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Changes in forest cover composition of *Boswellia papyrifera* (Del.) Hochst. stands and their consequences, South Kordofan, Sudan

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Abstract: Forest cover change of *Boswellia papyrifera (Del.) Hochst.* stands in South Kordofan State was assessed using remote sensing imagery of Landsat MSS (Multispectral Scanner), TM (Thematic Mapper) and ASTER (Advanced Space-borne Thermal Emission and Reflection Radiometer) level-1B. Cluster random sampling along the accessible sites was carried out. Both unsupervised and supervised classifications for each image separately were carried out. Then post-classification comparison approach was used. The resulting classified images were comprised of evergreen forest, deciduous forest, barren land, *Boswellia* species including *Combretum sp*., *Acacia sp*. and shrubs and grass. Best classification results were obtained with Principal Component Analysis. The final results were presented in the form of change maps and matrices. There was a change in the areas of all classes with significant decrease in Boswellia class and dramatic increase in the classes of bare land, plantation, Combretum, shrubs and grass. The direction of change is towards Acacia wood land. Forest cover change can be assessed with high accuracy using multi-temporal remotely-sensed data and field sampling. Post-classification comparison approach seems to be efficient, although its high accuracy relied partially on image dates, accurate ground control points and analyst knowledge of the geographical region.

Keywords: Change detection; *Boswellia papyrifera*; remote sensing; Principal Component Analysis; Post-classification.

Introduction

Boswellia papyrifera (Del.) Hochst. is a tree growing up to 10 or 12 m in height (Figure.1). It can be recognized easily by its papery pale yellow or brown bark. Its leaves are oblong lanceolate, compound with 6-9 pairs of serrate or toothed leaflets, with odd terminal one. The flowers are red panicle inflorescences with creamy white flowers, clustering at the end of the branches. Fruits are winged capsules, brown-pink and avocado pear-shaped [1,2]. *Boswellia papyrifera* grows on hill catena as pure stands or mixed with other species such as *Sclerocarya birrea*, *Sterculia setigera*, etc. It does not grow in very steep slopes. It was also seen in sandy soils (Goz) as well as in cracking clay soils [3]. The study area is rich in vegetation with considerably high diversity. Trees in the northern dry region are thorny trees (Acacias). Poor status of *Acacia senegal* with *Acacia mellifera* gives way to the south for *Banalities aegyptiaca* and *Acacia seyal*. On high altitudes of the Nuba plateau, we find *Boswellia papyrifera* and *Sterculia setigera* on the slopes and in slightly elevated areas, *Sclerocarya birrea*. In the lowlands *Anogeissus leiocarpus* and *Combretum* sp. are prevailing. Also *Hyphaene* thebacia and Borassus aethiopum exist on light well drained sites. Ground vegetation is very rich with herbs and grasses such as Asparagus sp., Triumpheta flavescens, Cympopogon nervatus, Tribulus teristeris, Acanthospermum hespideum, Hibiscus canabinus etc., making it very favorable for grazing by both domestic and wildlife animals. Other shrubby species, like Adenum obesum (toxic), Feretia apodanthera (used for tea), are also present. Many exotic trees were introduced in the area as plantation, like Azadirachta indica, Ailansus excelsa, Cassia siamea, Eucalyptus sp. together with Khaya senegalensis, as indigenous species [3]. It is a valuable species, which can contribute significantly to the livelihood of the local inhabitants. Boswellia resin is a whitish exudate from the trunk of the tree, which turns yellowish to brown when dried (Figure.1). It is used as incense and as raw material in food; perfumery and pharmaceutical industries and the leaves are used as fodder. In addition to the multiple uses of its wood in local carpentry work and other wood related industries (match-boxes, pencils, air-conditioning particles, etc.). Since 1970s till now, tapping of Boswellia papyrifera trees is continuously in a traditional manner practiced by the Bani Amir tribes of the border region with Eritrea and Ethiopia in eastern Sudan. Some interested local inhabitants are also involved in tapping which is recently more intensified since the number of tapping wounds and their dimensions have been increased leading to severe damage of many Boswellia papyrifera trees and reduction in the production of viable seeds [4]. In addition to this, there are also other factors such as fire hazards, uncontrolled grazing, agriculture encroachment, illicit felling and the lack of natural regeneration. Therefore, the current utilization of the Boswellia papyrifera by the direct users (tapers, herders, timber users. etc), result in more deterioration of their stands. According to [5] B. papyrifera is listed by World Wide Fund (WWF) and International Union for Conservation of Nature and Natural Resources (IUCN), among the endangered species, which need priority in conservation.

South Kordofan State is the most important area in Sudan, where *Boswellia papyrifera* trees are abundant and resin tapping is practiced in large scale. These stands witnessed natural and anthropogenic disturbances such as fire hazards, uncontrolled grazing, agriculture encroachment, intensive tapping, etc. This situation has been more aggravated by improper tapping practices. For these reasons, *Boswellia papyrifera* stands experienced rapid changes in structure and composition, which may lead to increasing deterioration and change of these stands.

Remote sensing is considered to be an important source of information that can play significant role in sustainable forest management world-wide through operational forest cover mapping, forest structure, change analysis and forest inventory assessment. Therefore, this study is focusing on change detection of *Boswellia papyrifera* stands in South Kordofan State concerning stand structure and composition using multi-temporal / multi-spectral remote sensing images of Landsat Multispectral Scanner (MSS) (band 4,2 and1), Thematic Mapper (TM) (band 4, 3, and 2), Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) level-1B (band 3N, 2, and1). As Remote sensors, optical and radar, offer the possibility of locating changes in forest areas using various analysis techniques, ranging from the purely visual interpretation to the implementation of a fully automated algorithm [6,7]. In this study Supervised (full Gaussian) maximum likelihood classification and Post-classification change detection were used to produce the final change map, as it is the most common method that can be used to detect the changes of multi-resolution/ multi-temporal data sets [8]. In this approach, images belonging to different dates were classified and labeled individually then the classification results were compared directly and the areas of change extracted.

Figure1. Boswellia papyrifera trees (left) and a trunk with resin (Right). Source: Modified from [3]

Materials and Methods

Remote sensing data for change detection of *Boswellia papyrifera* stands over time was collected, including remote sensing imagery. Data was obtained from three different sensors including Landsat Multispectral Scanner (MSS), with 4 bands and 80 m spatial resolution, Landsat Thematic Mapper (TM) with 7 bands and 30 m resolution and Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) with 14 bands and 15 m resolution. The dates of these images were 13/01/ 1976, 15/11/1986 and 17/04/ 2005, for MSS, TM and Terra ASTER level-1B respectively, covering the *Boswellia papyrifera* stands in South Kordofan. The selected images, which are cloud free, were geometrically registered to Universal Transverse Mercator (UTM) map projection, Zone 36 and Datum World Geodetic System WGS 84 North and Scene Corner Coordinates (latitude/longitude) in units of degrees. Cluster random sampling along the accessible sites was carried out by the use of GPS according to [8]. About 80 ground control points were collected; most of them (65%) were allocated to *Boswellia papyrifera* species. Additional data included South Kordofan map of 1976 (1:250 000), *Boswellia* map of 1997 (1: 100 000), reports and field observations.

All the acquired images were pre-processed, geometrically and radiometricaly rectified, enhanced and transformed.

Image to image registration was done using ground control points to geo-code the MSS and ASTER images to the TM image of 30 m resolution. Nearest neighbor algorithm was used for re-sampling using polynomial rectification of ERDAS Imagine software (ERDAS Imagine is a remote sensing application with raster graphics editor abilities designed by ERDAS for geospatial applications (latest version is 2015) to the images to keep the original spectral value as close as possible to the raw image. Concerning the atmospheric correction, Dark-Object Subtraction was used. Contrast stretching enhancement was used to increase the tonal distribution between various features in a scene to improve the appearance of the acquired imagery to assist in visual interpretation and better classification. Images were also transformed and spectrally enhanced using Normalized Difference Vegetation Index (NDVI), Tasseled Cap Analysis (TCA) and Principle Component Analysis (PCA) (Figure.2). Enhancements were used to measure accuracy of visual interpretation and of understanding imagery.

The contrast in the image with light toned areas appeared lighter and dark areas appeared darker, making visual interpretation and hence classification much easier. Figure 3 shows the enhanced image of ASTER (right) and the original one without enhancement (left).

Post-classification change detection was used to produce the final change map, as it is the most common method that can be used to detect the changes of multi-resolution/ multi-temporal data sets [8]. In this approach, images belonging to different dates were classified and labeled individually. Later, the classification results were compared directly and the area of changes extracted [9,10,11]. In this study Supervised (full Gaussian) maximum likelihood classification was reprocessed implementing the three images of ASTER April 2005, Landsat TM November 1986 and Landsat MSS January 1976. Prior to classification, image sub-setting was carried out, where the images were reduced in size to include only the areas of interest. This process eliminates the extraneous data and speeds up the classification process. Visual interpretation and ground control points were used for the generation of signatures and training samples for the different land cover classes. Supervised classification of each image separately was carried out. Then post-classification comparison approach was used, with the help of ground control points to detect the resulting change, which involves the comparison of independently classified images pixel by pixel or segment by segment to identify the change quantitatively [12]. The final results were presented in the form of maps and matrices.

Accuracy Assessment or Error matrix is a measure of how accurate a class can be classified in an image and the confidence of a class in a classified image. First the Producers Accuracy (PA) is obtained by dividing the number of correctly classified pixels (CCP) by the Reference Total pixels (RTP) multiplied by 100. Secondly the Users Accuracy (UA) is obtained dividing the number of correctly classified pixels (CCP) by the Classified Total pixels (CTP) multiplied by 100. Then the overall accuracy is the mean of Producers accuracy and Users Accuracy for the entire image and is calculated as follows [13] .

Producers Accuracy: PA= (CCP/TRP) *100
Users Accuracy: UA= (CCP/CTP) *100
Overall Accuracy: OA=(PA+UA)/2*100 = ((CCP/TRP) + (CCP/CTP))/2 *100

Results and Discussion

Change detection was performed to complement with the ground survey in order to assess the cover situation in the study area. Visual interpretation was utilized in this study for the classification and extraction of the obtained information. Elements such as color, shape and size were used to discriminate between objects (valleys, plantations…etc.) and generation of signatures. TCA for ASTER images of 2005 was first tried but the produced image was more confusing so that the discrimination between the different categories of classes became difficult and therefore, it is not so useful in this study for the classification and change detection of multi-temporal imagery[8]. Normalized Difference Vegetation Index NDVI is useful to differentiate vegetation from soil and non-vegetation classes or to discriminate between dense and light vegetation. It is thought, difficult to differentiate between the diverse classes of the species Boswellia, Combretum sp., Acacia sp. ,shrubs and grass (level III). Figure (2) shows the NDVI for the different images of ASTER 2005, TM 1986 and MSS 1976, where the lighter white parts are dense green vegetation, ranging in-between dark and white are scattered vegetation, the darker black parts are soil, hills, stones and other non-vegetation objects. Images were better enhanced by using PCA, as shown in Figure (3). In the transformed images of ASTER 2005, TM 1986 and MSS 1986 on the right side, the different classes are more separable compared to the original ones in the left side.

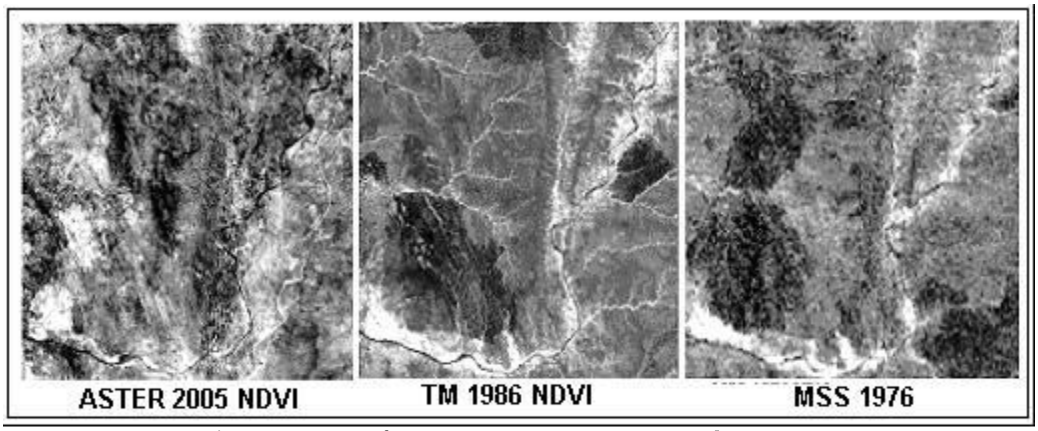

Figure 2. NDVI for ASTER 2005, TM 1986 and MSS 1976

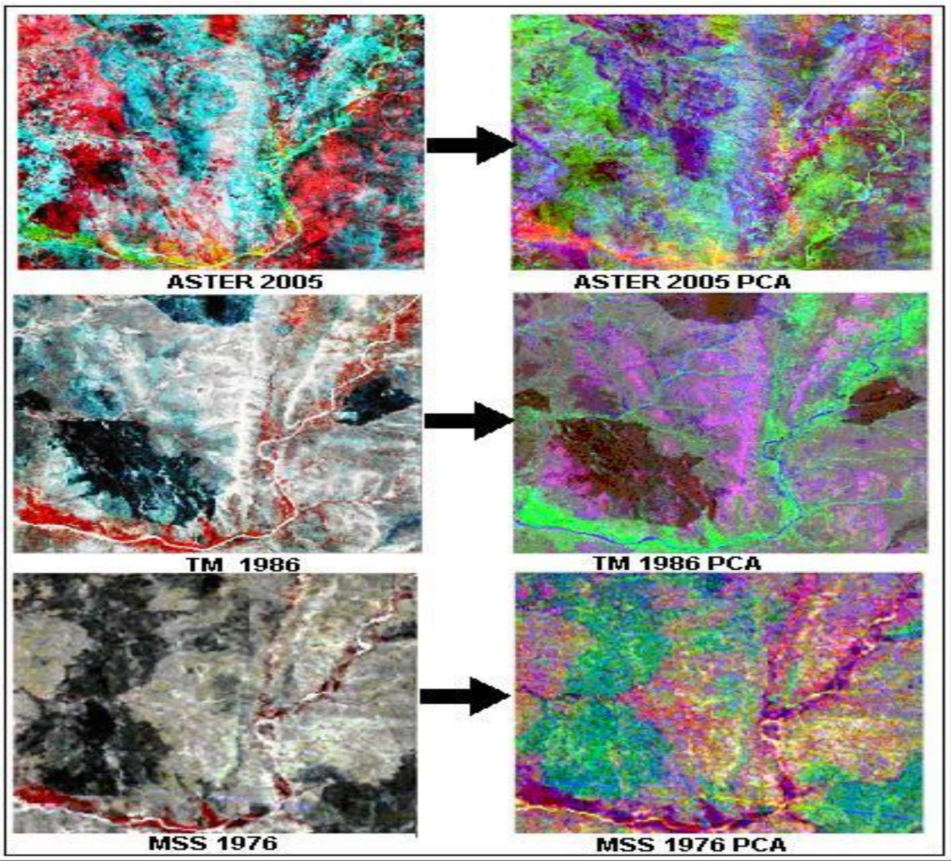

Figure 3. Original and PCA images of ASTER,TM and MSS

Although we found some difficulty in differentiating vegetation classes as a result of similar seasonal and phenological vegetation characteristics, due to the presence of more than 42 tree and shrub species in the study area, our knowledge, familiarity with the geographical region and the actual surface cover types present in the image facilitated the determination of the changes in the training sites. Initial training sites for signature generation were developed from points obtained from the GPS ground control data. This was combined with visual interpretation and vegetation phenology.

The maximum likelihood classifier was considered to give very accurate results, yet it is a much slower process due to the large number of calculations. However, the accuracy is largely dependent upon the quality of the signatures. The calculated overall accuracies for the classified images of TM 1986 and ASTER 2005 are 98.5% and 96.4% respectively. The resulting multi-temporal/multi-spectral classified images were comprised of evergreen forest, deciduous forest, barren land, species *Boswellia*, *Combretum* sp., *Acacias* sp. shrubs and grass, as explained in Table1 below, in a similar approach to that of [14]. The classified images are shown in Figures 4,5 and 6.

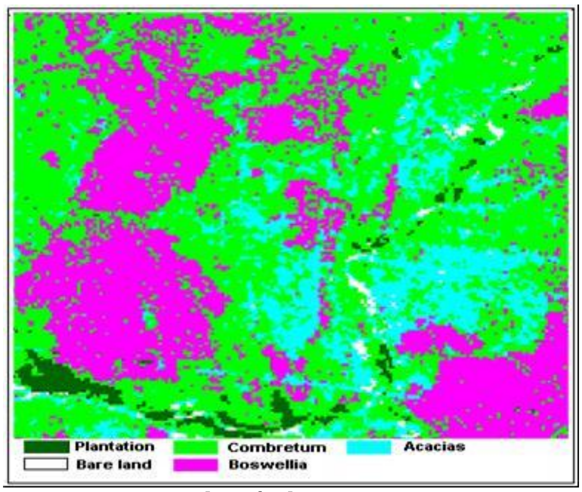

Figure 4. classified MSS 1976 image

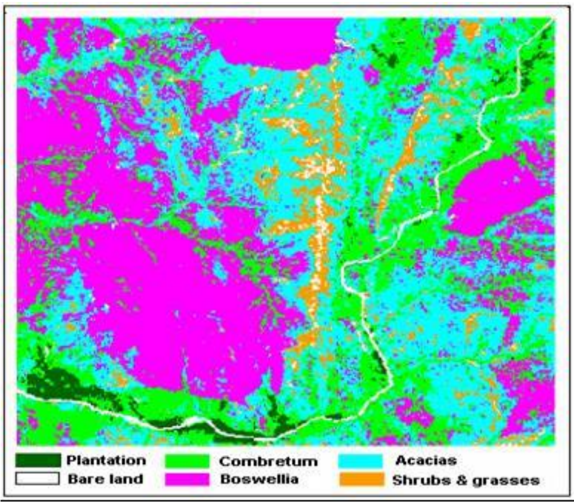

Figure 5. Classified TM 1986 image

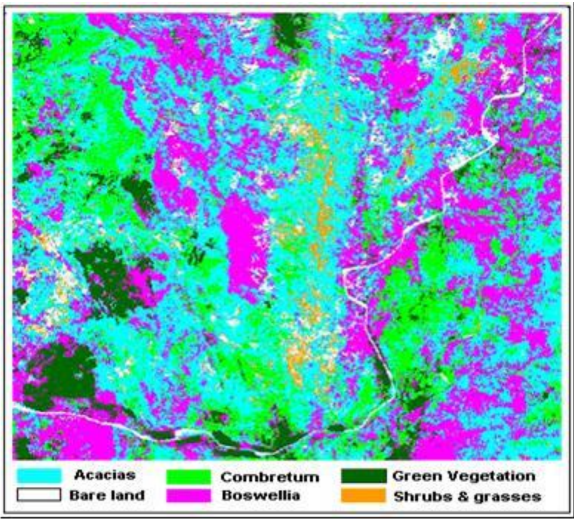

Figure 6. Classified ASTER 2005 image

The three classified multi-temporal/multi-spectral images of ASTER 2005, TM 1986 and MSS 1976, were compared to detect the resulting change over time. Tables 2 and 3, show the areas in the classified images of ASTER, TM and MSS for the periods of 2005, 1986 and 1976 respectively. The difference in number of classes and areas in the two tables was due to the enhancement of the images in Table (3). There was a change in the areas of all classes in both tables. The enhanced images in Table 3 represent a change in the areas of bare land from 1976 to1986 with an increase of 102.83 hectares, an increase of about 70 hectares for plantation, 755 hectares for *Boswellia*, 2483 hectares decrease in Combretum class, 1628 hectares increase in Acacias class and 45 hectares increase in the class of shrubs and grasses. For the period of 1986 to 2005, the change was about 354 hectares increase in bare land class, 18.6 hectares increase for plantation, 2368 hectares decrease in *Boswellia* class, 132 hectares increase in Combretum class and significant increase in the class of shrubs and grass. These changes were evaluated in change areas matrices in Tables 4 and 5 below for the periods of 1976-1986 and 1986-2005 as percentage of the total area of all classes. The positive sign indicates an increase in the area of the respective class, while the negative sign indicates the decrease.

Table 1. *Boswellia* stands change detection classification categories

Level II	Level III	Remarks
Evergreen forest	Plantation tree species	**Plantation including *Khaya senegalensis*, *Azadirachta indica*, *Eucalyptus* sp., and other species**
Deciduous	*Combretum* woodland	***Anogeissus leiocarpus*, *Combretum hartminianum*, *C. golutinosum*, *C. molle*, *Terminalia laxiflora*, *T. brownii***
Deciduous	*Boswellia* woodland	***Boswellia papyrifera*, *Sterculia setigera*, *Lanea sp.*, *Sclerocarya birrea*, *Commiphora sp.*,**
Deciduous	*Acacias*	***Acacia Senegal*, *A. seyal*, *A. gerrardii*, *Albizia amara*, *Dalbergia melanoxylon*, *Ziziphus spina-crista***
	Shrubs and grass	***Combretum collinum*, *Dichrostachys cinerea*, *Euphorbia candelabrum* and regeneration of the other species**
Barren land		**Bare soil, crop fields, seasonal water courses**

Level 1 comprises of main land cover types: Urban land, Water, Forest land, Barren land
Source: Adapted from [14]

Table 2. Areas (ha) in classified images of the *Boswellia* stands

Class	MSS 1976	TM 1986	ASTER 2005
Bare land	103.64	243.68	**504.45**
Plantation	256.67	239.61	**722.34**
Boswellia	3197.02	3760.76	**2995.29**
Combretum	5439.8	2282.5	**1586.78**
Acacias	1471.15	3335.5	**4435.18**
Shrubs and grasses	-	653. 46	**344.39**
Total	**10468.28**	**10515.52**	**10588.43**

Table 3. Areas (ha) in classified (PCA) images of the *Boswellia* stands

Class	MSS 1976 (ha)	TM 1986 (ha)	ASTER (2005) (ha)
Bare land	153.68	256.51	**610.5**
Plantation	245.30	315.23	**333.8**
Boswellia	3906.92	4661.58	**2293.5**
Combretum	4946.0	2463.07	**2595.5**
Acacias	1062.42	2690.58	**3194.1**
Shrubs and grasses	**153.68**	**198.35**	**1376.7**

Table 4. Change areas 1976-1986 (PCA)

Class	Area 1976 (ha)	%	Area 1986 (ha)	%	Change area 1976-86 (ha)	%
Plantation	245.30	2.34	256.51	2.42	11.21	**0.08**
Combretum wood land	4946.28	47.27	2690.58	25.43	-2255.57	**-21.84**
Boswellia	3906.92	36.34	4661.58	44.05	755.16	**7.71**
Acacias	1062.42	10.15	2463.07	23.28	1400.65	**13.13**
Shrubs and grasses	153.68	1.5	315.23	3.0	161.55	**1.5**
Bare land	**153.68**	**1.5**	**198.35**	**1.9**	**44.67**	**0.4**

Table 5. Change areas in *Boswellia* stands for the period 1986-2005

Class	Area 1986 (ha)	%	Area 2005 (ha)	%	Change area 1986-05 (ha)	%
Plantation	256.51	2.43	333.72	3.21	77.21	**0.78**
***Combretum* woodland**	2690.58	25.42	2595.49	24.95	-95.09	**-0.47**
Boswellia	4661.58	44.04	2293.49	22.04	-2368.09	**-22**
Acacias	2463.07	23.27	3194.06	30.70	731	**7.43**
Shrubs and grasses	315.23	3.00	1376.71	13.23	1061.48	**10.23**
Bare land	198.35	1.9	610.45	5.87	412.1	**3.97**
Total	**10585.32**	**100.0**	**10403.92**	**100**		

Change detection results of the classified three multi-temporal images of ASTER 2005, TM1986 and MSS 1976 were presented in the form of areas, matrices and maps. First comparison between TM 1986 and MSS 1976 was made and forest cover changes in the *Boswellia papyrifera* stands for the period 1976-1986 and 1986-2005 were evaluated. In all images, barren land, evergreen vegetation and deciduous forests cover classes are detectable, but For MSS imagery, due to low geometric resolution, shrubs and grass classes are difficult to be classified. But after enhancement of the image by using principal component analysis (PCA), it became possible to identify the above mentioned class, as shown in Table 3. Tables 4 and 5, show the changed areas for each class both positive and negative.

During the period of 1976-1986, the *Boswellia* class seems to have increased by 7.7%. This may be due to the change in climate and modifications in the site, as *Boswellia* prefers comparatively drier sites but during the period of 1986-2005 there was a reduction in the *Boswellia* class by 22%, detected as Sudan experienced severe drought during the 1980s, which significantly affected most of the vegetation cover.

On the other hand, the site became more favorable for the growth of *Acacia* sp., which seems to dominate the area within a short time. This argument is supported also by the results of field survey. The increase in *Acacia* species class for the period 1976-1986 was 13 %, while for the period 1986-2005 it was 7%, but the actual increase is supposed to be higher than 7% for the last period.

This may be due to some mix between *Acacia* species class and shrubs class, as the later showed an increase by 1.5 % for the period of 1976-1986 and 10% for the period of 1986-2005.

However, *Combretum* species class showed continuous decrease, together with *Boswellia* class, due to climatic changes, over exploitation, clearance for agricultural purposes and due to other physical and biological factors. Most of *Boswellia* and *Combretum* areas were converted to *Acacias* and Shrub classes and the rest had denuded bare land. Increase in the bare land for the period of 1986-2005 was about 4%. The plantation class was more or less in a balance. However, the direction and magnitude of these changes were shown in the change matrices' in Tables 6 and 7.

Table 6. MSS 1976 and TM 1986 change matrix

MSS 1976	TM 1986						Total 1976
	Boswellia	**Bare land**	**Plantation**	**Shrub**	**Acacia**	**Combretum**	
Boswellia	**1536.21**	39.23	0.41	230.19	1094.59	285.83	**3186.46**
Bare land	5.69	**25.59**	3.57	4.55	27.45	36.15	**103**
Plantation	3.74	6.99	**154.25**	0.81	7.31	83.09	**256.19**
Shrubs*	-	-	-	-	-	-	-
Acacias	372.74	70.83	45.49	**158.71**	624.87	235.07	**1507.71**
Combretum	1773.39	99.91	76.27	255.53	**1543.19**	1678.51	**5426.8**
Total 1986	**3691.77**	**242.55**	**280.00**	**649.79**	**3297.41**	**2318.65**	

* Not possible to be classify

Table 7. T M 1986-ASTER 2005 change matrix

	Bare land	Acacias	Combretum	Boswellia	Shrubs	Plantation	Total 1986
Bare land	**73.40**	77.94	7. 83	39.56	36.99	8.33	**244.04**
Acacias	130.77	**1667.9**	448.56	907.72	94.5	78.12	**3327.57**
Combretum	100.42	695.16	**339.21**	985.14	27.21	195.39	**2342.53**
Boswellia	129.58	1608.95	742.16	**900.05**	63.32	308.05	**3752.11**
Shrubs	62.39	353.93	34.97	77.38	**121.55**	1.643	**651.86**
Plantation	7.61	18.16	9.29	74.86	0.74	**128.84**	**239.46**
Total 2005	**504.17**	**4422.04**	**1582.02**	**2895.16**	**344.31**	**720.37**	

Tables 6 and 7 show the change of areas of certain classes into other classes, while the bold areas are the unchanged ones. In Table 7 for instance, the total area of *Boswellia* class for the period of 1986-2005, was 3752.53 hectares, in 1986, of which 129.58 hectares were changed to bare land, 1608.95 hectares to *Acacias* class, 742.16 hectares to *Combretum* class, 63.23 hectares to shrubs and grass, 308.05 hectares to plantation, while 900.05 hectares of *Boswellia* were unchanged. In 2005 the total area of *Boswellia* was 2895.16 hectares and the remained area from 1986 was only 900.05 ha, so the additional area of 1995.11 was due to the change of other classes to *Boswellia* class, 39.56 hectares bare land, 907.72 hectares *Acacias*, 985.14 hectares *Combretum*, 77.38 hectares shrubs and grass and 74.86 hectares plantation. The total changed and unchanged areas are shown in figures 6 and 7. The calculated overall accuracies for classified images of TM 1986 and ASTER 2005 are 98.5% and 96.4% respectively Tables 8 and 9. This indicate how well the information extracted from these areas can be used to categorize the area. They also mean that the training areas are homogenous, the training classes are spectrally separable and the classification strategy being employed works well in the training areas. The so high accuracies are due to the knowledge and familiarity with the geographical region and the ability to develop and generate good training sites and signatures after repeated classification trials.

Table 8. Error matrix for TM 1986 (Accuracy assessment).

Class Name	Reference or column total	Classified or raw total	Number Correct	Producers Accuracy	Users Accuracy
Boswellia	539	525	525	97.4%	**100%**
Plantation	345	340	338	98%	**99.4%**
Combretum	307	319	305	99.3%	**95.6%**
Bare land	100	108	100	100%	**92.6%**
Acacias	319	315	313	98.1%	**99.4%**
Shrubs and	276	279	276	100%	**98.9%**
Column total	**1886**	**1886**	**1857**		**Overall 98.5 %**

Table 9. Error matrix for ASTER 2005

Class Name	Reference or column total	Classified or raw total	Number Correct	Producers Accuracy %	Users Accuracy %
Bare land	348	358	346	99.4	**96.6**
Boswellia	395	358	347	87.8	**96.9**
Plantation	1132	1133	1131	99.9	**99.8**
Combretum	375	392	375	100	**95.7**
Shrubs and	120	129	115	95.8	**89.1**
Acacias	437	437	392	89.7	**89.7**
Total	**2807**	**2807**	**2706**		**Overall =96.4%**

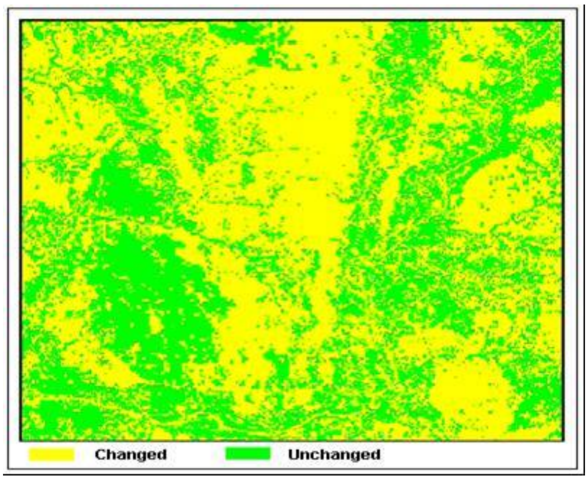

Figure 7. Change map 1976-1986

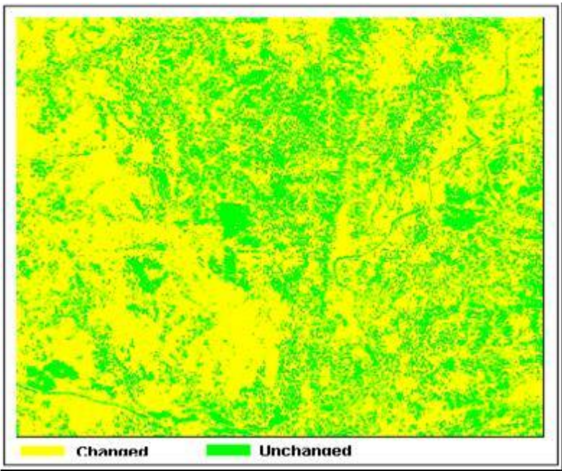

Figure 8. Change map 1986-2005

Conclusions

From the results of the assessment of the forest cover changes of *Boswellia papyrifera* stands during the periods between 1976-1986 and 1986- 2005, using post-classification comparison approach, we can conclude that significant change has been detected due to the natural and human induced factors.

Useful and cost effective information of considerably large forest areas can be obtained by the use of remote sensing technique for proper planning and sustainable management.

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