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APPLICATION OF REMOTE SENSING TECHNIQUE IN BIOMASS CHANGE DETECTION: A CASE STUDY OF BROMLEY AND CHIHOTA, ZIMBABWE

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Abstract

Biomass is defined as the total mass of living plant matter in a given unit of an environment area. Several factors influence the change in biomass content of an area. The rate of change varies from mass seasonal drying of grasslands to gradual degradation of forestry area. It is in the interest of environmental monitoring and sustainable development that biomass change be constantly determined. There are various field methods used worldwide to determine density of forest resources but have several limitations because of the nature of factors influencing biomass change. These include seasonal changes, human activities, forest fires etc. Remote Sensing as an enabling technology provides an efficient avenue of assessment of biomass content of any area. This research focused on biomass content that constituted forest resources. Two main methods used were qualitative analysis involving visual image interpretation relying on knowledge of spectral reflectance characteristics of ground cover types and quantitative analysis involving use of mathematical capacity of the computer to extract information on pixel digital number The techniques employed in these methods were complementary and were combined in a systematic manner to optimize the potential of remotely sensed data in biomass change. Comparison of two methods information, revealed that biomass content obtained from the remotely sensed data from the two study areas were almost identical. Extra ancillary data like population information and detailed land use data, can be integrated into GIS together with results from remote sensing analysis to enhance the decision making process.

Key Words*:* *Biomass, Forest, Image, Interpretation, Qualitative, Quantitative*

Introduction

The majority of the population in Zimbabwe reside in farming communities where agriculture is the main source of livelihood. This results in more land being cleared for agricultural purposes and in addition, the demand for firewood remains on the increase. Agricultural production in the rural areas is low-yield high-acreage partly because of poor mechanisation and inadequate inputs. Therefore, large parcels of land are cleared to yield relatively low output. Remote sensing has been used in recent times to monitor the

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changing patterns of land cover and it has shown great potential in areas like agricultural mapping and monitoring (Lillesand and Kiefer, 2000).

The net rate loss of forests in Africa is the second highest in the world, while the continent leads the globe in the frequency of forest fires. Globally Africa suffered a net loss of forests exceeding 4 million hectares per year between 2000 and 2005. This was mainly due to conversion of forest lands to agricultural. Forest cover went from 655.6 million hectares (ha) to 635.4 million (ha) during this period.' (www.fao.org.newsroom/en/news/2006). The common tenure in rural areas is communal ownership, and there are problems associated with collective responsibility. In such a set up there is increased pressure on resources and no incentives for proper utilisation which has in some cases resulted in unintended land use practices. According to some sources, e.g. http://www.tropicalforest.ch/files/other_contributions/Robledo_2007.pdf, Zimbabwe has lost an estimated average of 312,900 hectares of forest per year between 1990 and 2000 and the rates increased by 16.4% from 2000 to 2005. This translates to approximately 551,000 hectares

In the year 2000, the government embarked on the fast track land redistribution program meant to address past imbalances. This resulted in a marked shift in land tenure with a large portion of national arable area now under various resettlement schemes.

Remote sensing and Geographic Information system (GIS) have over the years been used by researchers for the efficient storage, analysis and presentation of geographic data (Patterson, 1998, Lillesand Kiefer, 2000). Remote Sensing is broadly defined as the art or science of collecting and interpreting information about a target without being in contact with the object or phenomenon (Sabins, 1997). The information is recorded by sensors on board land, air or space borne vehicles.

The remote sensing process is completed by processing of the data collected by the sensors to enable analyses either by interpretative and or measurement techniques. This provides useful information about the subject under investigation. These techniques are diverse, ranging from traditional methods of visual interpretation to methods using sophisticated computer processes. Accordingly, the two major components of remote sensing are data collection and data analysis (Avery and Berlin, 1992).

The objective of the research was to determine the biomass change in the study area using satellite remotely sensed data. Forest land was being lost at an alarming rate and this required monitoring. Conventional field observations were costly and labour intensive and repeating such tasks occasionally to establish trends and problem areas was difficult. Remote sensing, as an enabling tool, could provide an effective avenue to carry out this task with less resource.

Study Area

A relatively large area was selected for this research. It covers Bromley, a commercial farming area and Chihota, a communal farming area as in figure 1. The area is situated from $^{3}15^{000}$E to $^{3}41^{000}$E and $^{79}82^{000}$N to $^{79}94^{000}$N on an altitude of over 1200m above sea level. The summer rainfall for the area ranges from 700mm to 1000mm and the average temperature of 17.5^{o}c to 20^{o}c. Vegetation cover in the study area was predominantly sparse bush with isolated patches of dense vegetation Changes in land cover have resulted in significant changes in weather and climate patterns (Tateishi and Hastings, 2002).

Bromley on the other hand, was situated in between two towns, Harare and Marondera and such proximity to major urban centres resulted in increased agricultural activities. In Bromley there were several land use activities such as plantations, irrigation schemes and research farms. It was important to analyse how these various human activities were linked to biomass change. Of particular importance were plantations which were evergreen, and therefore crucial in green vegetation cover identification. This aspect was very important in false colour composites, in which vegetation was not necessarily green. Plantations therefore were used as a standard in vegetation cover identification. The area had a dense network of rivers which included Manyame and Nyatsime, two of the major rivers in Zimbabwe with many tributaries. In Bromley several dams were constructed on these rivers. The network of rivers and dams also allowed analyses to be carried out on relationships between natural and man-made reservoirs, vegetation and land use activities.

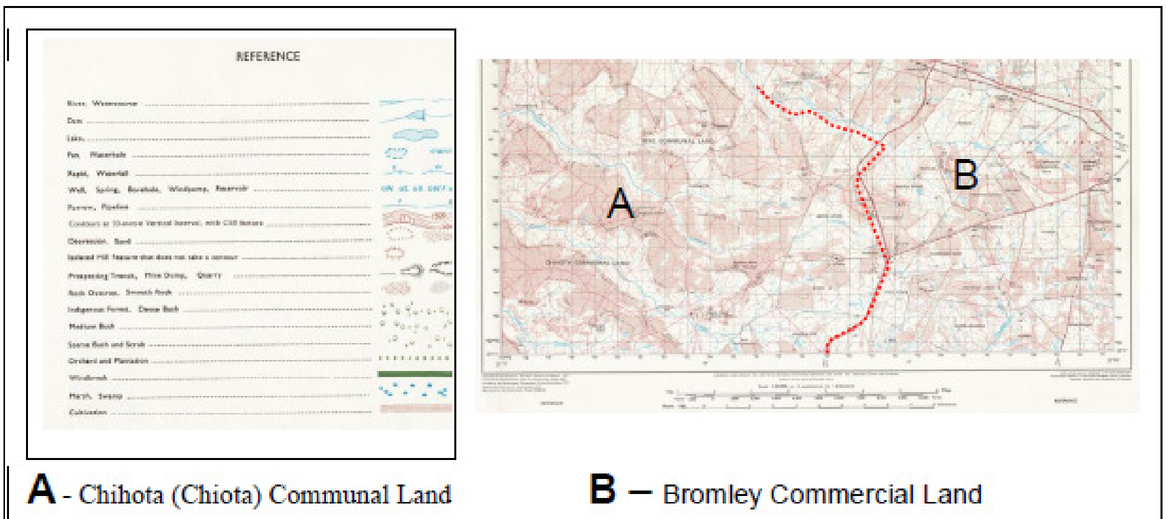


Figure 1: Location of study area

Methodology

Landsat imagery was used for this exercise and multi-temporal images were obtained as follows; May 1989, March1998, August 2001, July 2002. Selection was limited to available resources. The selected study area was extracted from a whole scene for all bands and this was accomplished using IDRISI software. Since there were huge time differences, features not susceptible to change such as road junctions, road-rail intersections and dam walls were chosen in windowing sub-scenes.

Geometric Image Registration

When the images were initially projected onto a plane, they were projected at different scales. Consequently, the grids on which the sub-scenes were projected had different numbers of rows and columns, despite having the same features. Image geometric registration was achieved using the linear mapping function of the RESAMPLE module with the nearest neighbor re-sampling type used. Nearest neighbour re-sampling chooses the actual pixel that has its centre nearest the point located in the image. This pixel is then transferred to the corresponding grid location. This is the preferred technique if the new image is to be classified since it then consists of the original pixel brightness simply rearranged to give correct image geometry (Richards and Jia, 1999). The RESAMPLE required that there be a correspondence file, which contained the X and Y coordinates of a certain number of a well distributed control points. In addition, the number of rows and columns plus minimum and maximum X and Y coordinate values of the output image were specified. The output reference parameters for the resample process on 1998 and 2002 sub-scenes were therefore matched to those of 1989 sub-scene.

Visual Image Interpretation

Appropriate band combinations were selected when creating color composites such that the overlay contained relevant information. For vegetation cover analysis using Landsat imagery, bands 3, 4 and 5 were found to be most suitable since they combined important spectral reflectance aspects of vegetation. (O'Brien, 2001)

24-bit colour composites were created for each sub-scene using the available bands 3, 4 and 5. The composite module was used in the procedure. The histogram equalisation stretch type was used first, and then linear contrast stretch with saturations.

With histogram equalisation, the output image formed was such that an equal number of input pixels fell into each ordered class. A histogram of the resulting image thus appeared flat, hence the name. In order to facilitate meaningful visual analysis, small portions of the color composites with large pixel sizes were extracted. A criterion for selecting the extracts was such that most of the areas were covered and that all features associated with vegetation were included. The pixel sizes facilitated the process of visually detecting any significant changes. The 1:50 000 topographic map proved to be a vital source of ancillary information which aided in feature identification and locating boundaries,

Seasonal spectral response variation of vegetation was employed in differentiating grasslands from woody areas. 1989 and 1998 images were taken in wet season and grasslands were predominantly green. These were compared with 2001 and 2002 images taken in winter, their spectral response significantly varied from that of dry grass.

Qualitative results from the procedures outlined above were compared with those from quantitative analysis. Results from quantitative analysis were taken as control since they are more accurate.

Image Differencing Techniques

Geometrically registered images taken at different dates were subtracted to come up with residual or difference images, which represented the change between the two dates. The resultant images were scaled to remove negative brightness values. Normally this is done so that regions of no change appear mid-grey, and those changes appear lighter or duller, depending on the sign of change (Richards and Jia, 1999).

Single bands from 1989 were subtracted from corresponding bands from 1998, 1998 bands were also subtracted from 2001 bands and 2001 bands from 2002, in similar fashion. Colour composites were created using difference images for the three bands, with band 3 difference image as blue, band 4 as green and band 5 as red.

Image Ratioing

Ratio images were prepared by dividing the pixels in a particular image band at a particular time by corresponding pixel values at a different time (Eden and Parry, 1986). Ratios of different spectral bands from the same image find use in reducing the effect of topography, as a vegetation index, and for enhancing subtle differences in certain spectral reflectance (Richards and Jia 1999). Single bands from1998 were divided by corresponding bands from 1989 image. Using OVERLAY module, simple division was first done and resultant ratio images were displayed on the standard IDRISI palette and also on grey scale. Colour Composite images were derived from three ratio images from the three available bands. The three ratio images, displayed on a grey scale, were each assigned to a color plane in the RGB format. Colour composites also highlighted several features including vegetation cover.

Image Regression

With image regression two image data sets for the same scene taken at different times were plotted on a Cartesian plane. A regression line was obtained from the scatter plot using some statistical principle. The regression equation was thereafter used to predict a new image for the later date image set. The logic of image regression in change detection is that the regression extrapolates trends and then the difference operation measures the deviation from these trends (Bakker, 2000). In image regression one image band was set as an independent variable, whose DN values were represented by the x-axis, and the other as the dependent variable. Regression lines and scatter plots were derived. Due to the nature of this mathematical operation, the images produced had DN values within a constricted range. The STRETCH module was applied to redistribute pixel DN values from 0 to 255, in order to facilitate meaningful differencing operations. An image differencing technique was then applied, that subtracted the predicted image values with the actual image band values to come up with a new difference image.

Unsupervised Classification

In unsupervised classification, the computer used statistics only without user-defined training of classes. The computer did this by identifying certain patterns in reflectance data. The output image required a lot of user intervention to make it useful. The classes developed in these images were sometimes called clusters because of the mathematical procedure used. (http//goeg.hkbu.edu.hk). Post classification processes were necessary to detect pixels that were wrongly classified and reassign them to correct fields. Results from supervised and unsupervised classification can be significantly different and visual comparison of the two can bring meaningful information. (Bortolot Z1999)

Since the goal in this project was to detect change, which could minute, classification was formed on the extracts that were used in the interpretation. This meant there were a reduced number of spectral classes per image and hence overally improving the accuracy of the classification process. Because of the few spectral classes in the extracts, supervised classification was not necessary. Equally accurate results could be produced by equating the number of output classes in unsupervised classification to the spectral signatures in the image. In the process of unsupervised classification, a histogram was displayed which showed the frequency of pixels belonging to each cluster. This histogram therefore formed the basis for choosing the number of clusters in final classified image and four were chosen.

Colour Composite Classification

Eight-bit Colour Composites for the different dates were classified using the CLUSTER module. 8-bit images were used because the procedure of generating them in the COMPOSITE module was the same as the first multi-dimensional histogram generation in the CLUSTER. In order to facilitate meaningful analysis from the color composite classification images, smaller sub-scenes were windowed that contained similar land use. These were compared with corresponding extracts from the scanned topographic map to ascertain class identification. These sub-scenes were a portion of Chiota Communal lands and another from farming estates, and were extracted using the WINDOW module by defining rows and columns

Change in biomass for the each of the periods 1989 to1998, 1998 to 2001 and 2001 to 2002 was analysed. The amount of change that occurred in these windowed areas, for each period, was determined by analysing the histograms of the two sub scenes. The percentage change in each of the windowed area was established by dividing the number of pixels in vegetation class for 1998 image by those from the 1989 image

Multi-date Overlay Composite Images

These composite images were generated by overlaying corresponding layers from different dates in separate color planes. Pixels whose DN values had changed were colored depending on how much change they reflected. Pixels without change were represented on a grey scale. This method was advantageous in that areas with change were quickly recognised by color. Three corresponding band images from three different dated images were overlaid into color images. The multidate color composite images were then coded, for instance, L16973_89-98-01 b3moc.

Vegetation Indices (Vis)

These were simple arithmetic combinations which focussed on spectral pattern response of vegetation in the red and near infa-red bands. Two slope based Vis were investigated, and these were Ratio Vegetation Index (RATIO VI) and Normalised Vegetation Index (NDVI). These two closely represented, in output, the remaining five indices.

$$\text{RATIO VI} = \frac{\text{NIR}}{\text{Red}} \qquad \text{NDVI} = \frac{\text{NIR-Red}}{\text{NIR+Red}}$$

The red band (band 3) and near infra-red (band 4) were used for this process. The resulting images were also classified with class width defined to cluster most non vegetation features into two classes and vegetation into three classes. Analysis on the three vegetation classes was then carried out using histograms of different date images. By comparing the number of pixels in each class, changes in woody cover were established. Visual interpretation was done to establish distribution of change and trends that were prevalent.

Results and Discussion

Visual Image Interpretation

The results of the visual image interpretation showed there were more pixels in the 1989 image than in the 1998 image, which represented a decrease in woody cover in the area during this period. These images were of the same scale in terms of rows and columns, and it could therefore be established that the cultivated areas were encroaching into the bushy areas. By zooming in and counting the number of pixels lost on the edges a rough estimate of the vegetation cover lost could be determined.

From the three Chihota Communal Lands color composites extracts that were analysed, there were significant woody cover changes that were detected between 1989 and 1998. Interesting trends were observed, especially between 1989 and 1998 imagery. There was a marked decrease in bush bordering the villages, probably due to expansion of areas under cultivation, since most pixels were lost to the bare soils class. This trend could also be attributed to logging for firewood and other domestic uses. Sparse bush areas in near proximity to river beds did not decrease significantly. This trend was noticeable around larger rivers, and could be attributed to distances from villages and strict conservation regulations.

For the period 1998 and 2001 there were noticeable changes, but marginal. Analysis for the period 2001 and 2002 showed that there was no change, although there were isolated points implying change. Five extracts were taken from Bromley faming estates since the area was larger and analysed.

Three of the five extracts suggested minor changes in woody cover in the period 1989 to 1998 but in one extract there was significant loss in biomass. In the final extract, there was significant biomass increase along a river stretch. Such a change was difficult to attribute anything to it. For the2001 and 2002 images, for all five Bromley extracts there was no significant change detected.

The table 1 summarizes the result from the qualitative analysis.

Table 1: Summary of qualitative analysis

	Bromley	Chihota
1989 – 1998	Minor	Extensive
1998 – 2001	Minor	Minor
2001 – 2002	Negligible	Negligible

These results were compared to quantitative analysis results by combining them. Quantitative results were more accurate since the process made use of the computers arithmetic capacity.

Difference Images

Difference images were very useful in identifying amount of change in all areas. Areas of major changes were analysed on corresponding earlier date color composites in an effort to link the change with associated features. Different images were particularly important in differentiating changes due to seasonal spectral reflectance variations and those due to land cover changes. A comparison of different images for two different seasons would indicate change in one image, which is not in another. This implied the change was not permanent hence it was due to vegetation seasonal spectral variations.

Difference Image Reclassification

Classification of difference enhanced the representation of information by clustering similar pixels and representing them with one color, thereby reinstating feature identification. This made the dams and fields clearer. The essence of information reclassification was to compare it with earlier date colour composites, check for vegetation in color composites and compare it with change information.

By simply running the mouse round the edges of the feature on both images displayed side by side, whilst in the process checking row and column positions on the status bar, amount of change could be visualised. One shortfall of reclassifying change information was inconsistency. This probably was because of pixel values aggregation in the classification process.

Difference Image Colour Composite

Difference colour composites showed the amount of reflectance in each band for land covet features. The color for each feature depended on the pixel DN values in each band. In light of this, the composites were of little help detecting vegetation cover change. These composites were useful in plant species differentiating and showed areas where some species would have been overgrown by others. This process however required finer detail of spectral reflectance values of several features.

Colour Composites Classification

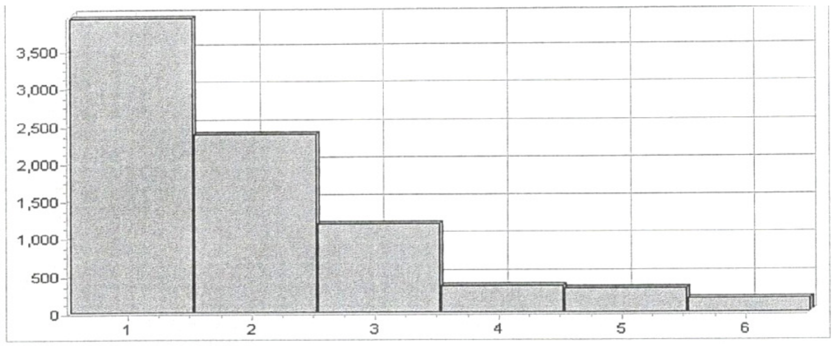
Information from color composite classification could be retrieved through visual interpretation, but most importantly through histograms. One important step was to carefully determine features in each cluster by comparison with color composite. Table below shows spectral classes in Chihota extract 2 colour composite classification images.

Table 2: Spectral classes in 1989 and 1998 classification clusters

Cluster	**1989**	**1998**
1	Cultivated	Cultivated
2	Cultivated	Cultivated
3	Bare Soil	Dark/moist soils
4	Dark Soil/ Water	Vegetation Cover
5	Vegetation Cover	Grasses
6	Vegetation Cover	Water

By matching spectral classes in table with pixel values in histograms, the amount of change for each class could be determined.

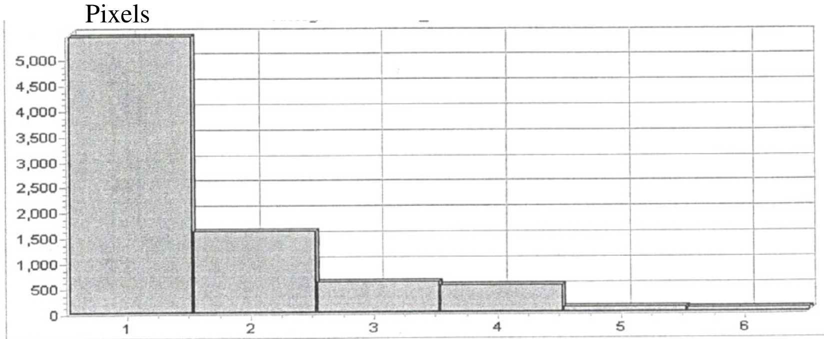
Pixels



Clusters

Figure 2: Histogram for 1989 classification image

Pixels



Clusters

Figure 3: Histogram for 1998 classification image

An analysis of the colour composites from which this information was taken showed that there was biomass increase in most parts of the area, but there were a number of fields that were probably fallowed due to low fertility, and were under vegetation cover. In such situations a further step was taken to fragment the image again to separate areas with a decrease with those with an increase in vegetation cover. Then the histograms of the two separate images could be analysed and amount of vegetation decrease or increase determined separately. For instance, the area under cultivation increased from 6500 pixels in 1989 to 1998 to 7000 pixels in 1998, which is an increase of 500 pixels. Since a single pixel is 30m*30m in dimension or 900 square metres, this means there was an increase of 450 000 square metres, or 45 hectares, in cultivated land during the period 1989 to 1998 in this area.

Multidate Overlay Composites

Multi-date overlay color composites provided useful information on change from three different dates on one instance. The colors bordering vegetated areas showed vegetation cover changes and different colors showed which period change occurred. These changes were compared with difference images in corresponding periods, and the changes tallied reasonably. A huge advantage exhibited by multi-date color composites was that trends were easily noticed by a quick rundown of the color dominating in the image. For instance, the field appearing yellow meant there was high spectral reflectance in the two bands allocated to the green and blue primaries.

Ratio Images and Vegetation Indices

Ratio images which were computed in this project and were suited for vegetation cover change detection were basically the same, in algebraic process, as the vegetation indices. The NDVI vegetation indices strongly emphasized vegetation cover, such that even visual interpretation could produce meaningful results. Therefore, the difference images produced from them were more informative than raw difference images. The simple ratio vegetation index was not of much use in detecting change. In the image, only non vegetated areas like dams and rivers were separated from other features, such that the image appeared almost all black, with large water bodies appearing green. This was probably because the difference in the ratios of most features was so small such that differentiating them was almost impossible.

Image Regression

The use of regression extrapolation in prediction resulted in loss of detail from the orignal images. Firstly the pixel value range was reduced from 0 -255 to 60 – 181. Secondly after a linear stretch was applied, in an effort to reconcile the ranges, there was further loss of information, detectible by mere visual comparison of the stretched predicted and original image. In order to establish the variation in information contained in the original and predicted images, image subtraction was carried out. The resulting difference image showed that various features that were in the original image were not predicted in the regressed image. This was further confirmed by comparing information from differencing regressed images with other results discussed above. The trends established by regressed images deviated significantly from others. In light of this the results from the regression technique were discarded.

The procedures followed in the methodology were such that most images from the quantitative techniques would be classified. This allowed histograms for these images to be generated, from which vegetation cover change in the area could be determined and represented numerically. The table below shows a merger of qualitative analysis results with ranges of averaged percentage loss in vegetation cover calculated using histograms. This representation was meant to show the uniformity of results from qualitative and quantitative analysis.

Table 3: Comparison of qualitative and quantitative results

Period	Process	Bromley	Chiota
1989 - 1998	Qualitative	Minor	Extensive
	Quantitative	7 - 8%	28 - 31%
1998 - 2001	Qualitative	Minor	Minor
	Quantitative	2 - 4%	3.5 - 5%
2001 - 2001	Qualitative	Negligible	Negligible
	Quantitative	<1.4%	< 1.8%

Conclusion

From the results of this research on the study areas, remote sensing proved to be an effective tool in biomass change detection. Firstly the effectiveness of remote sensing was inherent in the form of data acquisition, which gave it a unique temporal resolution. This property provided a lot of datasets and allowed researches to stretch back to archived data. With the advancement of technology spectral resolution has improved through the introduction of hyper-spectral image data, which covers wider parts of the electromagnetic spectrum. The marriage of remotely sensed data with the digital computer environment allows several techniques to be employed that compensate for its shortcomings. The techniques discussed above are complementary and need to be combined in a systematic manner in order to optimize the potential of remotely sensed data in biomass change detection.

The major setback in the remotely sensed data used was in the spatial resolution. For instance Landsat images had a spatial resolution of 30m, which meant four pixels only of vegetation cover change amounted to 3600 square meters. This was confirmed by the subtle differences detected in the 2001 and 2002 images. It is recommended in future researches that if available, imagery from satellites like SPOT and IRS, which have higher spatial resolutions, should be used in order to broaden the scope of the study. With better spatial resolution, the quantitative aspect becomes more accurate and the results carry more weight. Ground truthing should be done, where possible, to ascertain and identify some features or activities that have ambiguous spectral reflectance. With ground truthing, extra ancillary data can be collected which helps in the analysis and inference processes. Extra ancillary data such as population information and detailed land use data, can also be integrated into GIS together with results from remote sensing analysis in order to enhance the decision making process.

In a nutshell, remote sensing techniques can successfully replace the bulk of conventional field surveys in biomass change detection. A combined approach can be employed, in which only specific areas, identified using remote sensing, that need special attention will be visited and more ancillary data obtained

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