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Detection of Land Use Changes Through GIS Functionality: A Case Study in Randenigala and Kotmale Subcatchments

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ABSTRACT. *During the British colonial period, the hill country was open to devastation with the advent of plantation agriculture. Natural forest cover was removed for monocultures of coffee, rubber and then tea. The 1st detailed land use inventory was taken in 1956 long after this change. The Accelerated Mahaweli Development Programme (AMDP) was implemented in the 80s. Due to this development activity, the land use composition of the hill country changed again and an inventory has been prepared indicating the land use status after such changes. This study was carried out to detect the nature of land cover changes and quantify such changes in 2 selected sub-catchments through the use of spatial analysis tools of Geographical Information Systems (GIS).*

The results of the land use comparison reveal that there have been significant changes (more than +/-5% change) in some land use categories in the study area. The reason of decreasing annual crops (15.25%) and increasing forest (5.16%) and scrub land (9.01%) in Randenigala subcatchment is due to the establishment of Victoria, Randenigala and Rantambe (VRR) Sanctuary in 1987. Socio-economic and physio-geographic factors were the main cause for the decrease of tea cover by 6.04% and 12.52% in Randenigala and Kotmale subcatchments respectively. GIS databases are more advantageous than conventional techniques, because they can provide accurate assessments quickly. The results of comparisons in terms of spatial coverage provide vital information on land use changes for land use planning and thereby can be used to achieve sustainable management of catchment resources of the study area.

INTRODUCTION

Land use changes of the hill country were significant with the British conquest of the Kandyan Kingdom in 1815. However, the 1st detailed land use inventory of Sri Lanka was prepared in 1956–1961 period at a scale of 1:63,360 using aerial photographs, which were taken in 1956 at a scale of 1: 40,000 under the Canada-Colombo plan. Subsequently, Survey Department prepared the 2nd land use inventory in 1981 at a scale of 1: 100,000 on a district basis using aerial photographs and satellite imagery under the Sri Lanka-Swiss -

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Remote Sensing project. However, in this study, these land use map series were not considered suitable for detecting land use changes due to the smallness of the scale.

Inundation of considerable land area for multi-purpose reservoirs, resettlement programmes, infrastructure development, *etc.*, have been carried out within a very short period under the AMDP. In this period, Forest and Land Use Mapping Project (FORLUMP) of Mahaweli Authority has prepared detailed land use inventory for the Upper Mahaweli Catchment (UMC). These maps have been prepared using aerial photographs at a scale of 1: 15,000, which were taken in 1987. Field checking was carried out in 1992–1995 period and some areas have been updated using 1992, 1993 and 1994 aerial photographs.

In view of the considerable changes made on the land use in the UMC, it is important to detect the magnitude of changes and the spatial extent and distribution of such changes in the period prior to and after implementation of the AMDP. GIS is considered to be a powerful tool for detecting land use changes and hence used to identify changes of land use from 1956–1992.

Therefore, this study was initiated to assess the land use changes from 1956–1992, to utilize the strengths of spatial analysis functionality of GIS for change detection with high degree of accuracy, and to provide a vital set of information on land use changes for land use planing and sustainable watershed management.

MATERIALS AND METHODOLOGY

Location

The UMC consists of 4 main reservoirs constructed under the AMDP, namely: Kotmale, Victoria, Randenigala and Rantambe (Fig. 1). It covers Kandy and Nuwara Eliya districts and some parts of the Badulla and Matale districts. The selected area includes only 2 subcatchments of the UMC, namely: Randenigala and Kotmale. Agro-ecologically, Randenigala subcatchment belongs to the intermediate zone while Kotmale subcatchment belongs to the wet zone.

Data sources

GIS database in the environment and forest conservation division (EFCD) of Mahaweli Authority was prepared by digitizing the following paper maps: Land use maps of 1956 at the scale of 1:63,360 (source: Canada-Colombo plan, Hunting Survey, Survey Department, 1956/61), land use maps of 1992 at a scale of 1: 10,000 (source: FORLUMP, Mahaweli Authority, 1992/1995), contour maps at a scale of 1: 10,000 in 20 m interval (source: Dyeline copies of the contour maps, Survey Department of Sri Lanka) and the FORLUMP was added to spot heights between contours using an interpolation procedure. This digital information was used to detect changes and delineate the subcatchments boundary.

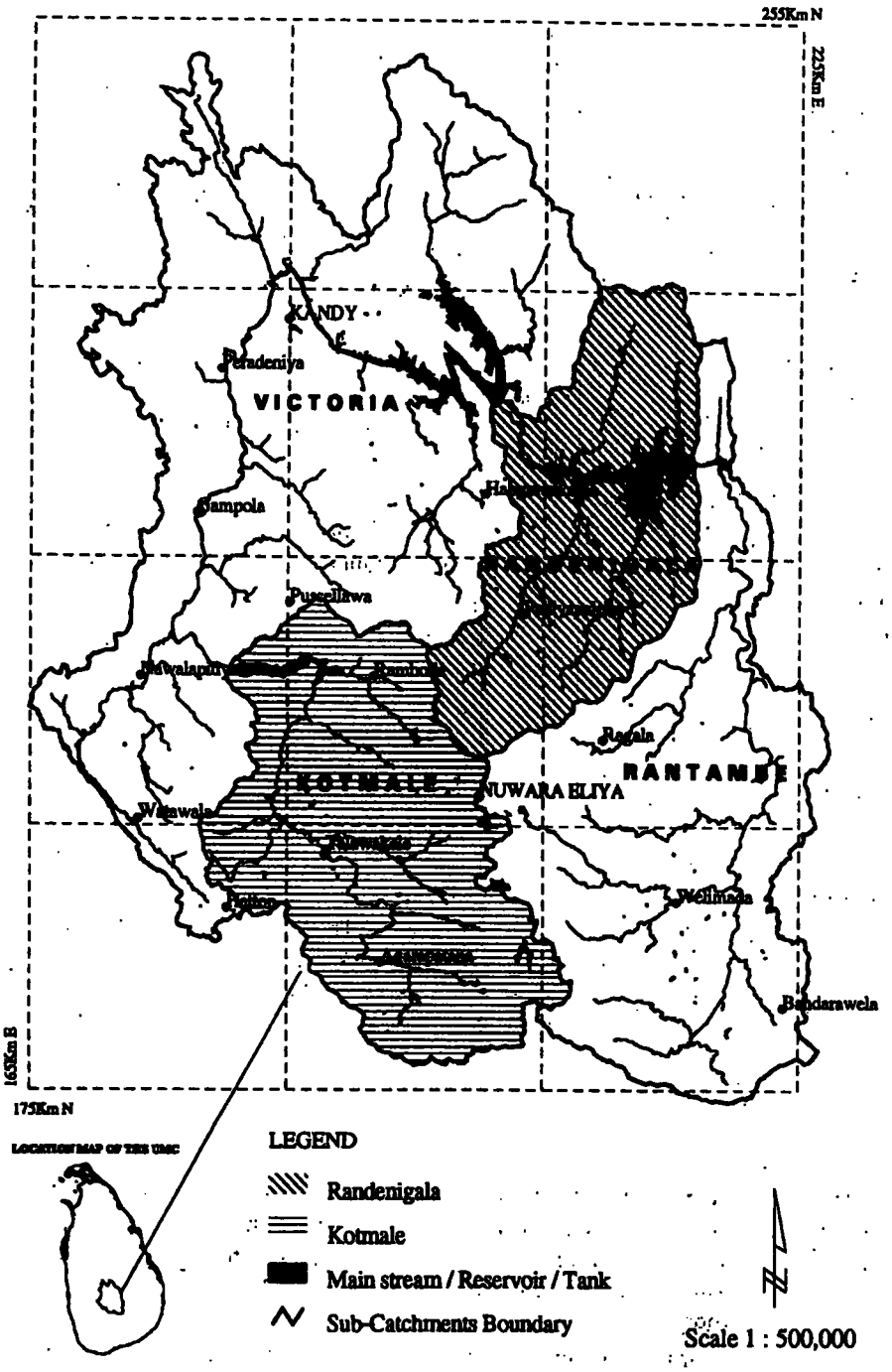

Fig. 1. Location map - subcatchments of the UMC.

Software tools

Workstation Arc/Info version 7.1.2 was used as the GIS software. In addition, TIN module and GRID modules of Arc/Info software were used to delineate sub-catchment boundaries. Arcplot and Arc/macro language facilities were used for digital cartography work.

Delineation of the subcatchments boundary

Digitized contours and spot heights were used to prepare Digital Elevation Model (DEM) in resolution of 10 m. The DEM is referred as digital representation of the elevation surface. The GIS has facilities to delineate catchment boundary by DEM. Finally, verification of the generated boundary was done through visual interpretation of the contours on the screen digitizing.

Map generalization

In this study, the two source maps were in tow different scales. The maps of 1: 10,000 contain more information than the maps of 1: 63,360. Therefore, in order to increase change detection accuracy, 1: 10,000 scale maps had to be reduced to 1: 50,000 scale. However, it is not realistic due to errors encountered in the process and time taken for such a process being very high. Therefore, a simple and quick technique called 'elimination' was used to increase the accuracy of change detection. The minimum mapping unit identified from the 1956 map was used as the minimum land parcel size *i.e.*, 10,000 sq. km for 1992 maps and those parcels which were smaller than this were eliminated.

Reclassification of legend

Land use legend of 1956 was somewhat different from the legend of 1992 maps. Digital land use maps of 1956 and land use map of 1992 were reclassified into a unified legend. The legend consists of 10 land use categories such as tea, perennial crops, paddy, other annual crops, grassland, scrub land, natural forest, forest plantations, urban/settlement/unproductive areas and water bodies.

Generation of statistics and map preparation

At 1st, land use maps of 1956 and 1992 were clipped upon to the delineated boundary of Randenigala and Kotmale subcatchments. Then, the GIS facilities were used to generate special extent for each category separately. Finally, the statistics for changes from 1956–1992 were calculated. Cartographic facilities of GIS were used to prepare maps for showing the changes.

RESULTS AND DISCUSSION

Change detection in land use

Land use changes that occurred from 1956–1992 in Randenigala and Kotmale subcatchments are tabulated in Table 1a and 1b. In addition, Fig. 2a and 2b show the spatial distribution of land use changes from 1956–1996 in Randenigala and Kotmale subcatchments respectively.

Table 1. Changes of major land use categories from 1956–1992 in Randenigala subcatchment.

Land use	1956		1992		Change
	Extent/ha	%	Extent/ha	%	%
Tea	6638.66	14.82	3933.28	8.78	-6.04
Other Perennials	2749.17	6.14	2896.90	6.46	0.32
Paddy	3756.06	8.39	3423.17	7.64	-0.75
Annual crops	15024.90	33.55	8184.63	18.30	-15.25
Grassland	3318.91	7.42	1119.13	2.50	-4.92
Scrub land	77.95	0.17	4111.58	9.18	9.01
Forest plantations	342.02	0.76	2221.74	4.95	4.19
Natural forest	12511.00	27.94	14812.90	33.10	5.16
Urban/settlements/unproductive	50.04	0.11	1329.87	2.95	2.84
Water bodies	315.17	0.70	2750.71	6.14	5.44
Total	44783.90	100.00	44783.90	100.00	

According to Table 1 and 2, some land use categories show significant changes *i.e.*, annual crops, scrub land, tea, forest and water bodies in Randenigala subcatchment and tea in Kotmale subcatchment.

Due to lack of natural forest cover at the required level, man-made forest or forest plantations have been established in the country. There are 5 categories of planted forest in the UMC such as Pine, Eucalyptus, Albizzia, mixed and other species according to the 1992 land use maps. In this study, all categories were taken as 1, because there were no separate categories in 1956 maps. As shown in Table 1 and 2 both catchments show the success of reforestation programme. Eucalyptus is the dominant plantation species in both catchments. Randenigala and Kotmale subcatchments have Eucalyptus plantation of 1097.87 ha and 3199.45 ha respectively. In addition, the extent of expansion of annual crops, scrub land and reduction of forest in Kotmale subcatchment and reduction of

Table 2. Changes of major land use categories from 1956-1992 in Kotmale subcatchment.

Lane use	1956		1992		Change
	Extent/ha	%	Extent/ha	%	%
Tea	32108.90	56.21	24955.60	43.69	-12.52
Other Perennials	1959.06	3.43	2072.32	3.63	0.20
Paddy	1164.35	2.04	806.17	1.41	-0.63
Annual crops	191.45	0.34	2040.19	3.57	3.23
Grassland	2506.33	4.39	3628.06	6.35	1.97
Scrub land	35.33	0.06	1950.97	3.42	3.35
Forest plantations	1960.60	3.43	4079.67	7.14	3.71
Natural forest	16531.60	28.94	14610.90	25.58	-3.36
Urban/Settlement/Unproductive	388.69	0.68	1864.80	3.26	2.58
Water bodies	273.79	0.48	1111.35	1.95	1.47
Total	57120.10	100.00	57120.10	100.00	

grassland in Randenigala subcatchment are is also considerable while for other crops, this is marginal. Small changes can be negligible due to the difference in the scales of the source maps.

Reasons for the changes

There are many socio-economic or physio-geographic factors that can be attributed to declining tea cover from 1956 to 1992 in both subcatchments. According to Perera (1982), after the nationalization of plantations in 1975, some of the old, uneconomical tea areas were diversified into minor export crops and settlements. Further, the national tea industry was re-privatised in 1992. Humbel (1983) mentioned that the loss of tea area is mainly a result of expansion of the settlement areas, construction of new water reservoirs and devastation of marginal tea lands. Heller (1998) attributed decreasing yield, village extension and crop diversification as reasons for decline in tea extent. Furthermore, loss of fertile soil, or deterioration of soil quality are the most important factors, which prevent replanting of old tea fields. According to Stockings (1992), some of the abandoned tea land had been handed over to smallholders for diversification and settlement, while some had been reforested. Large areas have been degraded into grasslands.

After the independence, most of the tea lands have become marginal. Thus the high demand for vegetables which grow well in the hill country has replaced tea in such lands. Hence, investigation of 1956 and 1992 land use maps show that the annual crops have invaded the former tea lands. High population pressure and scarcity of land also lead to clearing of forest for agriculture and settlement in Kotmale subcatchment.

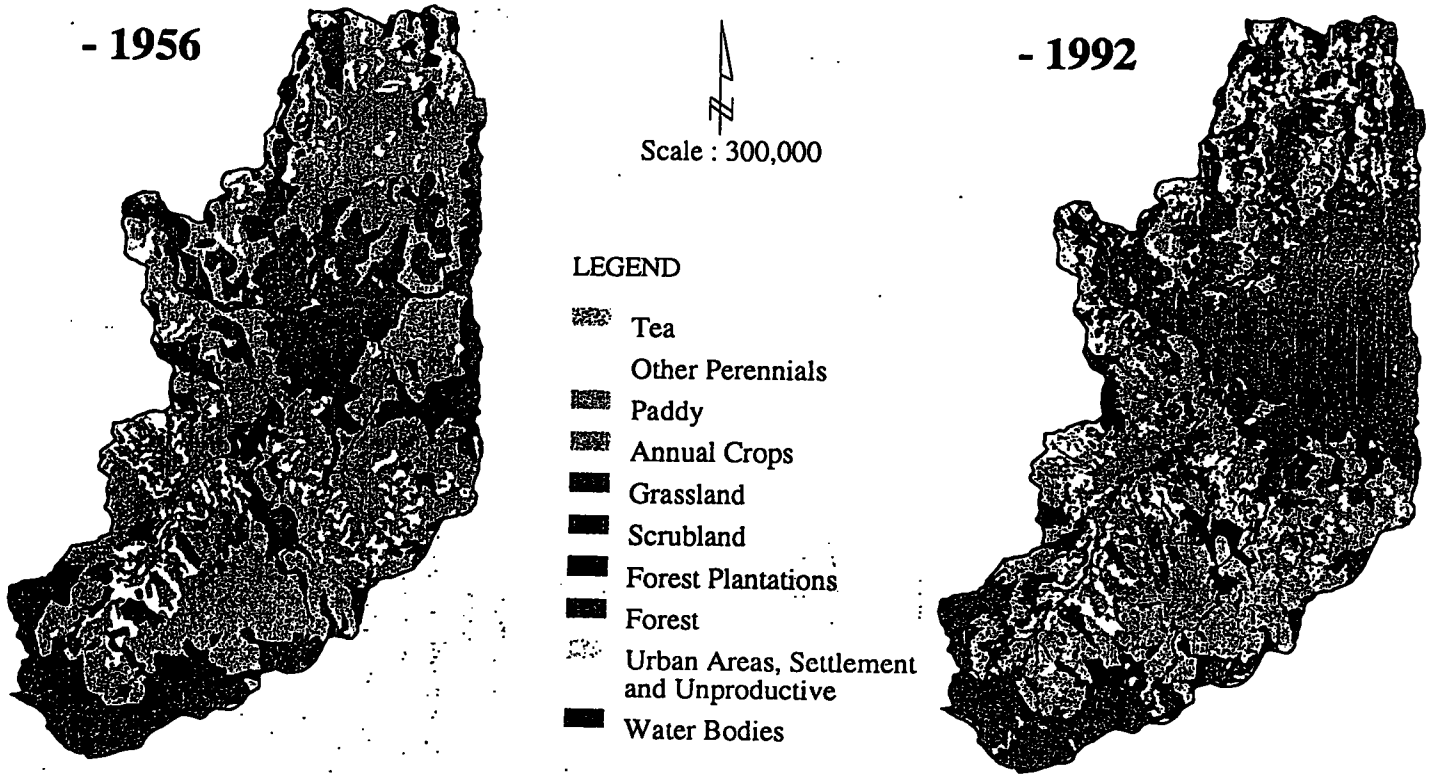

Figure 2a. Land use changes in Randenigala subcatchment.

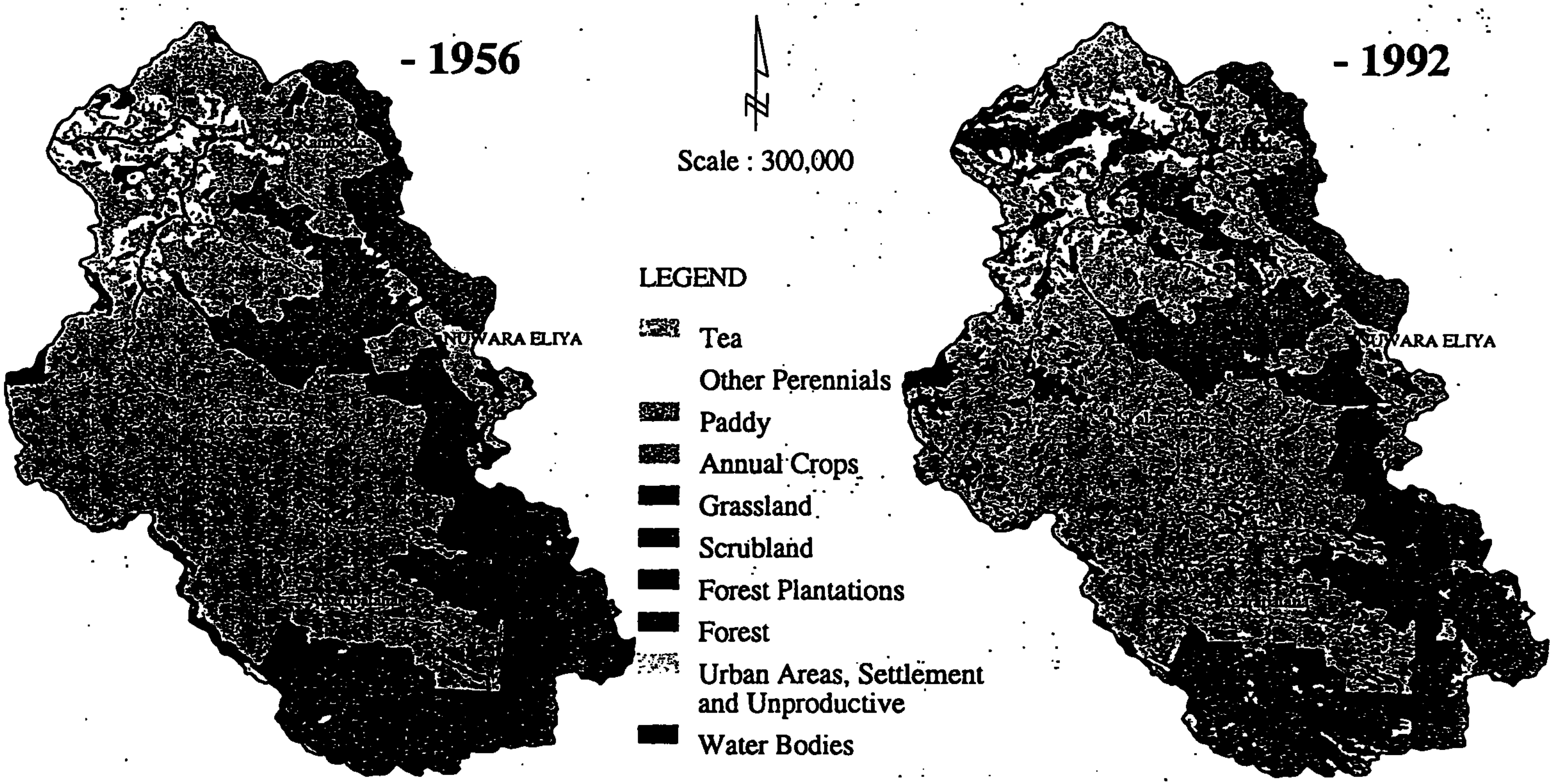

Figure 2b. Land use changes in Kotmale subcatchment.

Establishment of VRR Sanctuary in 1987 has been the main cause for shrinking of annual crops and expansion of scrub land and forest in Randenigala subcatchment. Investigation of the two land use maps indicated that, some land of annual crops in 1992 were tea land in 1956. It also revealed that some of the uneconomical marginal tea land have become post profitable annual crops specially vegetables in Kotmale subcatchment.

With the high population growth and agricultural development activities, yield of natural forests is not sufficient to fulfil the requirement of fuel wood for domestic consumption and timber for housing, industrial, furniture, *etc.* Therefore, aforestation and reforestation programmes have been launched to meet the demand of timber and fuel wood. On the other hand, forest cover maintained at adequate level is essential for the sustainable development concept. Most of the upper watershed management studies have identified soil erosion, siltation of reservoirs, land degradation as the critical problems. Hence, reforestation and aforestation programmes have been carried out as a remedy. These planted forests such as Pine and Eucalyptus are not only beneficial from a hydrological view point but also produces high quality timber and beautifies the terrain.

Investigation of land use maps in 1956 and 1992 indicated that some of tea land (specially in Kotmale catchment) have been converted into urban and settlement areas. Forest clearance for settlement is also visible in both catchments. Increasing trend of unproductive lands can be detected in both catchments that mainly brought heavy soil erosion, land slide due to long term over exploitation of human influences without conservation and mitigatory measures.

Limitations

The land use changes since independence have been recorded primarily through topographic mapping, air surveys and periodic agricultural censuses. Compared with most other third-world counties, land use changes over the years have been documented relatively better in Sri Lanka. Nevertheless, land use data from different sources often do not tally mainly due to differences in concepts and definitions (National Atlas, 1988). Hence, accurate detection of land use changes seems to be a complex task. However, there are some techniques that can be used to increase the accuracy and validity of such comparisons.

Scale

In this study, scale is the greatest limiting factor. However, minimum mapping unit technique is one of the solutions that can be applied through GIS to increase the accuracy while cutting down the work load and time spent on for the study. In this context, 'Minimum mapping unit' technique has increased the overall accuracy of change detection process while minimising the time taken for the study.

Legend

In available inventories, definitions of land use categories vary from case to case according to its objectives. Therefore, perfect comparison is impossible. However, careful investigation of the legends revealed more or less equality of some form in these definitions. Hence, reclassification of the legend is one way of increasing accuracy of comparisons.

CONCLUSIONS

This study highlighted that there have been considerable changes in some of the land use categories in the study area. Tea has significantly decreased from 1956–1992 while urban areas and settlements marginally increased in both subcatchments. Though forest cover has increased in Randenigala subcatchment, deforestation has been significant in Kotmale subcatchment. With the declining tea cover, it is inevitable to have an increase of the scrub land in the subcatchments.

The advantages of GIS databases and functionality are evident throughout the study when detecting land use changes. Capabilities of updating the GIS database for detecting changes after 1992 period is necessary for future studies by directly inputting the remotely sensed data, since it is a very useful tool for monitoring dynamic land use status.

The following conclusions can be drawn from this study:

GIS databases are more advantageous than conventional techniques in detecting land use changes, because they can provide accurate estimation or assessment with exact geographical identification quickly.

Though there are limitations, accuracy and validity of the results in the study proved to be at a satisfactory level due to generalization and reclassification processes.

Land use planning is required with continuous updating of change detection using recent satellite data by incorporating GIS and Remote Sensing techniques to monitor the effectiveness of catchment conservation strategies.

Digital mapping is encouraged due to its vast range of facilities to highlight the changes by attractive graphics.

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