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Mapping and detecting land use/cover change in Tobago using remote sensing and GIS

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ABSTRACT. **The Caribbean region has suffered from a severe deficiency in accurate and up to date information on land resources information. This study has used three Landsat Enhanced Thematic Mapper (ETM+) satellite images (2001, 2002 and 2003) for developing a land use/cover map of the island of Tobago to begin to fill this void. The images were corrected for geometric, atmospheric, cloud and cloud shadow and topographic effects. A supervised classification approach that employed a maximum likelihood classifier was applied. The overall accuracy of the output image was 94.7% and accuracies for the individual classes ranged from 85.7% for bamboo to 100% for urban. The kappa coefficient for the classified image was 0.93. Furthermore, a quantitative change detection analysis was performed, utilizing the classification output and a vectorised 1956 land use map of the island. The outcomes revealed a significant increase in urban sprawl contrasted by a significant decrease in agricultural land use over the 45 year period. The analysis indicated that this trend has emerged due to a direct exchange of agriculture for urban development.**

1. INTRODUCTION

It has been acknowledged that access to up to date information on land use/cover is critical for developing and monitoring effective sustainable management of land based resources and policy development, as well as countering human induced influences (Jansen and Di Gregorio, 2004; Kasetkasem et al., 2005; Sedano et al., 2005). Consequently, mapping land use/cover has gained approval as an effective tool for planning and management (Fisher and Unwin, 2005). Conventional methods of land use/cover mapping are labour intensive, time consuming and are concluded relatively infrequently (Foody, 2003). Remote sensing has proven to be useful for mapping land use\cover in tropical mountainous islands (Baban and Wan-Yusof, 2001; Foody, 2003). In addition to producing reasonably accurate maps for vegetation communities and other land use/cover types (Baban, 1998; Baban and Luke, 2000). In cases of inaccessible regions, this approach tends to be the only means of obtaining the required data in a cost and time-effective manner (Sedano et al., 2005). In fact, Latifovic et al. (2004) have shown that remote sensing based land cover mapping, even at coarse spatial resolutions, can provide key environmental information for scientific analyses, resource management and policy development at regional, continental and global levels.

Geographic Information Systems (GIS) which excel in storage, manipulation and analysis of spatial and socio-economic data (Burrough and McDonnell, 1998), when combined with remote sensing techniques, can provide a wider application for mapping and analysing land use/cover in tropical environments (Baban and Wan-Yusof, 2001; Colombo et al., 2004; Jensen, 2005).

Countries in the Caribbean region face unique development challenges arising from their small size and vulnerability to natural disasters as well as the resulting economic volatility (World Bank, 2005). However, it should be mentioned that in this region there is a severe shortage of reliable land use/cover datasets despite the ongoing rapid rate of urbanization, population growth and the substantial expansion of industrial and agricultural development (Baban, 2001; Baban et al., 2004).

This paper aims to develop an up-to-date Land use/cover map for Tobago, and to conduct a quantitative change analysis over the last 45 years using remotely sensed data and GIS.

2. THE STUDY AREA

The island of Tobago is one of two islands, which make up the twin island republic of Trinidad and Tobago (**Figure 1**). Lying between latitudes 10-12˚ north and longitude 60-62˚ west, it has the total land area of 300 km², and a population of about 54,000 (West, 2006; Saft, 1999). Tobago has a tropical climate with average annual temperature and rainfall figures of 26.6 C and 200 mm, respectively

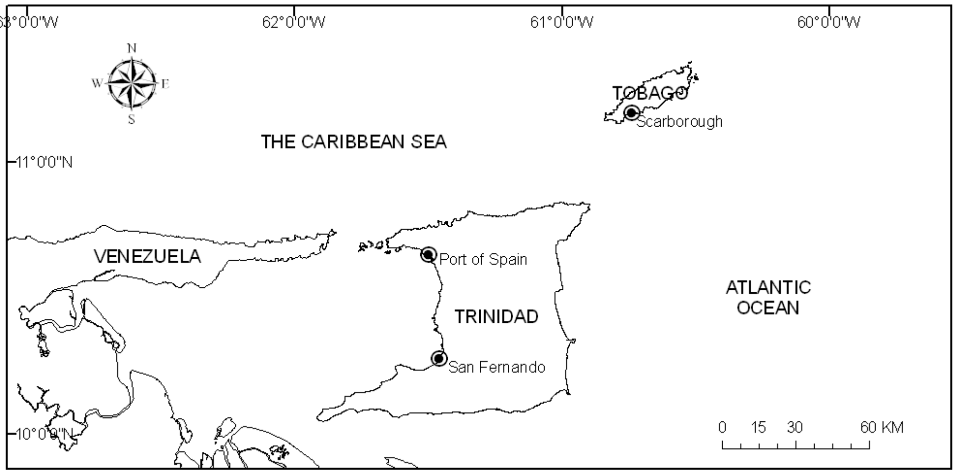

Figure 1. Location of study area

Table 1. Landsat ETM+ Scenes used in Study

Platform	Sensor type	Imagery date	Wrs path/row	Sun azimuth	Sun elevation
Landsat 7	ETM+	06/08/2000	233/52	77	62
Landsat 7	ETM+	13/11/2001	233/52	141	52
Landsat 7	ETM+	12/08/2002	233/52	80	61

(Horne, 2003). Rainfall varies considerably with location and season, being heaviest in the wet season which extends from June to November.

In Tobago, two main physiographic regions exist. First, a main ridge running in a northeast-southwest direction for nearly two thirds the length of the island, with the highest point being 576 m. This ridge consists for the most part of metamorphosed sedimentary rocks and igneous rocks. Second, a limited flat coastal plain of coral terraces in the southwest. Tobago's mountainous interior, covered by dense tropical forest, gives way to a periphery of white, palm-fringed beaches and open pastures. Much of the island is dominated by richly vegetated, hilly regions with steep slopes (Saft, 1999). The rugged topography has a limiting effect on development; the more easily developed flat land being very restricted in extent (Horne, 2003).

Agriculture has been, and continues to be, on the decline (Ragoonath, 1997) in Tobago. The island contains patches of intensive short-term crop cultivation and deforestation. These activities have caused extensive soil erosion, and landslides on the island have become synonymous with heavy precipitation. Furthermore, coral reefs are the mainstay of tourism, and terrestrial development related activities are having a direct impact on these vulnerable ecosystems (Williams, 2003).

Unfortunately, at present there are no accurate land use/cover maps for Tobago to assist with managing the aforementioned challenges. The current information base is the 1980 forest inventory map produced by the Ministry of Agriculture, however, this map is more than 26 years old and hence the information contained therein could be profoundly misleading. These issues demonstrate a pressing need for a recent land use/cover map which can form the basis for the formulation of new policies to facilitate sustainable growth and development in Tobago.

3. METHODOLOGY AND DATA DEVELOPMENT

Three Landsat ETM+ satellite images, spatial resolution 30 m, were used in this study (**Table 1**). Additional datasets included: aerial photographs; a Digital Terrain Model (DTM) consisting of digitised contour lines from a 1:25,000 topographic map; a DTM in the format of a layer of discrete elevation points as well as Vector data in the form of road and river networks digitised from a 1:25,000 topographic map of Tobago. In addition to a land capability map developed in 1974, a forest inventory map developed in 1980, a land utilization map dated 1921 (Niddrie, 1980), and the original natural vegetation map and the land use map of 1956 (Niddrie, 1961) were available.

The land use/cover classification scheme used for this study was derived from Anderson's classification scheme (Anderson et al., 1976) and Beard's classification scheme of the local vegetation in Trinidad and Tobago (Beard, 1944). The chosen classes were also based on amenability to accurate identification from available imagery, ancillary interpretation resources and field data (Li et al., 2004). In all, six categories were discriminated, these were;

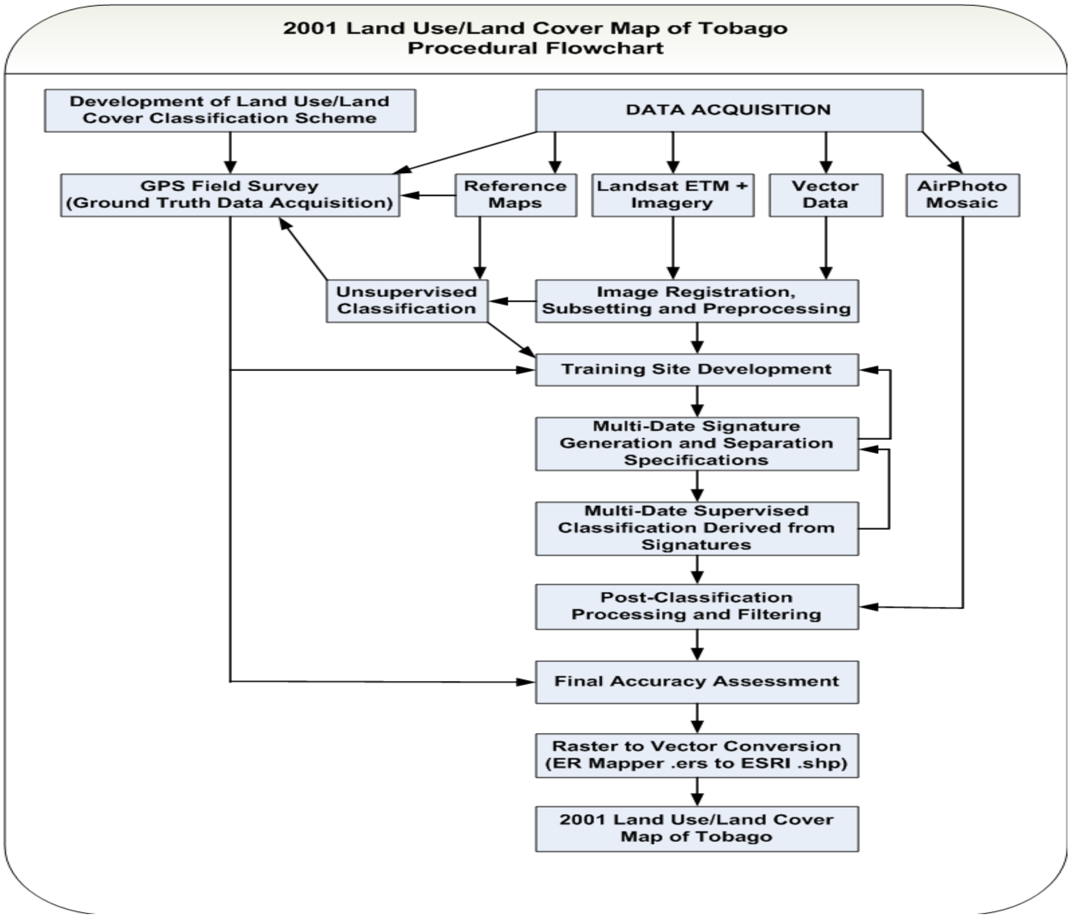

Figure 2. Procedural Flowchart for the Development of the Land use/Cover Map

forest, agriculture/pasture, urban, bamboo, mangrove and water. Anderson et al. (1976) divide forest land into three categories at level II (deciduous, evergreen and mixed). On Tobago, the following classes have been identified; littoral woodland, deciduous seasonal woodland, rain forest, swamp forest, lower montane forest, xerophtic rain forest, evergreen formations and some elfin woodland (Beard, 1944, Davis et al., 1986, Thelen and Faizool, 1980). These categories, with the exception of swamp forest, were used to specify the keys for forest classification. Beard (1944) has noted the existence of mangrove formations in Tobago and has described three main species, *Rhizophora mangle*, *Avicennia nitida* and *Laguncularia racemosa*. Due to its uniquely separable spectral characteristics along with its highly touted ecologic and economic importance, mangrove was included as an individual land cover class. It is important to reiterate here that the classification scheme developed for use in this research project was derived through the collective integration of an independent unsupervised classification, ancillary information, field visits and prior classification schemes developed by Anderson et al. (1976) and Beard (1944). Figure 2 shows a schematic diagram illustrating the steps followed; from data acquisition and creation of the classification scheme, to the final development of the 2001 land use/cover map for the island of Tobago. The methodology consists of three major phases, which are described in the following sections.

3.1 Data development and preprocessing

This phase dealt with preprocessing and therefore the necessary georeferencing, restoring, and enhancing of the satellite image were carried out. The 1994 air photo mosaic was used as the source dataset of the coordinate information and the three images were registered to this mosaic. The image to image registration was carried out using ER Mapper. For rectification of each of the three images, 20 ground control points (GCPs) were selected. Overall, A residual mean square (RMS) error of less than 14 m was achieved for each transformation (Zha and Gao, 2003; Jiang et al., 2004). The images were also atmospherically corrected using the darkest pixel approach (Chavez, 1988, Lillesand and Kiefier, 2000).

Clouds and their shadows presented a problem in all the images. This problem was managed by developing and employing cloud masks using threshold values in Landsat ETM bands 1 and 6, while cloud shadow masks were based on threshold values in bands 1, 4 and 8. The intention was to mosaic the masked images together subsequent to masking, in an attempt to create a single image, free from cloud and cloud shadow effects (Li et al., 1999).

An extensive field survey, using Global Positioning System (GPS) equipment, was performed in December 2005. A total number of 131 field points was collected with an accuracy of approximately 15 m. The survey was performed in order to obtain accurate location point data for the creation of training sites, for signature generation as well as validation of each land use/cover class included in the classification scheme (Currit, 2005). The land use/cover categories of focus were forest, agriculture/pasture, urban, bamboo, mangrove and water.

It should be noted that water areas were not classified from the image but digitized from the air photo mosaic. The three ground truth sample points collected for water areas were used for validation purposes. Mangrove areas were also small with mangrove accounting for only 4 km^2 of the entire island. Hence only a few sample points were recorded for this class. The bamboo class, although occupying a fairly large land area was also only sampled by a few points, as most of this area was inaccessible to both vehicular and/or pedestrian means.

3.2 Classification and post processing

This phase of the methodology was concerned with extracting land use/cover information through classifying the satellite image and using primary field data augmented with secondary datasets. As a preliminary task, an unsupervised classification of the image was performed to identify the major spectral categories related to land use/cover. A false colour composite image was created with a simple linear stretch that assigned ETM+ bands 3, 4 and 5 to the blue (B), green (G) and red (R) image band respectively. This combination has provided good results in terms of mapping different land use/cover types in tropical mountainous islands (Baban and Wan-Yusof, 2001; Lo and Choi, 2004). This composite was used to create an unsupervised classification of the imagery. The main purpose of the unsupervised classification was to assist in planning the field campaign, in conjunction with other reference datasets for the collection of the ground truth data. The result of the unsupervised classification, field data and the forest inventory map were then used to make a distinction between representative land use/cover classes, which included; forest, agriculture/pasture areas, urban and one unidentified which was later defined as bamboo. The mangrove and water areas were not spectrally distinguishable at this stage probably due to the small percentage of representative pixels.

In order to perform a supervised classification on the satellite image, training sites needed to be established for each class. Training sites for signature generation were initially developed using some of the points obtained from the GPS ground truth data. Before the signatures were generated, each training site was evaluated graphically to determine their spectral response patterns (Jensen, 2005). A total of 31 training sites was identified based on the result of the unsupervised classification, the secondary data together with the authors' prior knowledge of the island. The decision on the number of pixels for each land use/cover was based on a rule of thumb that at least 10 pixels per class per spectral band must be used (Eastman, 1999). Hence, a minimum of 60 pixels was selected for each class since six ETM+ bands were being used to create the signature files. The polygons defining each training area were digitised and assigned a unique identifier to each cover type. Then the spectral reflectance of each land use/cover was plotted against the six bands to further examine their spectral behaviour along the spectrum (Eastman, 1999).

Tobago is mountainous; therefore, the variations of reflectance values owing to topography are significant. This problem was managed through constructing a shaded relief map by using the Digital Elevation Model (DEM) to mimic shadows in the image caused by the relief (Howard, 1991; Baban and Wan-Yusof, 2001). The imagery was then divided into subscenes based on illumination. These signature files were used to categorize the continuum of spectral data in each of the topographically corrected images (2000, 2001 and 2002). This classification incorporated the pixel values (Digital Numbers) from ETM Bands 2, 3, 4, 5, and 7 from each scene. The resulting classified images were comprised of forest, savanna/agriculture, bamboo, urban and mangrove classes. Visual inspection of the three resulting classified images was promising with the exception of the missing water class, which had not been included in the supervised classification for reasons outlined previously.

Figure 3. Dominant Land use/cover types in Tobago. (a) Evergreen forest along the southern slope of the main ridge of the island. (b) Pasture along Shirvan Road in the south western part of the island. (c) Urban land use in the capital Scarborough. (d) Bamboo on the northern slope of the main ridge. (e) Mangrove located at the south eastern part of the island. (f) Perennial water body at Pigeon Point at the south western end of the island.

3.3 Development of the Land use/Cover map of Tobago

Subsequent to the image classification methodology, a mosaic of the classified images was produced that represented a single, complete image with all areas classified (Garcia and Murguia, 1996). Some measure of image post-processing was required to account for water areas in the classified image. This essentially involved the on-screen digitizing of water areas as separate polygons from the 1994 air photo mosaic. Vector polygons were created for water features in the 1994 air photo mosaic. These 'water' polygons were then included in the classified multidate image mosaic. Gaps that were created as a result of the mosaic process were filled by utilizing a similar method by classifying the unknown areas through visual interpretation of the 1994 air photo mosaic. The salt and pepper effects, which resulted from the classification and became apparent subsequent to making the mosaic were cleared up by smoothing the image through the use of a 3×3 kernel majority filter (Tottrup, 2004). The classified image was then draped over a DEM. This technique produced a model illustrating the changing land use/cover patterns with variations in topography.

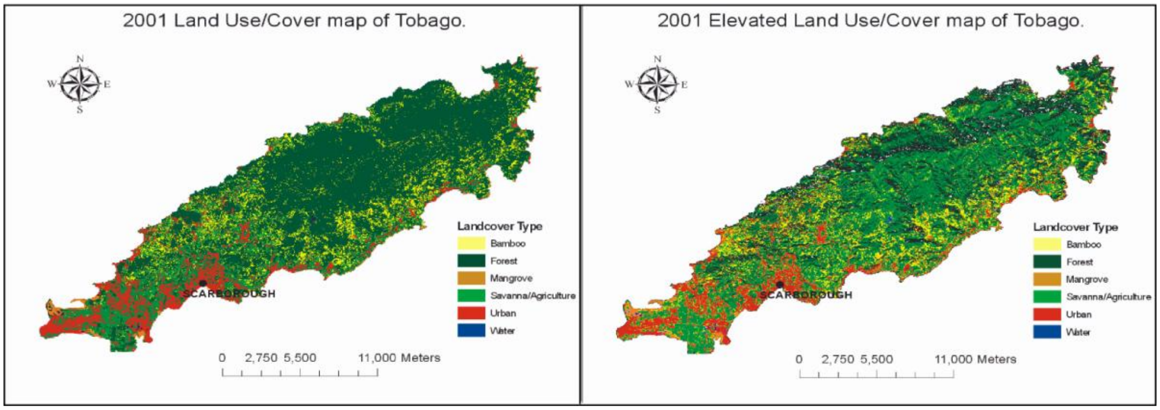

Figure 4. 2001 Land use/Cover map and elevated Land Use/Cover map of Tobago

Table 2. The error matrix

		Field Data						**Row Total**	**User's Accuracy**
		1	2	3	4	5	6		
Satellite Data Classification	**1: Forest**	33	-	-	-	-	-	33	100
	2: Agriculture/pasture	2	31	1	-	-	-	34	91.2
	3: Bamboo	-	-	6	-	-	-	6	100
	4: Urban	1	3	-	45	-	-	49	91.8
	5: Mangrove	-	-	-	-	7	-	7	100
	6: Water	-	-	-	-	-	2	2	100
Column Total		36	34	7	45	7	2	**Overall Accuracy 124/131 = 94.7%**	
Producer's Accuracy		91.6	91.2	85.7	100	100	100		

4. RESULTS AND ANALYSIS

4.1. Land use/cover map of Tobago and Accuracy Assessment

The land use/cover categories of focus were forest, agriculture/pasture, urban, bamboo, mangrove and water and **Figure 3** shows some of the field photographs representative of the land use/cover types in Tobago.

The classified image (**Figure 4**) shows the spatial distribution of the land use/cover types. The area shows that Forest represents the largest land use/cover class in Tobago and occupies some 189.61 km² (63%). This is followed by agriculture/pasture 42.35 km² (14%), then bamboo 32.36 (11%), then Urban 31.31 km² (10%), then Mangrove 4.04 km² which is a little above (1%), followed by water 0.33 km² which represents less than 1% of the total land use/cover of the island. Due to the similar spectral signature the natural grasslands also classified as agriculture/pasture.

On the island of Tobago, four major forest vegetation communities have been described: littoral woodland, deciduous seasonal woodland, rain forest and swamp forest (Beard, 1944). Lower montane forest, xerophytic rain forest, evergreen formations and some elfin woodland are also there (Beard, 1944; Davis et al., 1986; Thelen and Faizool, 1980). Due to highly touted ecologic and economic importance, mangrove was included as an individual land cover class. Bamboo was successfully classified as an individual land cover class because of its distinctively separable spectral characteristics and it has widespread coverage and probable importance for changing land use/cover patterns with consideration for future planning. In addition to agricultural and pasture land, some herbaceous and grassland were classified into agriculture/pasture category. Residential, Commercial and Services, Industrial, Transportation, Communications and Utilities, Industrial, Commercial Complexes, Mixed Urban or Built-up Land and Urban or Built-up are included in the urban land use category.

Lillesand et al. (2004) have described three descriptive measures that can be obtained from the error matrix (**Table 2**) that can help to quantitatively evaluate the classified image. The first two of these are, the 'overall accuracy', which is calculated by dividing the total number of correctly classified pixels by the total number of reference pixels, and the 'producer's accuracies', which is calculated by dividing the number of correctly classified pixels in each category by the number of training set pixels used for that category. Producer's accuracy is really a measure of omission

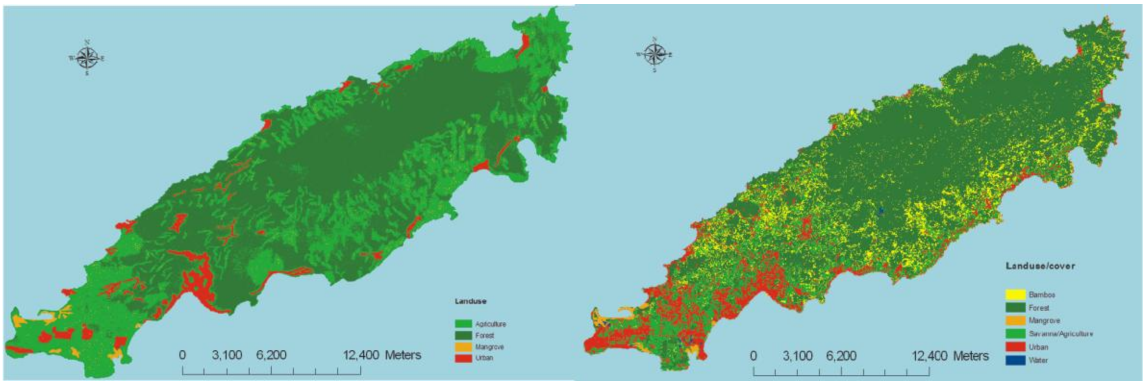

Figure 5. Contrast of the 1956 (left) and the 2001 (right) Land use/cover maps.

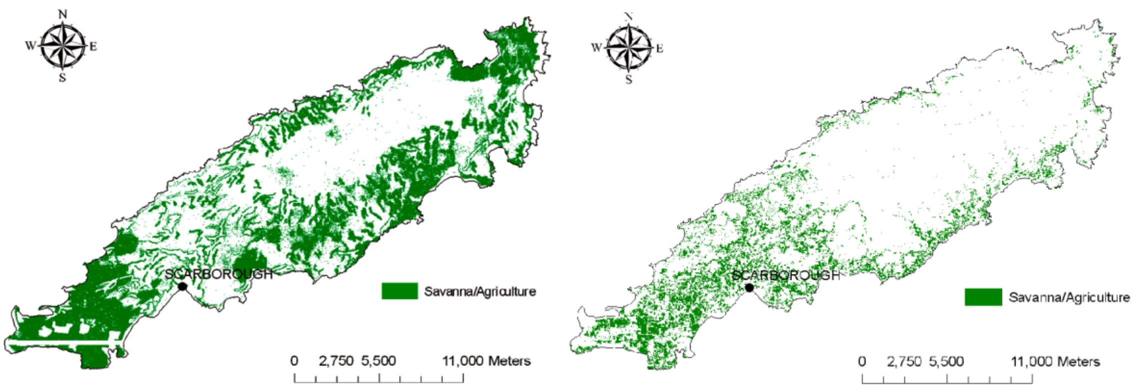

Figure 6. Change in Agricultural Land use distribution from 1956 (left) to 2001 (right).

error (Tso and Mather, 2001). The third measure 'user's accuracies' is computed by dividing the number of correctly classified pixels in each category by the total number of pixels that were classified in that category. The user's accuracy denotes the probability that a classified pixel actually represents that information class on the ground (Tso and Mather, 2001). Due to the small number of sample points used for the accuracy assessment it was possible to create the error matrix manually by checking the points on-screen. A method described by Jensen et al. (2005) for accuracy assessment by overlaying point locations of reference data over a classified grid was used for the accuracy assessment. The accuracy assessment error matrix (Lillesand et al., 2004) performed on the 2001 Land Use/Cover map of Tobago produced an overall accuracy of 94.7% with a kappa coefficient of 0.93. This was deemed to be satisfactory by modern image classification standards.

4.2. Quantitative Land Use/Cover Change Assessment

A basic assessment of land use/cover change for the period 1956-2001 was carried out by comparing the 1956 land use/cover map to the 2001 land use/cover map. A quantitative analysis of change detection was performed by utilizing spatial statistics tools within ArcGIS 9.0. Initially the hardcopy 1956 land use map was vectorised and populated with the corresponding attribute information for the land use types. The vectorised 1956 landuse map was displayed alongside the 2001 land use/cover map for visual comparison (**Figure 5**). The regions representing the two land use/cover types that showed the most significant change (i.e., agriculture and urban) were then extracted as separate layers from the vectorised form of each map. These regions were then displayed alongside each other to illustrate the changes in spatial extent and distribution for the 45 year period (**Figures 6 and 7**). The spatial analyst tool of the GIS software was further exploited to generate area figures for each the following land use/cover types for both years (agriculture/pasture, forest, urban and mangrove). These figures were then used to calculate the land use/cover change for each of the four land use/cover types and were given in terms of square kilometres and percentage land use/cover gained or lost (**Table 3**).

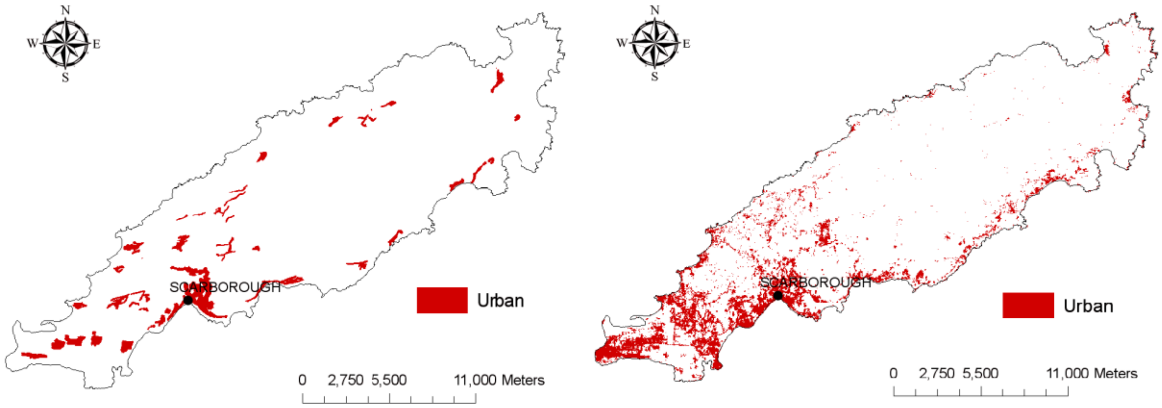

Figure 7. Change in Urban Land use distribution from 1956 (left) to 2001 (right).

Table 3. Quantitative Assessment of Land use/cover Change for 1956-2001

Landuse/cover Type	Year	Total area (km²)	Landuse/cover Change (km²)	Landuse/cover change (%)
Agriculture/pasture	1956	114.11	-71.76	-62.89
	2001	42.35		
Forest	1956	167.83	21.78	12.98
	2001	189.61		
Urban	1956	15.09	16.22	107.49
	2001	31.31		
Mangrove	1956	3.85	0.19	4.94
	2001	4.04		

Figure 6 clearly illustrates that there was a significant decrease in the amount of agriculture in Tobago during the period 1956 to 2001. This trend was supported by area figures calculated for agriculture for each of the two years (**Table 3**). Agricultural in 1956 accounted for an area of 114.11 km^2 that was about 38% of the area of the entire island. By the year 2001 this figure was reduced to 42.35 km^2 (14% of the island area). This change translated to a 62.89% decrease in agriculture over the 45 year period. The factors that may have been attributed to this dramatic decrease include hurricane Flora during 1963, increased urbanisation and a lack of proper planning with respect to the developmental process.

A 1956 land use map (**Figure 6**) shows that at that time agriculture on the island was limited to coconut, cocoa, banana and lime (Niddrie, 1961). Hurricane Flora then accounted for the demise of majority of the coconut estates as well as most of the other remaining small crops, triggering a further decline in agriculture on the island (Niddrie, 1980). The land use/cover distribution illustrated by the 2001 land use/cover map of Tobago has suggested that the land cover of Tobago seemed to be returning to its original natural vegetation pattern.

A visual inspection of **Figure 7** illustrates the effect of urbanisation in Tobago during the period 1956 to 2001. An examination of **Table 3** reveals that for the year 1956 urban occupied 15.09 km^2 of the land area on the island. This figure increased to 31.31 km^2 by the year 2001 representing an increase of 107.49% for this particular land use type. It should be noted that the greatest rate of urbanisation has occurred in the south eastern part of Tobago, which consists mainly of flat areas. In addition to this, the area was closest to both the airport and the coral reef, suggesting that the urbanisation process may also have been closely linked to the development and focus on tourism.

A highly prominent trend, which was synonymous with the current developmental thrust on the island, was noticed during the change detection analysis. Having already ascertained that there was a substantial decrease in agricultural usage, it was interesting to note that a considerable proportion of this loss was attributable to the increase in urban areas. The results of the analysis suggest that in many places agriculture was directly exchanged for built-up area. If urbanisation continuous to happen with the above trend, within the next 50 years the urban area will increase in size to about 60 km^2, 20% of Tobago. **Figure 8** shows the spatial trend of urban expansion and the encroachment of good land for agriculture mainly in the southwest of Tobago based on the land capability map. This is of special significance to the future of agriculture on the island, as prime

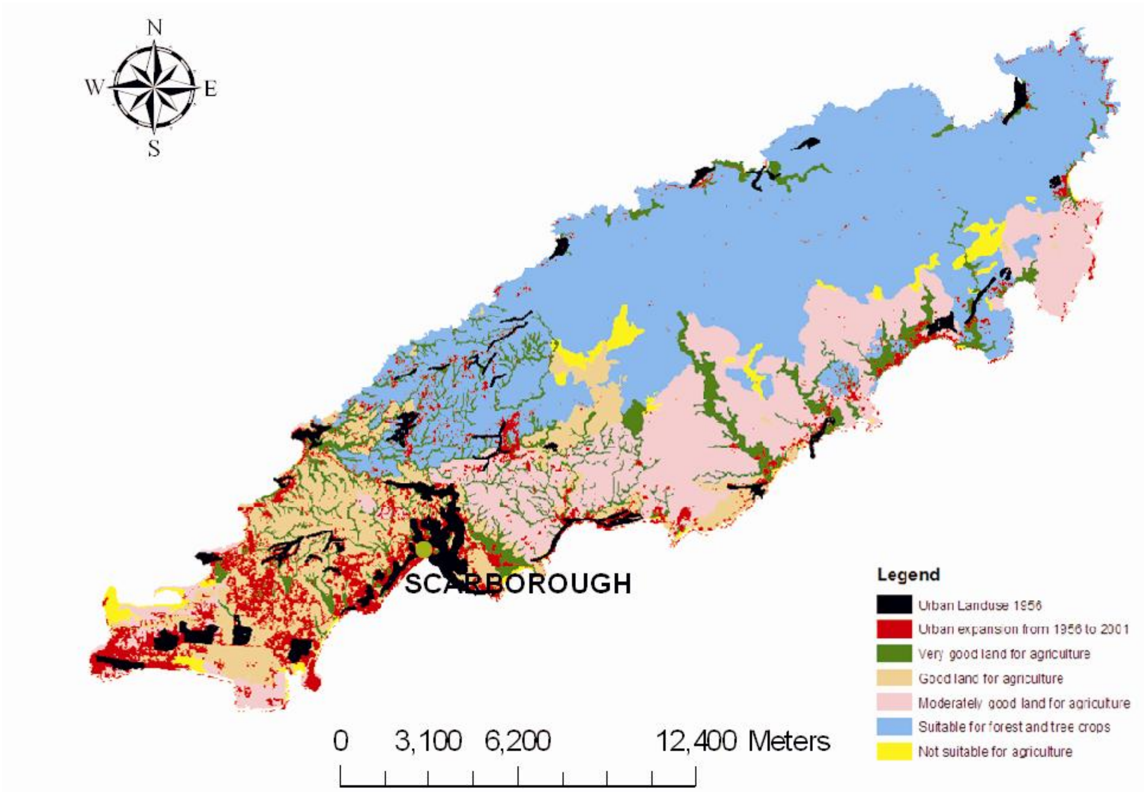

Figure 8. Urban expansion over the land capable for agriculture.

agricultural lands are being lost due to poor planning and unregulated urbanisation.

5. SUMMARY AND CONCLUSIONS

Much of the recent research that has been carried out in the Caribbean has shown that reliable, up-to-date information on land use/cover distributions are a rarity. Unfortunately, the information base map for Tobago is also incomplete and outdated therefore presenting a challenge for decision makers in a country developing at a fast rate. Still, the information base can be updated using remotely sensed data. However, due to the fact that Tobago is a tropical and mountainous island, shadows and clouds can represent major challenges. This paper developed a methodology to remove the regions with clouds and its shadows and replacing them with other imagery and secondary data, whereby the shadows caused by the terrain were corrected by separating the image into two sections. The sections are treated as separate images and are classified using the same classification scheme, and then the sections are put back together.

An overall accuracy of 94.7% with a kappa coefficient of 0.93 was achieved for the supervised classification and both the user's and producer's accuracies had very high probabilities for each class, indicating the reliability of the classified map. The results suggest that the spectral and spatial resolution of Landsat ETM+ data could serve to accurately classify land use/cover distribution in the tropical mountains island of Tobago. The ability of Landsat ETM+ to display spectral responses throughout the spectrum has proved the basis of accurately separating the individual classes. Furthermore, the outcome map can be used with confidence in planning for sustainable development in Tobago.

A quantitative assessment of land use/cover change on the island for the period 1956-2001 demonstrated a 107.49% increase in urban land use and a 62.89% decrease in agricultural land use. Both trends were somewhat predictable given the historical and current nature of development on the island. The results of the analysis also suggested that in many areas loss of agricultural land use was directly replaced by growth in urban development.

Awareness of these changes is essential to policy development for proper planning and management. The information produced here serves to further highlight the critical need for up-to-date information within the domain of land and natural resource information.

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