A GIS Approach to Land-Use Change Dynamics Detection

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ABSTRACT: A Geographic Information Systems (GIS) approach was applied to assess the impact of new town development in Tuen Mun, New Territories, Hong Kong, on the environment through integrating past and current aerial photographic data of land use with topographic and geologic data. The image overlaying and binary masking techniques were found to be particularly useful in revealing quantitatively the change dynamics in each category of land use which was impossible to accomplish by the conventional change detection technique. The same method was applied to assess the impact of such terrain attributes as slopes, surface hydrology, and geology on these land-use changes. It was revealed that the government had some successes in controlling the spread of eroded badland with reforestation as the intensity of urban land use increased, although the reforestation was hampered by rapid surface runoff on steep slopes. The GIS approach was evaluated to be accurate and capable of providing the planners with more insightful assessment of the impact of their actions on the environment.

INTRODUCTION

SEQUENTIAL AERIAL PHOTOGRAPHS have been commonly employed by planners to detect land-use change over a period of time in a region (e.g., Avery, 1965; Faulkner, 1968; Richter, 1969; Adeniyi, 1980; Campbell, 1983; and Lo and Wu, 1984). The method involves manually interpreting land-use categories from aerial photographs for each period of time and measuring their areas using a dot grid, planimeter, or digitizer. By comparing the area data between two or more periods of time, the predominant land-use changes in the region can be detected. However, this type of land-use change data generated is static, and cannot reveal the processes of changes that have occurred in space for each category of land use, i.e., the dynamics of land-use change, without going further into a laborious cross-referencing of each category of change in its spatial location

The recent advancement in microcomputer-based Geographic Information System (GIS) technology has availed the planners of a powerful tool which, by integrating spatial data collected from different sources and in different formats, allows overlaying of two or more maps to be carried out with ease (e.g., Williams, 1985; Wheeler and Ridd, 1985; Johnston *et al.*, 1988; Lindhult *et al.*, 1988; Hathout, 1988; Berry and Berry, 1988). In this paper, the use of a low-cost microcomputer-based GIS – IDRISI (Eastman, 1988a, 1988b) in land-use change detection from sequential aerial photographs is explained. In particular, the usefulness of the binary masking method in revealing the dynamics of land-use change and the impact of the change on the physical environment will be demonstrated. Finally, the accuracy of the GIS approach for change detection will also be evaluated.

THE STUDY AREA

The site selected for this application is East Teun Mun in West New Territories of Hong Kong, which is dominated by a rapidly developing new town called Tuen Mun (Figure 1). Hong Kong, which is a British Colony with a total land area of a mere 1,000 km² located on the South China coast, has experienced large population increases accompanied by dramatic economic growth since 1949. Most of its population was concentrated on a small metropolitan area occupying only 12 percent of the land area of Hong Kong. In order to decentralize population growth, the Hong Kong Government has, since the early 1960s, started building new towns in the suburban and rural areas. These new towns are self-contained and are characterized by a mixture of residential, commercial, and industrial uses. Residential use is dominated by high-density low-cost public housing planned and operated by the government. Today, as the level of affluence of the population increases, the government's new town objective has also shifted to emphasize higher quality public housing and a better planned urban environment (Leung, 1986). Teun Mun is a typical example of this new generation of new towns under development since 1975 (New Territories Development Department, 1977).

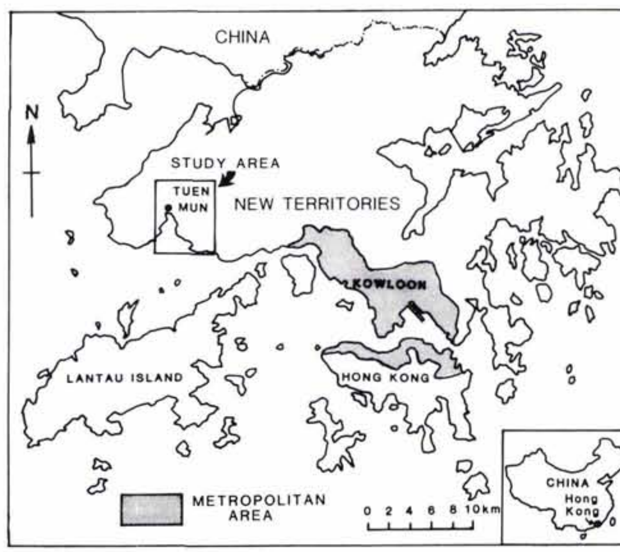

FIG. 1. Location map of the study area: East Tuen Mun, New Territories, Hong Kong.

The Tuen Num region, however, is restricted in growth by some physical constraints. These include limited land areas with gentle slopes and high erosion potential of the surrounding areas. The new town itself, which is sandwiched between two plateaux, was built on deposits of alluvium and colluvium of Tuen Mun Valley and on land reclaimed from Castle Peak Bay (Figure 2). According to the survey conducted by the Geotechnical Control Office (1987), the Tuen Mun valley is thought to be a fault controlled "graben" structure with a thrust fault forming the western plateau which rises to a height of 583 metres. The

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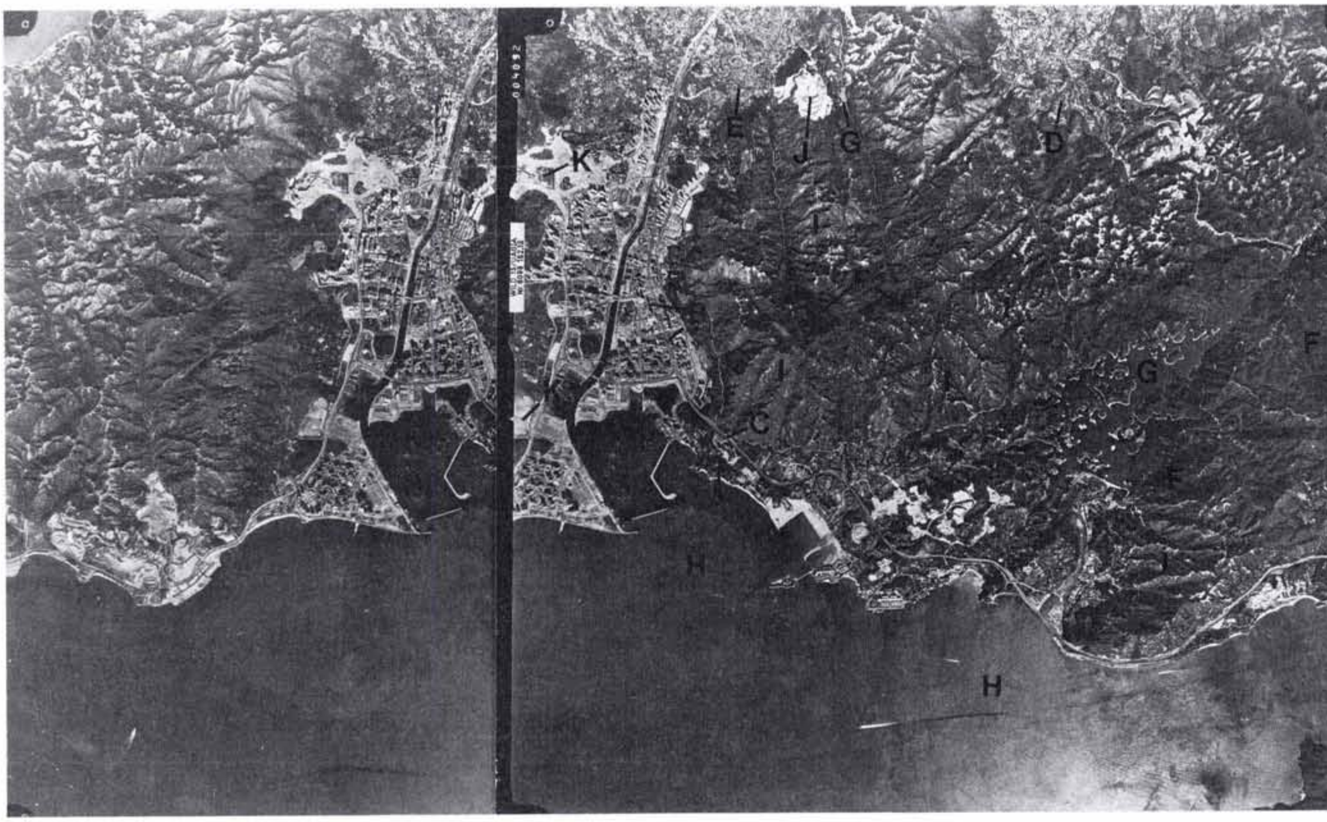


FIG. 2. Stereogram of East Tuen Mun study area 5 January 1987 (original photographic scale 1:40,000). A = Low Density Urban; B = High Density Urban; C = Transportation; D = Cultivated Land; E = Argicultural/Residential; F = Mixed Woodland; G = Reservoir; H = Bays; I = Eroded Badland; J = Barren Land; and K = Transitional (Copyright: Hong Kong Government).

eastern plateau reaches an elevation of 511 metres with a substantial part of the area above 300 m. The two plateaux are made up mainly of granites with essentially similar mineralogy, which exhibit distinct rock jointing. There are also numerous faults criss-crossing the area, the most dominat of which trend north to south with a lesser curvilinear series trending east northeast to west southwest. The combination of geology, slope, and a monsoonal climate favors weathering and erosion in these plateau areas. The granite ridgecrests and sideslopes are often weathered to a depth of at least 20 m. Sheet erosion, rill erosion, and gully erosion were found to occur in different parts of the study area, thus accounting for a significant level of soil loss which, in turn, results in thin vegetation cover dominated by grass and shrubs. All these have given rise to slope instability. The new town itself is bisected into two halves by a north-south trending ditch of 80-metre width, which is really an artifically channelled Tuen Mun River for the purpose of accommodating the very rapid runoff from the surrounding hill slopes in order to avert flooding during periods of heavy rainstorms. The study site is, therefore, an environmentally sensitive area, the use of which requires careful planning.

DATA AND METHODOLOGY

The best source of land-use and land-cover information at different times is aerial photographs, for which Hong Kong has excellent coverage. Two sets acquired on 23 November 1976 and 5 January 1987 at a nominal scale of 1:25,000 and 1:40,000, respectively, were selected for this study because the year 1976 marked the beginning of visible new town development in Tuen Mun while the year 1987 signified the maturing of the new town after 11 years. Full technical details of these aerial photographs are shown in Table 1. A total of seven photographs was employed for this research—four for 1976 and three for 1987 (Figures 2 and 3).

Complementing these aerial photographs are topographic and geologic maps of the study site at 1:50,000 scale, from which terrain attributes relating to elevation, slope, aspect, surface hydrology, watershed, geology, and transportation were extracted (Table 2).

The methodology for land-use change dynamics detection involves five stages: (1) data extraction, (2) data capture, (3) data integration, (4) data analysis, and (5) output of results.

TABLE 1. TUEN MUN AERIAL PHOTOGRAPHIC INFORMATION.

	1976 Photographs	1987 Photographs
Date of acquisition	23 November 1976	5 January 1987
Time of acquisition	2:10 P.M. local time	11:42 A.M. local time
Scale	1:25,000	1:40,000
Focal length	152.53 mm	152.12 mm
Flying height	3,810 m	6,096 m
Camera type	Wild RC10	Wild RC10A
Frame numbers	16511-16514	A08422-A08424
Film format	23 × 23 cm	23 × 23 cm
Endlap	70%	64%
Quality	very good	good
Agency	Surveying and Mapping Office, Hong Kong Goverment	Surveying and Mapping Office, Hong Kong Government

FIG. 3. Stereogram of East Tuen Mun study area, 23 November 1976 (original photographic scale 1:25,000). The annotations are the same as in Figure 2. (Copyright: Hong Kong Government).

TABLE 2. DATABASE ATTRIBUTES AND MAP SOURCES.

Attribute	Source
Elevation	Hong Kong 1:25,000-scale topographic map: Sheet 5, Castle Peak; Sheet 6, Yuen Long. Hong Kong Government, 1969.
Slope	derived from elevation data
Aspect	derived from slope data
Surface Hydrology	Map of the Territory of Hong Kong, 1:50,000-scale: Sheet 1 of 2. Hong Kong Government, 1986.
Watershed	derived from aspect data
Geology	Geological Map of Hong Kong, Kowloon, and the New Territories, 1:50,000-scale: Sheet 1 of 2. Hong Kong Government, 1972.
Transportation	Map of the Territory of Hong Kong, 1:50,000-scale: Sheet 1 of 2. Hong Kong Government, 1986.

TABLE 3. MODIFIED U.S.G.S. LAND-USE/LAND-COVER CATEGORIES.

U.S.G.S. Level II Code Equivalent	Description	Code
11,16	Low Density Urban	11
12-15	High Density Urban	12
14	Transportation	14
21	Cultivated Land	21
None	Agricultural/Residential	24
43	Mixed Woodland	43
53	Reservoirs and Ponds	53
54	Bays and Estuaries	54
None	Eroded Badland	70
74	Barren Land	74
76	Transitional Land	76

DATA EXTRACTION

The primary data extraction is manual interpretation of the aerial photographs for land-use/land-cover information of the study area based on a modified Level II classification scheme (Table 3). Because of the high degree of intermixing between residential, commercial, and industrial uses, two general categories of urban use, namely, low-density and high-density, were identified. The area, being rural in nature, was also characterized by the occurrence of village clusters and their associated agricultural activities. Manual interpretation was aided by collateral materials from Tuen Mun supplied by New Territories Development Department (1977) and Geotechnical General Office (1988) as well as generalized land-use maps of Hong Kong produced by the Lands Department, Hong Kong Government in 1977 and 1982. All these efforts ensured that the interpretation accuracy met the minimum 85 per cent required by the U.S. Geological Survey's classification scheme (Andersen *et al.*, 1976).

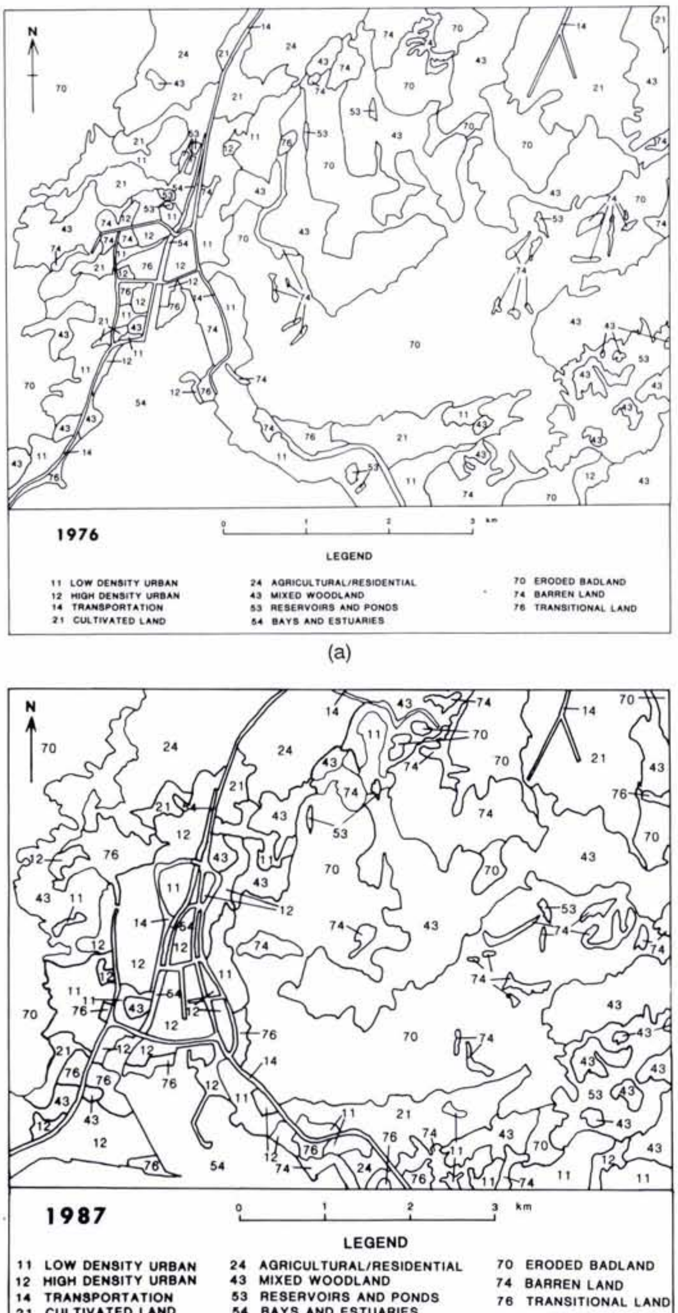
The land-use catergories were delineated onto clear mylar overlays for the aerial photographs of each year. This was executed both stereoscopically with the aid of a mirror stereoscope (3 times to 6 times magnification) and monoscopically with a hand-held 2 times magnifying glass. The land-use categories delineated on the mylar overlays were then transferred to a

1:25,000-scale base map using a Bausch and Lomb Zoom Transferscope based on common control points between the maps and the aerial photographs. The result was land-use maps of the study area for two different years, which could be *accurately* registered together (Figure 4).

Data Capture

Data capture refers to the digitizing process by which map data are transformed to digital format for storage in the computer. For this project, a Summagraphics Microgrid II digitizer(with an accuracy of ± 0.254 mm and a resolution of 40 lines per mm) connected to an IBM personal computer and a computer program called CAPTURE were employed for encoding. The digitized coordinates of points from the map were then transformed into Universal Transverse Meractor (UTM) coordinates using four to five ground control points in UTM coordinates and an affine transformation program. Each land-use map of the study area was individually digitized and transformed into UTM coordinates. The resultant root mean square error in planimetry ($RMSE_{xy}$) at the 1:25,000 map scale was found to be $\pm$ 6.0 metres at 90 percent level of confidence, which is better than the ± 7.5 metres planimetric error permitted by the U.S. National Map Accuracy Standards.

Other maps of varying scales that have been digitized and transformed in the same manner included elevation, geology, and surface hydrology. A digital terrain model (DEM) was created by digitizing over 800 sampled elevations from the topographic map.



(a)

(b)

FIG. 4. Land-use maps of East Tuen Mun as interpreted from aerial photographs for the years (a) 1976 and (b) 1987.

Data Integration

Data integration is the process by which all "layers" of the digital data are made to conform in format and geographic reference. Because the GIS software (IDRISI) employs a grid-based or raster format, all the digitized maps obtained in the data capture stage, which are in vector format, have to be converted to raster format using the rasterizing algorithm supplied by IDRISI. The grid size selected was 20 by 20 metres, which is compatible with the scale and resolution of the aerial photographs used in a Level II land-use classification. The grid size is further constrained by the storage capacity of the microcomputer. After the vector-to-raster conversion of the map data, a 3 by 3 mode filter was passed over each data layer to eliminate any "slivers" which tended to occur between digitized polygons sharing common boundaries (Figure 5). Finally, each data layer was registered to a common grid system or map projection. For this application, the UTM (Universal Transverse Mercator) projection was used.

Data Analysis

The basic data analysis techniques employed for land-use change dynamics detection and impact assessment are image overlaying and binary masking (Pilon *et al.*, 1988). Each pixel value for the 1976 land-use image was subtracted from its corresponding pixel location on the 1987 land-use image. The result was a new image made up of positive, negative, and zero values. Zero values denoted pixels where no change has occurred, while positive and negative values represented pixels where change has taken place. The positive and negative values were reclassified to 1, leaving unchanged the zero values. The resultant image was a binary change mask consisting only of "zeros" and "ones" (Figure 6). Values of "ones" represent areas which have undergone change in land use since 1976. "Zeros" represent areas where no change in land use has occurred. The binary change mask was then multiplied to each of the original land-use images, thus giving rise to a masked classification image for 1976 and 1987 individually. The masked 1976 image indicated spatial locations of those land-use categories that would be lost, while the masked 1987 image indicated the corresponding spatial locations of those land-use categories that had been gained (Figure 7). Quantitative areal data of the overall land-use changes as well as the gains and losses in each category of land use between 1976 and 1987 could be compiled for the study area. In addition, land-use change maps could also be produced.

The next stage of data analysis was to assess the relationship between the changed land-use categories and the physical environment. Only three terrain characteristics were used: slope, geology, and surface hydrology. From the digital elevation model obtained in the data capture stage, a slope map was produced by applying a second interpolation function of the IDRISI program. The binary land-use change mask was multiplied to each of the

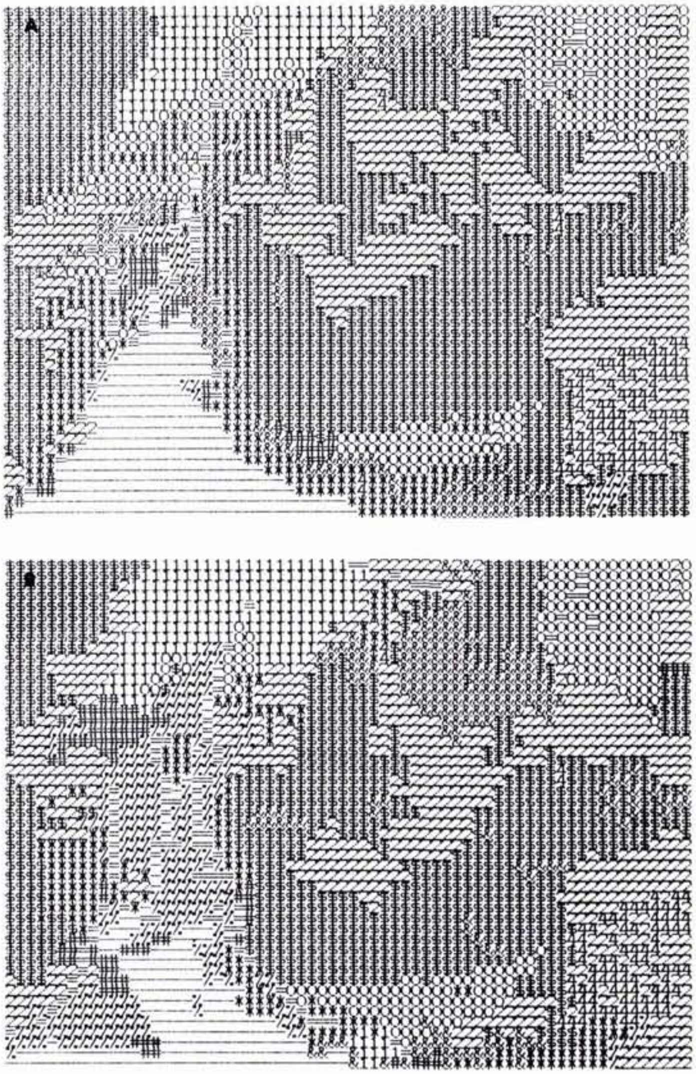


FIG. 5. Rasterized land-use map of East Tuen for the years (a) 1976 and (b) 1987. Key: --- Bays, = = = Transportation, * Low Density Urban, % High Density Urban, & Barren Land, # Transitional Land, $ Eroded Badland, 0 Cultivated Land, 1 Agricultural/Residential, 2 Mixed Woodland, and 4 Reservoirs.

three terrain characteristics maps. In this way, spatial locations of land-use change were correlated with individual terrain characteristics. In order to evaluate the impact of steep slopes on land use in 1976 and 1987, a binary steep slope mask was developed, which distinguished slopes of 24 percent and above. The criterion of 24 percent as the lower limit of steep slopes was suggested on civil engineering grounds by the Geotechnical Control Office in Hong Kong (1988), which regarded slopes of more than 24 percent neither safe nor economical to develop. This binary steep slope mask was multiplied individually to the 1976 and 1987 land-use images in the GIS.

Output of Results

The GIS approach permits the results of the analysis to be displayed in maps and table forms. The IDRISI program allows hard copies of maps to be produced in color by the Hewlett-Packard PaintJet Color Graphics Printer. However, because of the cost of color reproduction, only black-and-white pattern maps are used throughout this paper.

FIG. 6. Map of Binary change mask showing areas which have undergone land-use changes between 1976 and 1987 (black), and areas where no land-use changes have occurred (white).

RESULTS OF ANALYSIS

Characteristics of Land Use of the Study Area as Interpreted from Aerial Photographs

The land use of East Tuen Mun was characterized by a mixture of urban and rural activities which were readily interpretable from the aerial photographs. Major urban land uses were concentrated in the new town where *High Density Urban Land Use* (12) tended to predominate. This occurred in the form of high-rise buildings which were distinctly identifiable from the stereo-pair of aerial photographs (Figure 2). This class represented an amalgamation of high density residential, commercial and services, and industrial land uses. *Low Density Urban Land Use* (11), on the other hand, was exhibited as low-rise buildings on the aerial photographs, which occurred along the lower hillslopes flanking the new town. These buildings comprised squatter structures, bungalows, and other detached houses. Development of a new town in a rural area required the contruction of highways and roads to link it to the major metropolitan area of Hong Kong. *Transportation* (14), therefore, appeared as a very important form of land use in the study area, which was distinguished by its light tone and narrow linear and curvilinear shape. *Cultivated Land* (21) could still be found along Tuen Mun River and its tributaries with specialization in vegetables and other high-value market gardening crops. Another interesting land use was *Agricultural/Residential* (24), which described the intermixture of village house clusters and small cultivated fields. These represented the sites of villages of the original rural inhibitants in the area. These were found to the north of the new town along Tuen Mun River in close association with the *Cultivated Land* (21). On the mountain areas to the east and west of the new town, *Mixed Woodland* (43) occurred. This composed both deciduous and coniferous tree species. On the aerial photographs, this class of land use was distinguished by very dark tones and fine texture, and was associated frequently with the foothills of the mountainous eroded areas. *Reservoirs and Ponds* (53) were found both in the river plain and the mountain area. In the plain, these were mainly fish ponds associated with the agricultural activities and/or for decorative purpose. In the mountains, they are reservoirs which supply drinking water to the population of Hong Kong. Tai Lam Chung Reservoir, which occupies the drainage basin of Tai Lam River, is the largest

FIG. 7. Rasterized land-use maps displaying land use categories where changes have occurred: (a) 1976 (losses) and (b) 1987 (gains). For symbol key, see, Figure 5.

reservoir in this area for this purpose. Tuen Mun new town is located on a bay (Castle Peak Bay) which is being artificially reclaimed southward to provide more land for the new town to develop, hence the category of land use, *Bays and Estuaries* (54). As has already been mentioned, the mountain areas flanking the new town are very susceptible to weathering and erosion, especially along the ridgecrests and sideslopes. The erosion was so well developed that the term "badland" was given to them hence the land-use class *Eroded Badland* (70), which could be distinguished by the light tone on the aerial photographs and its association with ridgecrests and steep slopes. Indeed, gullies could also be detected in areas of intense erosion by stereoscopic examination of the aerial photographs (Figure 2 and 3). The study area also showed *Barren Land* (74), which included rock quarries, highly eroded localized areas where bare rock was evenly exposed, and areas where reclamation or excavation has been undertaken but no development existed. Finally, inside the reclaimed areas of the new town, *Transitional Land* (76) tended to occur. In this class of land use, some type of development was underway, such as in paving or construction. Transitional lands displayed light to medium grey tones on the aerial photographs and were somewhat darker and more regularly shaped than *Barren Lands* (74) (Figures 2 and 3).

LAND USE CHANGE DYNAMICS

The initial analysis of the 1976 and 1987 land-use map images (Figure 5) by the GIS approach generated Table 4 which displayed the static land-use data of the study area for the two years. It is clear that for both years Eroded Badland was most dominant, followed by Mixed Woodland. However, a comparison of the statistics revealed a decline in Eroded Badland from 36.5 percent to 29.8 percent, and an increase in Mixed Woodland from 20.1 percent to 21.6 percent, while High Density Urban use has jumped dramatically from 1.4 percent to 7.9 percent during this period. Subsequent analyses using the image overlaying and binary masking techniques as explained previously generated Figure 7 and Table 5. Figure 7 pinpointed the spatial locations where land-use changes have taken place. Figure 7(a) indicated the locations of the original land use categories in 1976 which would be changed while Figure 7(b) indicated what the new land-use categories were for the same locations by 1987. Table 5 summarized these changes in terms of "losses" and "gains," and one clearly sees a net gain (+ 6.5 percent) of High Density urban use and a net loss (− 6.7 percent) of Eroded Badland. By comparing the before-change and after-change maps (figure

TABLE 4. LAND USE IN EAST TUEN MUN, 1976 AND 1987.

	1976		1987	
Land Use Class	Pixels*	% of Total	Pixels*	% of Total
11 Low Density Urban	11,049	9.2	7,323	6.1
12 High Density Urban	1,645	1.4	9,480	7.9
14 Transportation	1,396	1.2	3,574	3.0
21 Cultivated Land	11,191	9.3	9,130	7.6
24 Agricultural/ Residential	5,130	4.3	7,976	6.6
43 Mixed Woodland	24,054	20.1	25,934	21.6
53 Reservoirs and Ponds	3,272	2.7	3,027	2.5
54 Bays and Estuaries	10,732	8.9	7,172	6.0
70 Eroded Badland	43,826	36.5	35,774	29.8
74 Barren Land	6,106	5.1	7,517	6.3
76 Transitional Land	1,599	1.3	3,093	2.6
TOTAL	120,000	100.0	120,000	100.0

*Each pixel is a 20 × 20 m cell or 0.04 hectare.

TABLE 5. LAND-USE CHANGE IN EAST TUEN MUN 1976-1987. SHOWN ARE THE NUMBER OF PIXELS IN EACH LAND-USE CATEGORY BEFORE (1976) AND AFTER (1987) CHANGES HAVE OCCURRED.

	1976 (Losses)		1987 (Gains)		1976-1987
Land Use Class	Pixels*	% of Total	Pixels*	% of Total	Net Change%
11 Low Density Urban	7,714	6.4	3,988	3.3	−3.1
12 High Density Urban	619	0.5	8,454	7.0	+6.5
14 Transportation	846	0.7	3,024	2.5	+1.8
21 Cultivated Land	4,478	3.7	2,417	2.0	−1.7
24 Agricultural/ Residential	294	0.2	3,140	2.6	+2.4
43 Mixed Woodland	12,146	10.1	14,026	11.7	+1.6
53 Reservoirs and Ponds	248	0.2	3	0.0	−0.2
54 Bays and Estuaries	4,125	3.4	565	0.5	−2.9
70 Eroded Badland	16,886	14.1	8,834	7.4	−6.7
74 Barren Land	5,120	4.3	6,531	5.4	+1.1
76 Transitional Land	1,599	1.3	3,093	2.6	+1.3
Unchanged	65,925	54.9	65,925	54.9	0
TOTAL	120,000	99.8	120,000	99.9	

*Each pixel is a 20 × 20 m cell or 0.04 hectare.

TABLE 6. LAND-USE CHANGE DYNAMICS IN EAST TUEN MUN, 1976-1987*.

Land Use Class	11	12	14	21	24	43	53	54	70	74	76	Total (1987)
11 Low Density Urban	0	304	70	271	0	1,195	75	114	1,203	620	136	3,988
12 High Density Urban	1,842	0	432	857	2	426	81	2,725	267	973	849	8,454
14 Transportation	892	182	0	346	169	109	10	301	105	796	114	3,024
21 Cultivated Land	815	29	21	0	24	765	0	0	341	147	275	2,417
24 Agricultural/Resid.	701	0	119	1,130	0	408	79	0	589	114	0	3,140
43 Mixed Woodland	1,064	0	58	408	99	0	3	20	10,657	1,617	100	14,026
53 Reservoirs and Ponds	0	0	0	0	0	3	0	0	0	0	0	3
54 Bays and Estuaries	217	95	127	2	0	0	0	0	6	5	113	565
70 Eroded Badland	360	0	0	758	0	6,917	0	0	0	787	12	8,834
74 Barren Land	569	0	0	25	0	2,142	0	167	3,628	0	0	6,531
76 Transitional Land	1,254	9	19	681	0	181	0	798	90	61	0	3,093
TOTAL	7,714	619	846	4,478	294	12,146	248	4,125	16,886	5,120	1,599	54,075

*All values are given in numbers of pixels. Each pixel is a 20 × 20 m cell or 0.04 hectares.

7) category by category using the same binary masking method, a picture of the land-use change dynamics in the study area was obtained. Table 6 displayed the constituent components of losses and gains in each category of land use undergoing change. Thus, one knows from Table 5 that 7,714 pixels of Low Density Urban Land were lost. But from Table 6 one finds that, of these 7,714 pixels, 1,842 pixels (or 23.9 percent) were lost to High Density Urban Land, 892 pixels (or 11.6 percent) to Transportation, 815 pixels (or 10.6 percent) to Cultivated Land, 1,064 pixels (or 13.8 percent) to Mixed Woodland, 1,254 pixels (or 16.3 percent) to Transitional Land, and so on. On the other hand, 3,988 pixels of Low Density Urban Land were gained from 304 pixels (7.6 percent) of High Density Urban Land, 70 pixels (1.7 percent) of Transportation, 271 pixels (6.8 percent) of Cultivated Land, 1,195 pixels (30.0 percent) of Mixed Woodland, 1,203 pixels (30.2 percent) of Eroded Badland, and so on (Table 6).

Based on a careful interpretation of the land-use change dynamics revealed in Table 6, one can make the following generalizations:

(1) There was quite a substantial increase in High Density Urban Land at the expense of Low Density Urban Land, probably resulting from clearing the squatter areas (catergorized as Low Density Urban) on the lower hillslopes flanking the new town.

(2) There was a dramatic reduction in Eroded Badland, most of which was converted to Mixed Woodland by 1987. But a very small area of Eroded Badland had also become Low Density Urban Land, with the implications that *either* new squatters continued to spread *or* the government had developed the land.

(3) The Mixed Woodland had increased in area.

(4) In the Reservoirs and Ponds category, a great loss had occurred, apparently resulting from filling up the fish ponds in the cultivated area immediately to the north edge of the new town.

(5) As expected, there was a great loss in Cultivated Land, especially in the area adjacent to the new town where most of the Cultivated Land was converted into urban use. But a large area of Cultivated Land had also become Agricultural/Residential use, probably resulting from Chinese immigrant farmers building their own houses on the cultivated land.

(6) The development of the new town was still in progress even by 1987 because a great increase in Transitional Land occurred.

(7) The fact that much of the new town was built on land reclaimed from the sea was reflected by a great loss in the area of the Bays and Estuaries category.

(8) There was also a great increase in Barren Land resulting from an increase in the number and size of quarries necessitated by the intense building activities in the new town.

RELATIONSHIP BETWEEN LAND-USE CHANGE AND TERRAIN CHARACTERISTICS

Tables 7 and 8 displayed the relationship between land-use change and the three terrain characteristics of steep slopes, surface hydrology, and geology employed for this study, made possible by the same binary masking technique. It is clear from Table 7 that High Density Urban use, which shunned the steep slopes and high surface drainage areas in 1976, established itself on steep slopes and high surface drainage areas by 1987. On the other hand, Eroded Badland located on steep slopes and high surface drainage areas appeared to have decreased in area by 1987, and Mixed Woodland located on steep slopes was also drastically reduced in area by 1987. From Table 8 one sees that steep slopes tended to occur in Sung Kong Granite (medium-grained), Cheung Chau Granite, and Needle Hill Granite (both fine-grained and medium-grained), where, in addition to Colluvium Deposit, Undifferentiated Alluvium, and Reclaimed Land, most of the land-use change during this period was also found. Clearly, the new town development has encroached on steeper slopes and the coastal zone as urban development intensified. While Eroded Badland has decreased and Mixed Woodland has increased in area during this period when the government attempted to stabilize the slopes with reforestation,

TABLE 7. SUMMARY OF TERRAIN ATTRIBUTES PERTAINING TO LAND-USE CHANGES, 1976 AND 1987 CATEGORIES.

	1976		1987	
	Pixels*		Pixels*	
Land Use Category	Steep Slopes (>24%)	Surface Hydrology	Steep Slopes (>24%)	Surface Hydrology
11 Low Density Urban	752	328	987	319
12 High Density Urban	0	59	248	108
14 Transportation	82	28	183	132
21 Cultivated Land	979	499	976	438
24 Agricultural/ Residential	28	111	177	234
43 Mixed Woodland	7,994	1,317	43	1,451
53 Reservoirs and Ponds	42	28	42	28
54 Bays and Estuaries	84	0	115	3
70 Eroded Badland	18,395	3,066	16,671	2,534
74 Barren Land	1,369	232	2,901	418
76 Transitional Land	128	29	141	32
TOTALS	29,853	5,697	29,853	5,697

*Each pixel is a 20 × 20 m cell or 0.04 hectare.

TABLE 8. LAND-USE CHANGES RELATED TO GEOLOGY AND STEEP SLOPES, 1987.

	Number of Pixels*		
Geologic Unit	1987 Total	Total in Changes	Total in Steep Slopes (>24%)
Undifferentiated Alluvium	10,181	5,401	124
Raised Alluvium	1,606	224	8
Colluvium Deposit	12,237	5,705	1,501
Reclaimed Land	5,709	4,978	64
Marine Sediments	99	93	0
Repulse Bay Formation	8,916	4,791	1,762
Lok Ma Chau Formation	1,542	921	267
Needle Hill Granite (fine-grained)	10,432	5,944	3,125
Needle Hill Granite (medium-grained)	15,544	5,768	3,165
Cheung Chau Granite	19,065	10,857	8,138
Sung Kong Granite (fine-grained)	1,423	634	312
Sung Kong Granite (medium-grained)	22,667	7,523	11,277
Reservoir	2,895	3	1
Bay	7,684	1,233	109
TOTAL	120,000	54,075	29,853

*Each pixel is a 20 × 20 m cell or 0.04 hectares.

steep slopes with abundant surface drainage developed in granite area remained difficult to be forested.

ACCURACY OF ANALYSIS

The accuracy of the results of land-use change dynamics analysis using the GIS approach depends on the reliability of the spatial databases and the precision with which each layer can be registered together in the raster format. The reliability of the spatial database depends on the data sources and the procedures of data extraction, which, in the present case, involved interpretation of aerial photographs and existing topographic and geologic maps. The accuracy of the land-use interpretation from aerial photographs met the 85 percent minimum standard for Level II details based on checking with existing land-use maps and other collateral materials. On the other hand, the precision of registration of map layers depends on how accurately the maps can be rasterized and incorporated with the GIS databases under the data integration stage. In turn, this determined the accuracy of image overlaying and the developed binary masks. For the present project, all maps were rasterized to 20-m by 20-m grid cells which represent the pixel size. In order to quantitatively evaluate the accuracy of map rasterization, 16 check points on the boundaries of land-use polygons common to both the original line map and the rasterized map of the same year were selected, and using five additional evenly distributed points as control, an affine transformation with a least-squares adjustment was performed. It was found that, for both the 1976 and 1987 rasterized land use maps, the RMSE for planimetry were determined to be ± 24.5 metres and ± 25.8 metres at map scale, respectively, which were slightly over one pixel size. The accuracy was obviously determined by the precision of the digitizer used and the size of the grid cell selected for rasterization. Subjected to these limitations, the rasterized maps were therefore shown to be capable of retaining quite accurately the positions of the boundaries of the land-use polygons of the original maps. In order to determine quantitatively how accurately rasterized land-use maps of two different years could be registered, the coordinates of the four corner points of one map (which delimited the areal extent of the study area) were mathematically transformed to those of the other map. The resultant RMSE in planimetry was found to be ± 13.2 metres which is slightly larger than half a pixel size. Thus, the overall conclusion is that the GIS developed for land-use change and environmental impact analysis for this project is accurate within 1/2 pixels. This accuracy can be improved if a digitizer with better resolution and higher accuracy (say, an accuracy of ± 0.127 mm and a resolution of 80 liner per mm) is used.

CONCLUSIONS

It has been demonstrated in this research that the GIS approach is most powerful in detecting land-use change dynamics and assessing the impact of these changes to the environment. Such an approach permits the incorporation of aerial photographic data of current and past land-use data with other map data. The operation of the GIS for this application is characterized by the use of image overlaying and the binary masking technique in extracting and quantifying changes and terrain impacts. A major contribution of the technique is its capability to understand land-use change dynamics. Hard copies of color maps displaying land-use losses and gains and their impacts can be produced for documentation and visual analysis. All these can be carried out speedily, accurately, and at low-cost with the microcomputer.

The analysis conducted for East Tuen Mun for the period of 1976 and 1987 revealed that, despite careful government planning in the development of the new town (such as in flood control and slope stabilization), high density urban use had encroached on steep slopes as the new town developed. The combination of extensive granite rock and monsoonal climatic condition made this area most susceptible to soil erosion with the production of gullies and badland in areas of steep slope and abundant surface drainage. Efforts to reforest the hillslopes took place and some success was seen in the increase in the area of mixed woodland, while the steep slopes continued to be difficult to reforest. Thus, the analysis undertaken with the GIS approach allows the planners to update quickly their land-use data and to make decisions for new town development and environmental protection in a physically constrained environment.

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