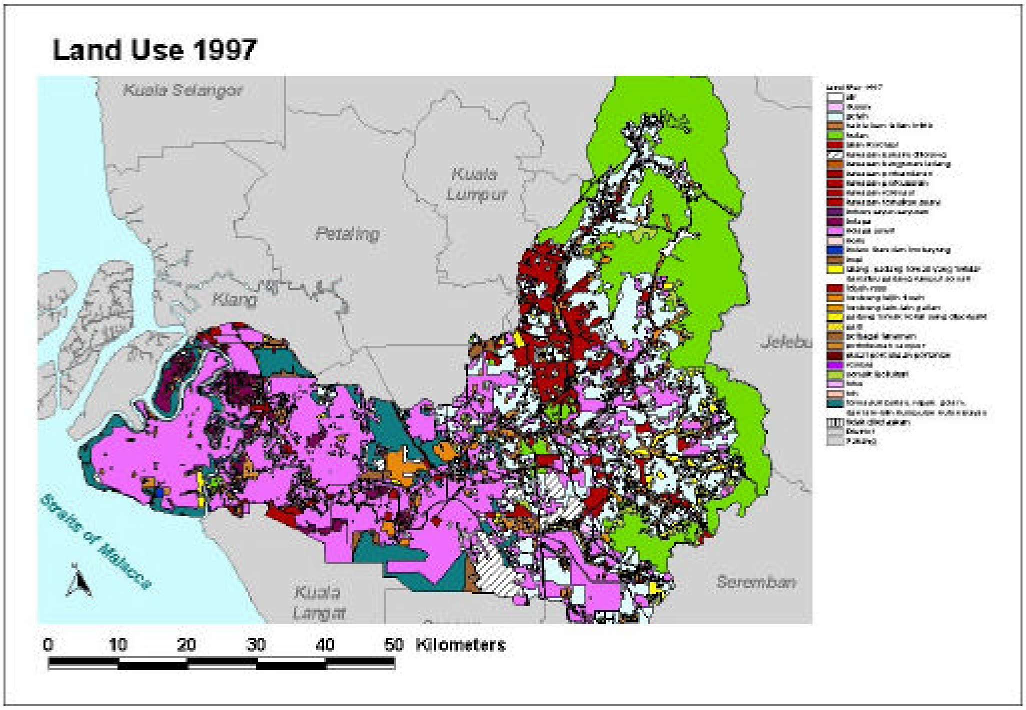

Figure 2d: Land use of the study area, 1997.