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The Integration of Remote Sensing and GIS Technologies for the Development of a Land Use/Cover Map of the Island of Tobago.

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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 utilized remote sensing and geographic information systems (GIS) for the development of a land use/cover map of the island of Tobago in a start at filling this void. Three Landsat Enhanced Thematic Mapper (ETM+) satellite images (2001, 2002 and 2003) were utilized in a multidate approach. The images were corrected for geometric, atmospheric, cloud and cloud shadow and topographic effects. A hybrid unsupervised-supervised classification approach which employed a full Gaussian maximum likelihood classifier was applied. Post processing techniques involving on-screen digitizing from a 1994 airphoto mosaic were used for water areas. 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. A 1956 land use map was digitized and used along with the 2001 classified map produced in a quantitative change detection analysis utilizing spatial statistic tools in ArcGIS. This analysis revealed a 107.49% increase in urban sprawl contrasted by a 62.89% decrease in agricultural land use on the island during the 45 year period. The results of the analysis suggested that this trend was primarily due to a direct exchange of agriculture for urban development.

Keywords: Land Use/Cover Mapping, Remote Sensing and GIS Integration, hybrid unsupervised-supervised classification, Tobago Map 2001, Landsat ETM+.

1. Introduction

In the light of growing human needs and the vast changes humans are making to ecosystems, it is imperative that wise choices be made in the use and conservation of these ecosystems (Li *et al.* 2004). Land use/cover mapping has gained recognition as a major tool for planning and management (Fisher and Unwin 2005). Land cover information is needed to monitor the impact and effectiveness of management actions associated with sustainable development policies (Sedano *et al.* 2005). Countries within the tropics are developing rapidly, producing land cover changes of ecological and climatic significance, such as colonization of marginal lands, deforestation, dry lands degradation, landscape fragmentation and rapid urbanization (Lambin 1999). Inevitably these processes place great pressure on natural resources, perhaps most noticeably on forests (Foody 2003). These factors together with events such as sea level rise and global climate change warrant the urgent need for development of appropriate management policies for the region (Baban 2002). Accurate statistics on land use are not available in most tropical countries and detailed GIS studies describing the dynamics of land use/cover change are still lacking, particularly nation-wide studies (Ochoa-Gaona and Gonzalez-Espinosa 2000). Tottrup (2004) has noted that mapped tropical forest data is often incomplete and inaccurate due to great survey costs, large spatial extent and poor accessibility of these areas. Conventional methods of land use mapping are labour intensive, time consuming and are done relatively infrequently (Foody 2003). In recent years, satellite remote sensing techniques have produced multi-sensor satellite data at very high spatial, spectral and temporal resolutions (Liang 2004). This data coupled with improved computer processing and storage capabilities (Bossler 2002) have proved to be of immense value for preparing up to date and accurate land use/cover maps in less time, lower cost and with better accuracy (Foody 2003; Cingolani *et al.* 2004; Jansen and Di Gregorio 2004; Tottrup 2004). In cases of inaccessible regions this technique is perhaps the only method of obtaining the required data in a cost and time-effective manner (Sedano *et al.* 2005). Geographic Information Systems (GIS) which excel in storage, manipulation and analysis of spatial and socio-economic data (Burrough and Mc Donnell 1998), provide a wider application when combined with remote sensing techniques which have been effective in land use/cover mapping of tropical environments (Baban and Wan-Yusof 2001; Colombo *et al.* 2004).

2. Study Area

The island of Tobago which was the area of interest for this research is one of the two islands which make up the twin island republic of Trinidad and Tobago. Lying between latitudes 10-12 degrees north and longitude 60-62 degrees west, the two island nation completes the southern end of the West Indian archipelago. Trinidad and Tobago has a total land area of 5128 square kilometres. Of the total land area, Trinidad is 4828 square km and Tobago is 300 square km (West 2006). Tobago is situated approximately 32 kilometres to the northeast of Trinidad (Saft 1999). The islands share the typical tropical climate of regions with a similar global orientation i.e. average annual temperature and rainfall figures of 26.6°C and 200 mm respectively (Horne 2003). Rainfall varies considerably with location and season however, being heaviest in the wet season (June to November), in the eastern half of Trinidad and in Tobago and in the more precipitous regions of the country. This distinction in precipitation has particular implications for agricultural land use distribution and also contributes to the great diversity of flora and fauna on the islands. Tobago's mountainous interior consisting of dense tropical forest gives way to a periphery of white, palm fringed beaches and open pastures. The general form of the island is fishlike, being 42 kilometres long and 13 kilometres wide at its broadest and running on a north-easterly axis (Saft 1999).

3. Methodology

3.1 GPS Ground Truth Data Collection.

This survey was performed in order to obtain accurate locational point data for validation of each land use and land cover class included in the classification scheme as well as for the creation of training sites and for signature generation. In addition, an independent data set reserved for accuracy assessment was created**.** The land use and land cover categories of focus were forest, savanna/agriculture, urban, bamboo, mangrove and water. The GPS ground truth data for this project was collected over a five day period starting Monday 5th December 2005 and ending on Friday 9th December 2005. A total number of 131 field points were collected. Prior to the field reconnaissance trip, mission preplanning was conducted to ensure successful data collection. This was centred on an unsupervised classification and incorporated a vector road layer and the existing land use and topographic maps of the island. The GPS equipment utilized in the field survey was a Garmin Rhino handheld receiver. This receiver produced readings with an accuracy of approximately 15 metres. This was sufficient for the 30 metre resolution of the Landsat image. The optimum size of the sampling unit for this study based on spatial resolution of the satellite and geometric accuracy of the image was a minimum area of 30 × 30 m. An attempt was made during the field surveys to collect as many 'good' samples as possible, yet this was still not practical for all land use classes. With respect to perennial water bodies, 30 × 30 m homogenous plots were difficult to locate and only three points were sampled on the ground for this class. 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 as well. The bamboo class, although occupying a fairly large land area was only sampled by a few points as well, as most of this area was inaccessible to both vehicular and/or pedestrian means. This was due to the fact that most of the bamboo landcover occurred along the steep slopes of the mountain ridge and within narrow gorges close to water courses, as is characteristic of this vegetation type. The small sample sizes for these classes had implications for the error matrix and accuracy assessment as (Mather 1999) has suggested that a sample size of 30 should be used for the error matrix and accuracy assessment. Van Genderen and Lock (1977) have suggested that small sample sizes may produce misleading results; however, the areas for which these samples were produced were also very small, thus reducing the probability of error.

3.2 Image Preprocessing

The ETM+ images provided for use in this project were already geometrically corrected and registered to the World Geodetic System (WGS 84); they however, needed to be georeferenced to the local coordinate system for Tobago. The conversion from one coordinate system to another was done to facilitate the use of the images with other datasets (vector and raster) for the area which were all created using the coordinate system for Tobago. This conversion was done using ER Mapper version 6.4 and employed the following parameters, Tobago Grid, Cassini Projection and the Clarke 1858 Spheroid. A 1994 airphoto 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 a third order polynomial rectification and the nearest neighbour option within the geocoding wizard of ER Mapper.

Atmospheric correction was done using the Dark Object Subtraction (DOS) haze reduction method (Chavez 1988). This method measures the haze value to be removed by quantifying the radiance in some deep, clear water or shaded areas in the image where the radiance in the near infrared bands is zero or near to zero. Any over-zero value was considered to be a result of scattering and path radiation (Chavez 1988).

A method put forward by Martinuzzi *et al.* (2003) was modified for cloud and cloud shadow masking. For the three Landsat ETM images cloud masks were created by using threshold values in Landsat ETM bands 1 and 6, while cloud shadow masks were created by using 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. This part of the procedure was adopted from (Li *et al.* 1999) where the image containing the least cloud cover is taken as the base image; the cloudy areas are masked out, and then filled in by cloud-free areas from other images acquired at different times. The Landsat ETM+ image dated November 13th 2001 was used as the base image for the process in this study. Prior to mosaicking however, a method for topographic correction developed by Garcia and Murguia (1996) and utilised previously by Baban and Wan Yusof (2001) was applied to each cloud and cloud shadow free image to reduce the radiometric effects generated by the terrain. This technique primarily involved the use of a Digital Elevation Model (DEM) to mimic shadows in the image caused by the relief (Baban and Wan Yusof 2001). The imagery was then divided into subscenes based on the outcome of the previous step with classifications being performed on each subscene then combining the results into one image (Garcia and Murguia 1996). The topographically corrected images were then classified using an integrated unsupervised and supervised technique. Subsequent to the classification process, the images were mosaicked together to form one 'complete' classified image for the area. The methodology used in this project was illustrated using only the 2001 Landsat 7 ETM+ image. This image was used as the base image for the final mosaic as it was the most cloud free of the three Land ETM+ images available. When multiplied by the original image, the cloud and cloud shadow mask would effectively cause all areas with clouds and cloud shadows to have zero values and be masked out (see Figure 1).

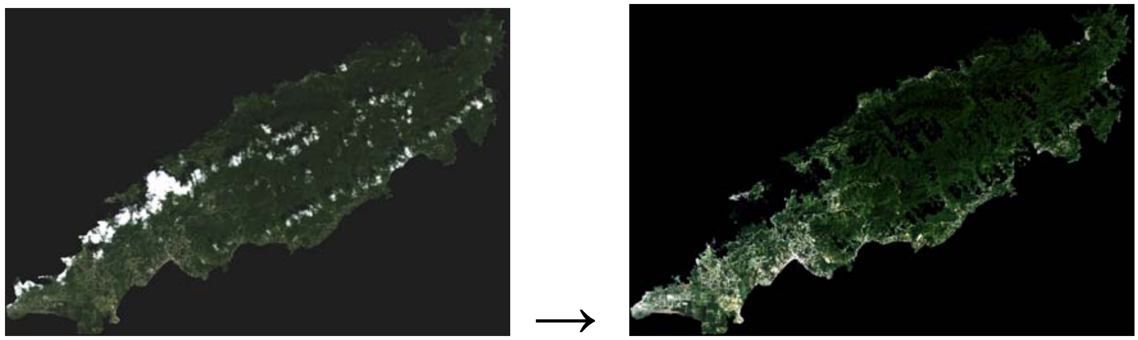

Figure 1: Cloud and Cloud Shadow masking of the Landsat ETM+ 2001 scene.

3.3 Land Use/Cover Classification Scheme.

A multilevel, hierarchical land use classification was derived from the author's *a priori* knowledge of the study area and reference information. This classification system was based primarily on an Anderson level II classification (Anderson *et al.* 1976). The chosen classes were also based on amenability to accurate identification from the available imagery, ancillary interpretation resources and field data (Li *et al.* 2004). In all, six categories were discriminated, these included forest, savanna/agriculture, urban, bamboo, mangrove and water. Anderson (1976) divides forest land into three categories at level II (deciduous, evergreen and mixed). In 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 also occur (Beard 1944; Davis *et al.* 1986; Thelen and Faizool 1980). These categorizations, with the exception of swamp forest, were used to specify the keys for forest classification. All land cover classes relative to herbaceous, grassland, rangeland, forage land, agricultural land and pasture were merged into one Anderson level II category, "grass and pasture lands". This classification name however, was changed from "grass and pasture lands" to "savanna/agriculture" to accommodate local naming conventions applied to a previously created land use land cover map for the island of Trinidad. The field visit revealed that presently Tobago experiences very limited agricultural production with respect to crop growth. The minor regions of agricultural production were not spectrally separable from the other vegetation types included in this category; hence the merging of the two groups (savanna and agriculture) into a single class. Due to its distinctively separable spectral characteristics, widespread coverage and probable importance for changing land use/cover patterns; bamboo was included as an individual land cover class. Urban classification was based entirely upon an Anderson level II classification as illustrated in Table 1.

Table 1: Urban Land Use Classification Categories.

Level I	Level II
1 Urban	11 Residential.
	12 Commercial and Services
	13 Industrial
	14 Transportation, Communications and Utilities.
	15 Industrial and Commercial Complexes.
	16 Mixed Urban or Built-up Land
	17 Other Urban or Built-up Land

Classification of water areas in this study was based upon only one level II water category (perennial water) from Anderson's classification, due to the multi-date characteristics of the imagery employed. It is important to note here that the classification scheme developed for use in this research project was derived through the integration of an independent unsupervised classification, ancillary information, field visits and prior classification schemes developed by Anderson *et al*. (1976) and Beard (1944).

3.4 Unsupervised Classification.

Both supervised maximum likelihood, and unsupervised, ISOCLUS, remote sensing classification methodologies were utilized in a multi-step approach for this project. The maximum likelihood classifier was chosen because good separability among training sites and training site statistics was achieved. Eastman (2001) has suggested that when there is good delineation of training sites the maximum likelihood classifier outperforms the minimum distance to means. The unsupervised ISODATA clustering method was initially used to segment the image into a user specified number of homogenous clusters (Lo and Choi 2004). The ISODATA clustering method was applied to a three band composite of the Landsat 2001 ETM image with a maximum number of 50 clusters specified. The scattergram results for various two band combinations were assessed for degree of correlation between the two bands. High correlation is represented by a linear pattern on the graph and means that both bands are giving similar results, thus one of the two may be excluded from the composite (Earth Resource Mapping Pty Ltd. 2004). Which one of the two to exclude from the classification process depended on technical knowledge of what features give good reflectance in what band and the aim of the classification. The unsupervised classification layer was eventually generated using a three band composite comprising Landsat ETM bands 3, 4 and 5. These bands were selected because they provide complementary information. Band 3 exhibits low noise and provides good delineation of non vegetated surfaces while bands 4 and 5 allow for good discrimination among vegetation classes (Lillesand *et al.* 2004). The highly vegetated nature of the study area also influenced the choice of bands for the composite. Subsequent to the classification process the resulting clusters were merged with the aid of reference maps, to form 4 basic clusters representing land use and land cover. This process of cluster agglomeration has been described by Latifovic *et al.* (2004). The four newly derived clusters included forest, savanna and agriculture areas, urban and one unidentified which was later defined as bamboo. The mangrove and water areas were not spectrally distinguishable at this stage due to the small percentage of representative pixels. The unsupervised classification was used in conjunction with other reference datasets to assist in planning the field campaign for the collection of the ground truth data and also for the supervised classification.

3.5 Supervised Classification (Training Site and Signature Generation).

Effective classification of remote sensing image data depends upon separating land cover types of interest into sets of spectral classes (signatures) that represent the data in a form suited to the particular classifier algorithm used (Tso and Mather 2001). Difficulty in generating 'good' signatures was a reflection of the heterogeneity within the study area, and thus internal spectral variety within the training sites. Training sites for signature generation were initially developed using some of the points obtained from the GPS ground truth data. However, statistically, groups of single pixels do not make for good training sites. The more pixels that can be used for training (within reason), the better the statistical representation of each spectral class (Lillesand *et al.* 2004). Therefore, each ground truth point used was treated as a seed pixel. These points were overlaid onto (RGB) 3, 2, 1 true colour composites of each multidate image for the delineation of the training areas. Reference maps and the previously executed unsupervised classification map were used to assist in the determination of the extent of the training regions. Each training area was digitized on-screen at a specified distance from its seed pixel. Each training area contained at least one pixel that was no more than 2 pixels away from the original ground truth point. It must be stressed here that the original ground truth 'seed' pixels were not included in the training sites purposely, in order to maintain an independent data set reserved for accuracy assessment. Other composites of various band combinations were used to assist in delineation of training regions for specific features of interest. For example forest training sites were digitized over a (RGB) 4, 3, 2 band combination (false-colour composite) as well as the (RGB) 3, 2, 1 true-colour composite. Forest vegetation appeared red to bright red in the false-colour composite image and green to dark green in the true-colour composite. By viewing these different band combinations simultaneously, side by side in full resolution windows, forest vegetation patterns could be visually interpreted with relative ease. This specific training site development method was also used for identification of training sites for the urban, savanna/agriculture, bamboo and mangrove classes. No training areas were delineated for water areas as it was very difficult to find 'pure' pixels in the image to represent water areas. 'Pure' meaning not contaminated or mixed with the spectral characteristics of adjacent earth features. This was due to the fact that perennial water bodies on the island were rare and those that did exist were small, barely spanning a 30×30 metre area. These problems were further complicated by overhanging tree canopy along the borders of these water areas. The exception to this was the single reservoir on the island, the Hillsborough Dam. The predicament here however, was that in all three multidate images the reservoir was obscured by clouds and hence could not be used to delineate training sites. In order to include the significant water features on the island in the final land use and land cover map, additional post-classification procedures had to be implemented.

All training sites were digitized as vector polygons using ER Mapper software. A separate vector layer created over the image composite was used to define the training regions. The training areas were then labelled according to their respective landcover category and assigned an appropriate colour for display. The statistical information on spectral characteristics enclosed within these vector polygons (training sites), were then utilized in the generation of signatures required for the supervised maximum likelihood classification. Sufficient signature separation implies that the signature generated from each training site has a high probability of being correctly classified (Lillesand *et al.* 2004). A signature is a set of data that statistically defines the training site for each land category of interest. Before the signatures were generated, each training site was evaluated graphically to determine their spectral response patterns. By visually evaluating training site graphics, analysts are able to determine whether signature data is a true representation of the pixels to be classified for each land category (Jensen 2005). Two-dimensional scattergrams, in the form of feature class ellipses, were calculated from the means and standard deviations derived from the range of pixel values in each training site, in different two band combinations. The scattergrams offer visual analysis of the correlations between various spectral bands to determine which combination of bands captures the desired features in the image (Earth Resource Mapping Pty Ltd. 2004). When feature class ellipses in the scatterplot show extensive overlap, then the spectral characteristics of the pixels represented by the training site signatures cannot be distinguished in the two bands that are graphed (Lillesand *et al.* 2004). In the best case, there is no overlap. Some overlap, however, is expected. After extensive viewing of each feature class scattergram with multiple two band combinations, the best two band combination that depicted the least amount of overlap between feature classes was of bands 3 and 5 of the Landsat ETM 2001 image. All feature class ellipses were displayed together to visually determine final overlap between feature classes. There was some degree of overlap between savanna/agriculture and bamboo feature classes. Otherwise, virtually no overlap occurred among the remaining feature classes. This method for training site development and signature generation was applied to each of the three Landsat ETM images prior to classification.

Once 'good' separation of the training sites was determined, a supervised, (full Gaussian) maximum likelihood classification was carried out on each of the three multidate Landsat ETM 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, based upon the signatures generated for each land cover category. 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. Following the multitemporal image classification techniques employed here, post classification methods were used to demarcate water areas in the classified images.

3.6 Development of the Land Use/Cover Map

Subsequent to classification the images were overlain to produce a mosaic with all areas classified. A mosaic is an assemblage of two or more adjacent or overlapping images to create a continuous representation of the area (Earth Resources Mapping Pty Ltd 2004). Post-processing methods were then used to account for water areas. These techniques involved the on-screen digitizing of water areas as separate polygons from a 1994 airphoto mosaic. The salt and pepper effects from the classification were then cleared up by smoothing the image through the use of a 3×3 kernel majority filter (Tottrup 2004).

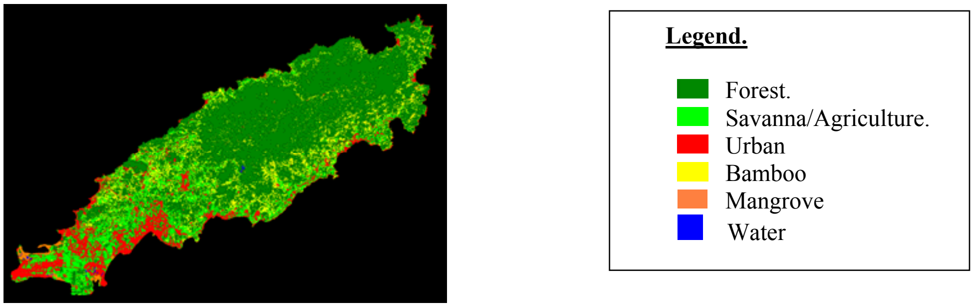

Figure 1: Final Mosaic (2001 Landuse/cover Map).

4. Accuracy Assessment

One of the most common means of expressing classification accuracy is the preparation of a classification error matrix (sometimes called a confusion matrix or contingency table) (Lillesand *et al.* 2004). 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 vector layer displaying the labelled field points was overlaid on the classified image in ArcGIS 9.0 and each point was cross-referenced with the image for correct classification. A similar method is described by Jensen *et al.* (2005) for accuracy assessment by overlaying point locations of reference data over a classified grid. A simple count was done and the figures were inputted into the error matrix (see Table 2)

Table 2: The Error Matrix.

	Field Data (Known Cover Types)						
	Forest	**Savanna/Agriculture**	**Bamboo**	**Urban**	**Mangrove**	**Water**	**Row Total**
Classification Data							
Forest	**33**	0	0	0	0	0	**33**
Savanna/ Agriculture	2	**31**	1	0	0	0	**34**
Bamboo	0	0	**6**	0	0	0	**6**
Urban	1	3	0	**45**	0	0	**49**
Mangrove	0	0	0	0	**7**	0	**7**
Water	0	0	0	0	0	**2**	**2**
Column Total	**36**	**34**	**7**	**45**	**7**	**2**	**131**

Producer's Accuracy	
Forest	= 33/36 = 91.6%
Savanna/Agriculture	= 31/34 = 91.2%
Bamboo	= 06/07 = 85.7%
Urban	= 45/45 = 100%
Mangrove	= 07/07 = 100%
Water	= 02/02 = 100%

User's Accuracy	
Forest	= 33/33 = 100%
Savanna/Agriculture	= 31/34 = 91.2%
Bamboo	= 06/06 = 100%
Urban	= 45/49 = 100%
Mangrove	= 07/07 = 100%
Water	= 02/02 = 100%

Overall accuracy = (33 + 31 + 6 + 45 + 7 + 2)/131

= 124/131

= 94.7%

The kappa statistic for the classified map was calculated to be = 0.93. This implies that the kappa value of 0.93 represents a probable 93% better accuracy than if the classification resulted from a random, unsupervised, assignment instead of the employed maximum likelihood classification. The kappa coefficient lies typically on a scale between 0 and 1, where the latter indicates complete agreement, and is often multiplied by 100 to give a percentage measure of classification accuracy. Kappa values are also characterized into three groupings: a value greater than 0.80 (80%) represents strong agreement, a value between 0.40 and 0.80 (40-80%) represents moderate agreement, and a vale below 0.40 (40%) represents poor agreement (Congalton 1996). The accuracy assessment produced an overall accuracy of 94.7% with a kappa coefficient of 0.93 and was deemed to be satisfactory by modern image classification standards.

5. Quantitative Land Use/Cover Change Assessment.

A modest assessment of land use land cover change for the period 1956-2001 was done using a 1956 landuse map and the 2001 landuse/cover map. A quantitative analysis of change detection was performed by utilizing spatial statistics tools within ArcGIS 9.0. Both maps were vectorised and populated with the corresponding attribute information for the land use types using ArcGIS. The regions representing the two landuse/cover types that showed the most significant change (i.e. savanna/agriculture and urban) were then extracted as separate layers from the vectorised form of each map. The spatial analyst tool of the GIS software was further exploited to generate area figures for each the following landuse/cover types for both years (savanna/agriculture, forest, urban and mangrove). These figures were then used to calculate the landuse/cover change for each of the four landuse/cover types and were given in terms of square kilometres and percentage landuse/cover gained or lost (see Table 3). Area figures calculated for agricultural landuse for each of the two years show a dramatic decrease for this class. Agricultural land use in 1956 accounted for an area of 114.11 km^2 which was roughly 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 the landuse type over the 45 year period. Furthermore, considering the fact that savanna/agriculture landuse for 2001 consists of a nominal proportion of actual agricultural landuse, the percentage decrease in pure agricultural landuse for the period is actually much higher than the figure calculated here. The factors which may have been attributed to this dramatic decrease include the natural disaster event (hurricane Flora), increased urbanisation and a lack of proper planning with respect to the developmental process. An examination of Table 3 reveals that for the year 1956 urban landuse 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 a hike of 107.49% for this particular landuse type. A noteworthy point was that the area in which the greatest urbanisation took place occurred almost entirely in the south eastern sector of the island. This area consists of land with little or no slope making it highly conducive to development. 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.

Table 3: Quantitative Assessment of Landuse/cover Change for 1956-2001

LANDUSE/COVER TYPE	YEAR	TOTAL AREA (Km²)	LANDUSE/COVER CHANGE (Km²)	LANDUSE/COVER CHANGE (%)
Savanna/ Agriculture	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		

A highly prominent trend which was synonymous with the current developmental movement on the island was noticed during the change detection analysis. Having already ascertained that there was a substantial decrease in agricultural landuse, it was interesting to note that a considerable proportion of this loss was attributable to the increase in urban landuse. The results of the analysis suggest that in many places agriculture was directly exchanged for built-up area. This is of special significance to the future of agriculture on the island, as prime agricultural lands may be being lost due to poor planning and unregulated urbanisation.

6. Draping the Land Use/Cover Map over a DEM.

The Land Use/Cover Map was draped over a DEM. This technique produced a model illustrating the changing land use and land cover patterns with variations in topography. This application can be used to model drainage patterns while simultaneously examining the influence of slope and elevation on land use and land cover types and is excellent for planning, development and management purposes. Other vector layers such as; roads, rivers and major population centres may be overlaid on the land use/land cover map within a GIS environment to increase the analytical capabilities and output information that can be attained.

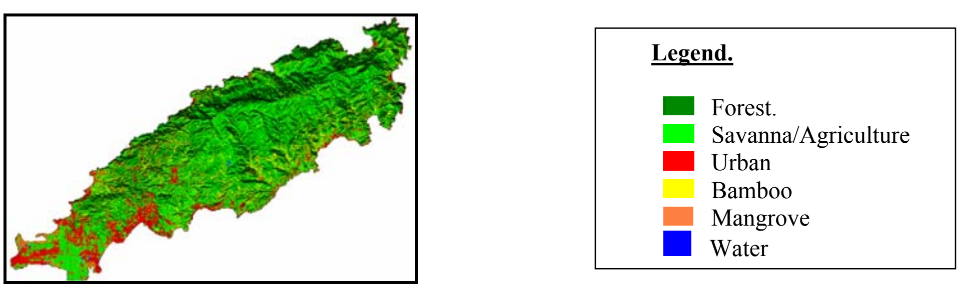

Figure: 2001 Elevated Land Use/Cover map of Tobago.

7. Summary and Conclusions

Much of the recent research that has been carried out in the Caribbean has shown that up to date information on land use/cover distribution is virtually non-existent (FAO 2001; Ochoa-Gaona and Gonzalez-Espinosa 2000; Baban 2002; Tottrup 2004). This type of information is essential for the formulation of policies which promote sustainable development. Previous studies done by Ragoonath (1997) have shown that the island of Tobago is progressing in a negative direction with respect to its development. This evidence has suggested that the above mentioned policies and the consequent land use/cover information can be of significant benefit to development on the island. It is therefore important to develop methodologies that can locate, quantify and map these two categories effectively and efficiently. The use of remote sensing technologies in this research has proved to be a suitable and cost efficient way for providing the data necessary for generating the necessary land use/cover information. The role of geographic information systems (GIS) was essential to the principal methodology, as it provided an environment for the efficient storage and manipulation of the remotely sensed data. 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. By modern standards these figures are very high and show that the classified map produced is very reliable. A quantitative assessment of land use change on the island for the period 1956-2001 demonstrated a 107.49% increase in urban landuse and a 62.89% decrease in agricultural landuse. The analysis also suggested that in many areas loss of agricultural landuse was directly replaced by growth in urban development. The results of the change detection analysis show that for at least two major landuse categories there have been considerable transformations with respect to their spatial extent and distribution. 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.

There are a few specific limitations to this research which should be addressed and noted as a means for improvement or potential for strategies for future study. The main limitation to using a multidate technique is the possibility of obtaining satellite scenes of sufficient quality. High incidence of cloud cover makes the use of optical sensors in tropical regions difficult (Li *et al.* 1999); consequently acquiring adequate cloud free satellite scenes at critical times during a year can be a complex task. Nevertheless, when applied, the multidate approach employed in this study was effective for improved land use/cover mapping as it provided an up to date and accurate representation of the earth surface features. With reference to the methodology applied for acquiring ground data, bias with respect to proximity to roads is characteristic of the data. It should be noted that this is not critical to the overall accuracy assessment of the land use/cover map, however, it is important to mention.

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