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# Quantifying the Historical Development of Abugadaf Natural Forest Using GIS-Remote Sensing Analytical Techniques/ Blue Nile State/Sudan

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**ABSTRACT:** *The main objective of this research is to provide current information about the growth and general status of Abugadaf natural forest reserve in Blue Nile State, Sudan, and to identify the possible agents and factors that contributed to the current forest status whether positive or negative. The secondary objective of the study is assess and demonstrate the capabilities of RS and GIS analytical tools in addressing the issue of monitoring and assessing natural forest areas in Sudan. Four satellite images covering the period1990, 2000, 2010 and 2018 were selected from cloud-free Land-Sat (TM, ETM and Land-Sat 8) covering the study area. All images were false color composite (FCC). Images 1990 and 2000 were thematic mapper (TM), while Image 2010 was enhanced Thematic Mapper (ETM), and image 2018 was Land-sat 8. Land-sat 8 was used as a base to assess the change detection, and GPS data used to extracts topographic information in the study areaThe tentative locations of the Land cover and land use sites were selected using image analysis aided by actual ground surveying. GPS (Garmin 62C) was used to navigate among check samples and to record the coordinates (X, Y and Z values) of all samples. The total number of samples covering the study area were 144 (800 x 400 m). The recorded data in each sample include tree species, regeneration, grass type, tree stumps, dead trees, density of survival trees, diameter at breast height, and total tree height. All training sites were utilized in the generation of signatures required for supervised maximum likelihood classification. Supervised maximum likelihood classifier used the Gaussian threshold stored in each class signature to determine if a given pixel fell within class or not. The study with the help of remote sensing facilities has succeeded to highlight the condition and development of the study area during the period 1990 – 2018. The study concluded that although there were some fluctuations in the amount of annual rainfall in the area, there are no enough evidences to support their direct effect on the growth of vegetation cover. The study also indicated that the availability of other vegetation cover, such as grasses, in the forest can reduce the pressure on mature forest tress and seedlings caused by domestic animal herders. In the last decade of the study period, the decrease* *of forest cover is mostly associated with decrease or absence of vegetation cover as in that case forest trees and young seedlings become the main source of animal feeding. If other forest destruction agents are added due to the absence of management control, the present forest will disappear within the coming five years.*

**KEYWORD:** Forest assessment, monitoring land cover, land use, Illicit cutting, commercial forest utilization, remote sensing, GIS

## INTRODUCTION

Any natural forest is usually assumed to be in its natural balance unless affected by abnormal external factors. These factors are mostly due to the interference of man either directly through overcutting or indirectly through his domestic animals, especially the goats which feed on seedlings and sapling of trees. The villagers who assumed to be the usual neighbors of these natural forests are considered to have no negative effects unless shift from domestic use to commercial exploitation of forest trees. The domestic forest utilization by these villagers is in most cases within the range of few weekly bundles of dead wood and occasional some branches for building or renewing their simple huts and thorny hedges, in addition to some medicinal roots or bark of some selected tree species. The issue becomes different if they think to utilize these type of forests for commercial purposes. In such cases, especially in Sudan, no forest will be able to exist for more than two to three years. The usual commercial exploitation of natural forest in Sudan is either in form of fire wood for brick kilns and traditional bread bakeries or conversion to charcoal. Such practices had led to disappearance of millions of natural forest hectares in some areas such as Darfur and Blue Nile States.

These affected areas in Sudan in the recent decades were usually associated with the camps of displaced Sudanese citizens or refugees from neighboring countries due tribal conflicts or internal wars. The reasons for such association can be connected to three facts. The first one is placement of such camps in remote areas close to natural forests away from towns or large villages for easy control and/or security reasons. The second reason is that the NGOs and other aid donors usually provide only food items to these peoples without any alternative means for cooking other than firewood. In addition, such people are also in need for some cash money to cover their other leaving needs in which case the trading in forest products will be the only available and free alternative(Osman, et al, 2018).

Other important fact in this issue is that the official forest authorities, whether national or local, pay very little attention to natural forests compared to plantation forests, partly because they do not have enough patrolling facilities and partly due to poor income that could be gained due to bad quality and expensive transportation cost (Hamed et al, 2022).

In order to stop what is going on and to rehabilitate natural forests of Sudan, we should first know the quantity and quality of what is now available on the ground, in addition to the rate of change, whether negative or positive, and the possible causal agents. These objectives can only be achieved by monitoring for quite long period through series of repeated measurements and analysis that might not be financially justifiable considering the poor financial outcomes from these forests, unless we consider the other intangible forest benefits.

The conventional forest inventory techniques using ground surveying and forest menstruation techniques are both expensive, time consuming and inaccurate (Osman, et al, 2018). Remote sensing (RS) and geographical information system (GIS) analytical techniques can provide good and cheap alternative to gap such weaknesses. However, analysis using RS and GIS alone can only provide the quantitative forest cover changes along any selected monitoring period without accurately telling the reasons for such changes. Some ground witnesses are needed to consolidate any proposed hypothetical reasons.These include measuring quantitative tree variables of some sample trees, observing and counting the presence of tree stumps, quantifying the abundance of tree species seedlings and saplings, presence of any signs for forest fires, the type and quantity of grazing animals, in addition to the observation of some elders in the area concerning historical tree species in the forest. The main tasks of RS and GIS techniques in such equation are to provide frequent, cheaper and accurate information of mapping and calculation of large forest areas. Change detection is an important process in monitoring and managing natural resources and urban development because it provides a quantitative analysis of the spatial distribution of the population of interest (Hamed et al, 2022). The remote sensing and GIS techniques were widely used in Sudan for as monitoring, assessing and mapping the status af all terrestrial resources beside estimation of desertification processes and some bio-physical properties of soils e.g., (Ali *et al. 2012;* Edris, *et al. 2013;* Biro, *et al. 2013*; Ibrahim, *et al. 2013*; Adam, *et al. 2014;* Abdelwahab, *et al. 2014*; Fadl, *et al. 2014*; Ibrahim, *et al. 2014*; Mohammedzain, *et. al. 2015*; Elhaja, *et al. 2017;* Abuzeid, *et al. 2017;* Elhag, *et al. 2018;* Ibrahim, *et al. 2018;* Hamed*, et al. 2022).*

The main objective of this research is to provide current information about the growth and general status of Abugadaf natural forest reserve in Blue Nile State, Sudan, and to identify the possible factors and agents that contributed to the current forest status whether positive or negative. The secondary objective of the study is to demonstrate the capabilities of RS and GIS analytical techniques in addressing the issue of monitoring and assessing natural forest areas in Sudan. Specifically, the study intended to investigate, classify and map the rate of growth development in the forest through the integration of RS=GIS technology and other ground assessment techniques. This will be achieved through survey (fieldwork sampling) and satellite image interpretation utilizing a time series analysis based on historical Land-Sat data from 1990, 2000, 2010 and 2018.

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## MATERIAL AND METHODS

### Material

#### Study area

Abugadaf natural forest reserve is located in the Blue Nile State, which is located at the southeastern part of the Sudan. It lies between latitudes 9.30 and 12.30 N and longitudes 35.3 and 33.5 E., with a total area of 40000 $km^2$(UNDP, 2010). The State is bordered by Ethiopia from the east and southeast, South Sudan from the west and south, and Sinnar State from the north. The State lies in the fertile woodland savannah belt of eastern Sudan, and receives significant rainfall through the year. It is characterized by vast clay plains, the Ingessana Mountains and the Blue Nile River that flows northwest from the Ethiopian highlands.

Abugadaf Natural Forest Reserve is located at about 71 km south east of El-Damazin town between the longitude 34.85 and 34.89 E and latitude of 11.43 and 11.44 N. The study area lies exactly at Land Sat the path 173 and row 52 (Figure 1).The total area of the forest is approximately 10900.4 feddan (4542 ha), with about 27.3km of external boundary used as fire line. The forest was reserved in 1995 and declared as government forest reserve. It has no administrative divisions but managed as one unit, with a general objective of preserving biodiversity of the area. The forest hosts large number of different tree species dominated mainly by*Anogeisus leiocarpus, Balanites aegyptiaca, Lannea fruticosa, Combretum hartmannianum, Boswellia papyrifera* and *Sterculia setigera.* The forest is surrounded by many villages with different tribes practicing traditional subsistence agriculture and domestic animal rearing.

The climate of the study area is typical of the high rainfall Woodland Savannah. The average rainfall between 750 mm and 1200 mm, it starts in May and reaches peak in August and ends in October. The relative annual humidity is between 60 – 65% and the average annual temperature range between 35-40 $C^o$.The area is characterized by the presence of various soil types, mainly the heavy cracking clay with dark grey or dark brown color. All surface layers are alkaline used for growing various crops, trees and as pasture land. The newly developed soils, hill and mountain soils and reservoir basin soil are suitable for a variety of investments in crop and animal production. The area also supports a rich diversity of flora and fauna. Over 50 species of birds have been identified in the area including migratory species.

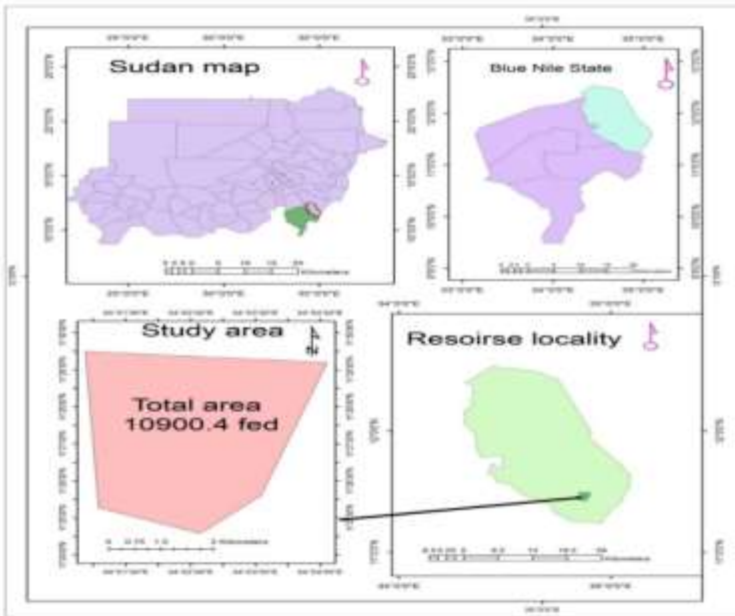


**Figure 1: location of the study area**

**2.1.2 Remote sensing Data:**

Four satellite images covering the period1990, 2000, 2010 and 2018 were selected from cloud-free Land-Sat (TM, ETM and Land-Sat 8) covering the study area. All images were false color composite (FCC). Images1990 and 2000 were thematic mapper (TM), while Image 2010 was enhanced Thematic Mapper (ETM), and image 2018 was Land-sat 8.Land-sat 8 was used as a base to assess the change detection, and GPS data used to extracts topographic information in the study area (Table 1).

**Table 1: Satellite image Characteristics**

| Image | Path/Row | Sensor | Band | Resolution | Area ($km^2$) |
|---|---|---|---|---|---|
| 1 | 173/52 | TM | 1-7 | 30 M | 185×185 |
| 2 | 173/52 | TM | 1-7 | 30 M | 185×185 |
| 3 | 173/52 | ETM | 1- 7 | 30M | 185×185 |
| 4 | 173/52 | Land-Sat 8 | 1 - 8 | 30&15M | 185×185 |

Source: WWW.earthexplorer.USGS.GOV

**Method**

**Pre field work**

This stage started with entering the coordinates of the study area boundaries into GPS system. These coordinates were then transferred to the appropriate geo-referenced satellite image. A rectangular grid was set at spacing of 800 min north to south direction and 400 m in east to west direction with a map scale of 1:200,000 (Figure 2). Land cover and Land use were later checked, described and tentatively classified at the intersections of the grid points. A sample map was compiled using the point coordinate to select the best gridline crossing all the features. Land cover map 2010, 2018, satellite images and topographic sheet of the area study were used to locate the area.


**Figure 2: Sampling Map of the study area**

**Field work:**

The tentative locations of the Land cover and land use sites were selected using image analysis aided by actual ground surveying. GPS (Garmin 62C) was used to navigate among check samples and to record the coordinates (X, Y and Z values) of all samples. The total number of samples covering the study area were 144 sample (800 x 400m). The recorded data in each sample include tree species, regeneration, grass type, tree stumps, dead trees, density of survival trees, diameter at breast height, and total tree height. For soil analysis, 144 auger samples (0.5 kg) were collected from the surface (depth 0 -30 cm) and kept in properly labeled plastic bags. The main types of soil found in the study area were crack Clay soil, Sandy Soil and rocky area.

**Software and Hardware:**

**a- Remote sensing Software**

The following set of RS software were used:

I. Erdas imagine 8.5 and 14 advanced software were used for image processing and analysis.

II. LCCS -Land cover classes are defined by a string of classifiers, but due to the heterogeneity of land cover, and with the aim of achieving a logical and functional hierarchical arrangement of the classifiers, certain design criteria have been applied. The Land Cover Classification System (LCCS 2004) has been designed.

**GIS Software**

GIS Software used for this study was for data analysis, Geo-statistics analysis and final production of maps. The software used were:

I. ArcGIS 10.3 advanced software used for data input, data analysis, management, manipulation and final production of maps.
II. Geo-statistics analysis Software: Arc GIS 10.3 used for Geo-statistics analysis of the survey data.
III. Others software:

Photo shop software used for Images and photos manipulation, Google Earth and Earth map, SURFER32 for surface and contour maps, Geocalc software to transform from geographical to projection or from UTM to degrees and Garmin GPS.

**Inventory and Soil hardware:**

Tree Caliper, Diameter Tape, Sunnto clinometers and measuring tape were used to determine tree variables. pH Meters, Ec Meter, Soil Hydrometer, oven, measuring cylinder, Auger, sensitive balance, flame photometer, thermometer and measuring tape were used to collect and determine Soil properties in the field and laboratory.

**Remote Sensing and GIS Methods:**

Remotely sensed data produced by Land-Sat (TM, ETM+ and Land-sat8), were visually interpreted using the facilities of image interpretation. Changes in land cover, land use, were detected and different maps were generated. The following steps were followed during the process of data processing.

**Data acquisition**

Complete review of the availability of Land-Sat images dataset in the NRL repository was checked and updated. Free-cloud images covering years 1990, 2000, 2010 and 2018 were selected from USGS website, and the band composite (Red, IR and G) appropriate for land cover were prepared.

**Image processing:**

Pre-processing consisted of sequential operations, including: atmospheric correction or normalization, image registration, and masking (e.g., for cloud, water, irrelevant features) (Coppin and Bauer, 1996). All the images were geometrically co-registered to the rectified ETM+2018 (UTM north zone 36). Geo-referencing was achieved by selecting and applying ground control points (GCPs). Nearest-neighbor re-sampling technique was used. The root mean square (RMS) error of geo-referencing was approximately 0.5 pixels. Subsets of the study area were selected. Effective classification of remote sensing image data depending upon separating land cover types of interest into sets of spectral classes (signatures) that represented the data in a form suited to the particular classifier algorithm was used (Richard and Kelly, 1984). Supervised classification involved the initial selection of areas (training sites) on the image which represented specific land classes to be mapped, (Robinove, 1981). All training sites were utilized in the generation of signatures required for supervised maximum likelihood classification. Supervised maximum likelihood classifier used the Gaussian threshold stored in each class signature to determine if a given pixel fell within class or not.

**Image classification**

1. **Unsupervised classification:**
   In this study Unsupervised Classification were used to create general map for the fieldwork and to minimize the classes of study area.
2. **Supervised classification**
   This technique and signature editors with the data collected from the field were used to classify the study area to different sets and create the type of classes.

**Post classification approach:**

Change detection was done through the following sequence of steps:

1. **Map Calculations:**
   Quantity assessment of land degradation and land-use change was performed through map calculation option. Map calculation was also used to calculate the occurrence and extent of changes on land surface during the period of study (1990 - 2018).

**Interpolation:**

This is a method of constructing new data points from a discrete set of known data points, In engineering and science one often has a number of data points, as obtained by sampling or experiment, and tries to construct a function which closely fits those data points. This is called curve fitting or regression analysis. Interpolation is a specific case of curve fitting, in which the function must go exactly through the data points.

## RESULTS AND DISCUSSION

Tables 2 -7 and figures 2 – 6 present the results of the study for the period 1990 to 2018. The existence, composition structure and frequency of tree species in natural stands depend on different dynamic factors that influence tree regeneration, growth, vertical profile characteristics and adaptability to the conditions within any site (Lampricht, 1989). The dynamic changes of tree growth parameters is a long term process which require investigations on trees species composition

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and densities per unit area in addition to dominance, frequencies, vertical profile, coverage and the interaction of these components with the ecological and social components.

An important aspect related to the vertical distribution of tree size classes is the diameter, total tree height and crown diameter distribution. They indicate the status of sustainable development and balance of size classes across the vertical structure of the species. Table 3 shows the distribution of the diameter of all species along the diameter classes in the study area, in which 31 species were recorded. *Combretum hartimanium* (Habeel), *lanea fruiticosa* and *anogeisus leiocarpus* respectively are the most relatively frequently distributed, being found in all sample plots.

The soil characteristic represents the origin that affects the tree species composition, tree structure and height layering above ground that give a picture about the temporal development of trees during their lifetime. Rainfall plays importance role in forest initiation and sustainability of forest. Rain is the main factor that helps in seed germination and seedling growth (Fig. 3).

The challenge in digital change analysis techniques is the ability of the existing systems to automatically determine, within specific time intervals whether there is change or not, and to locate the spatial distributions and the extent of the change as well as to quantify the trend and magnitude of the dynamics precisely. The surveys and investigations permitted calculation of a series of characteristic parameters including dominance, frequencies and abundance of tree species, Table 4 shows the dynamic characteristic of species inventoried in the study area (mature and sapling trees) presented as, relative (abundance, dominance and frequency). It is measured as absolute number of individuals per species and as relative abundance expressed in percentage of each species of the total number of all species. It is synonymous to abundance of a species.

**Vegetation covers.**

**Tree-size distribution**

The forest stands analysis (Table 3) showed high variation in terms of species composition in which 31 tree species are found with high percentage of *Combretum hartimanium.* Specifically in the north part of the study area and represents about 25 % of the total stems in the forest. In the other sites the dominant trees are *Anogeisus leiocarpus* (18 %) followed by *Lanea fruitcosa (*18 %). These results reveal that although these three tree species constitute about 61 % of the total number of trees in the forest, their maximum average dbh is less than 25 cm. On the other hand, the largest tree dbh in the study area were found to be between 45 cm to 50 cm. This group constitutes either tree species unsuitable for any domestic use (Ficus religiosa and Sterculia africana) or trees considered as holy species (Taboo) in the local communities (Tamarindus indica). Such variation in tree size class reflects distance variables (human impact).The tree species diversity was explained more strongly by local topographic variables (Tables 3). This fact agrees with previous studies that found strong correlations between the patterns of plant richness and climate (Francis and Currie 2003; O'Brien 1998).

**Vegetation Dynamic**

The occurrence of different tree species in the study area may be assumed to be a function of area characteristics such as soil, and social interventions (Seidahmed 2004). From this study, it was very clear that tree species increase from south toward the north. Damage done by human activities and environmental conditions, such as droughts, rains and hurricane winds the frequency and intensity of fires and insect pests are expected to affect species growth, while survival depends for a large part on climate variables. The results in Tables 4 agree with the findings of Lamprecht (1989) who stated that combination of high abundances and high frequencies characterize species with a regular horizontal distribution. On the other hand, species with low abundance and low frequencies are the rare species that characterize this combination and mostly have economic importance to the communities. Their importance varies with the type of uses and services they provide. In the present study, the percentage of seedlings was found to be high in areas with high number of species, mainly for *Anogeisus leiocarpus, Balanites aegyptiaca* and *Ziziphus spina –Christi*. The last two tree species mentioned above have edible fruit preferred by most grazing animals, such as sheep and goats, and that helps in their distribution all over the forest. On the other hand, low percentages of seedlings was found in the species of Acacia *Seyal Var seyal* followed by *Acacia Senegal* due to harsh environmental condition such as fluctuation in rainfall. This result also agrees with those of Bradshaw *et al*. (2000) and Good & Good (1972). According to them, the regeneration phase is a critical life stage for species in which changes in climatic controls hinder or enhance a species response to change. Other factor that can affect the availability of seedlings for these two species is that they are very palatable to browsing animals such as goats which are considered as the main enemy of tree seedlings. Acacia seyal is also one of tree species that produces class one quality charcoal which makes it the first target for illicit cutting.

Forest degradation is detected more in south part of the study area. This may be attributed to the fact that, several villages are located near the study area and is therefore vulnerable to overcutting as the majority of the populations rely heavily on firewood. People living in these villages derive their income from various combinations of the three main forms of land use: crop cultivation, animal rearing, and forest exploitation, without adoption of any measure to combat land degradation

**Land covers change detection**

The results shown in Tables 6 and 7 clearly indicate that during the first period 1990 – 2000, forest cover and vegetation covers have increased by about 32 % and 5 % respectively, while, accordingly, bare soil and bare rock have decreased in area (45 % and 16 %). The increase in vegetation cover in this period could be attributed to the high rainfall of the year 1999 (Fig, 3), which might not be the case for the forest cover that depend on accumulation of growth and other complicated factors.

In the period 2000 – 2010 the forest cover decreased by about 75 %, while vegetation, bare rock and bare soil have increased in area by about 151 %, 15 % and 7 % respectively. The decrease in forest area and increase in vegetation area in the same period may reject the effect of overgrazing or fire destruction and puts heavy weight on the assumption of illicit tree felling for firewood or charcoal production.

The third period 2010 – 2018 witnessed further destruction of forest cover (31 %) and vegetation cover (47 %), which obviously met by an increase in bare rock cover (10 %) and bare soil cover (167 %). According to Figure 3, the study area received relatively low amount of rainfall (less than 120 mm) that affected the growth of plant cover. As a result it is expected that there was no enough pasture for the grazing animals, a condition that may encourage herders to chop tree branches or cut small trees to feed their animals. Such condition might be aggravated by felling trees for production of firewood and charcoal in addition to the other domestic uses of wood.

The overall trend of the land cover change (Table 7 and Figure 6) indicate that during the study period of 28 years (1990 – 2018) about 78 % of forest cover and 35 % of vegetation cover were lost for bare soil and bare rock. This indicates that the average rate of forest destruction was about 3 % per year. This could be logical, but not accepted, for other nearby natural forests in the area and not for reserved government forest under full control of forest authorities. It is quite clear that there is no management plans for such types of forest and/or no available human and logistical support for control or rehabilitation.

**Table 2: Forest Stand Table**

| Trees | DBH(m) | | | Height(m) | | | BA/t ($m^2$) | | | BA/h | Tree volume($m^3$) | | | V/h | D/h |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SE | CV% | Mean | SE | CV% | Mean | SE | CV% | | Mean | SE | CV% | | |
| *Acacia Senegal* | | | | | | | | | | | | | | | |
| 340.00 | 0.15 | 0.00 | 32.44 | 9.05 | 0.10 | 25.10 | 0.02 | 0.00 | 66.24 | 0.03 | 0.10 | 0.00 | 0.12 | 0.16 | 1.54 |
| *Acacia seyal var seyal* | | | | | | | | | | | | | | | |
| 287.00 | 0.17 | 0.00 | 29.40 | 10.13 | 0.17 | 29.70 | 0.03 | 0.00 | 58.40 | 0.03 | 0.14 | 0.00 | 58.40 | 0.18 | 1.30 |
| *Acacia sieberana* | | | | | | | | | | | | | | | |
| 7.00 | 0.30 | 0.04 | 39.00 | 12.83 | 0.72 | 14.80 | 0.08 | 0.02 | 81.90 | 0.00 | 0.56 | 0.18 | 81.90 | 0.02 | 0.03 |
| *Adansonia digitata* | | | | | | | | | | | | | | | |
| 8.00 | 0.41 | 0.05 | 32.90 | 11.30 | 1.34 | 33.60 | 0.15 | 0.03 | 56.70 | 0.01 | 1.09 | 0.22 | 56.70 | 0.04 | 0.04 |
| *Aegle marmelos* | | | | | | | | | | | | | | | |
| 2.00 | 0.19 | 0.05 | 40.00 | NA | NA | NA | 0.03 | 0.02 | 74.00 | 0.00 | 0.21 | 0.11 | 74.00 | 0.00 | 0.01 |
| *Albizia amara* | | | | | | | | | | | | | | | |
| 6.00 | 0.22 | 0.03 | 29.00 | NA | NA | NA | 0.04 | 0.01 | 46.80 | 0.00 | 0.27 | 0.05 | 46.80 | 0.01 | 0.03 |
| *Anogeisus leiocarpus* | | | | | | | | | | | | | | | |
| 1868.00 | 0.24 | 0.00 | 45.30 | 12.54 | 0.09 | 31.30 | 0.05 | 0.00 | 97.83 | 0.46 | 0.38 | 0.01 | 97.83 | 3.22 | 8.44 |
| *Balanites aegyptiaca* | | | | | | | | | | | | | | | |
| 955.00 | 0.22 | 0.00 | 45.21 | 11.64 | 0.12 | 30.66 | 0.05 | 0.00 | 93.98 | 0.19 | 0.29 | 0.01 | 93.98 | 1.27 | 4.32 |

DBH (m)≡ Diameter at Breast Height, BA/t ≡ Basal Area/tree, BA/h ≡ Basal Area/hectare, V/h ≡ Volume/hectare, D/h=Density/hectare, NA ≡ Not Available, SE ≡ Standard error and CV% ≡ Coefficient of Variation

**Table 3: (con…) Forest Stand Table**

| Trees | DBH(m) | | | Height(m) | | | BA/t ($m^2$) | | | BA/h | Tree volume($m^3$) | | | V/h | D/h |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SE | CV% | Mean | SE | CV% | Mean | SE | CV% | | Mean | SE | CV% | | |
| *Bauhinia rufesens* | | | | | | | | | | | | | | | |
| 9 | 0.129 | 0.012 | 28.700 | NA | NA | NA | 0.014 | 0.003 | 54.090 | 0.001 | 0.095 | 0.017 | 54.090 | 0.004 | 0.04 |
| *Bombax coslatum* | | | | | | | | | | | | | | | |
| 8 | 0.198 | 0.012 | 17.680 | NA | NA | NA | 0.032 | 0.004 | 33.590 | 0.001 | 0.214 | 0.025 | 33.590 | 0.001 | 0.04 |
| *Boswellia papyrifera* | | | | | | | | | | | | | | | |
| 487 | 0.297 | 0.004 | 29.690 | 11.870 | 0.153 | 28.440 | 0.075 | 0.002 | 62.190 | 0.166 | 0.500 | 0.014 | 62.190 | 1.100 | 2.20 |
| *Combretum adenogoniam* | | | | | | | | | | | | | | | |
| 7 | 0.110 | 0.005 | 11.400 | NA | NA | NA | 0.009 | 0.001 | 22.830 | 0.000 | 0.065 | 0.006 | 22.830 | 0.002 | 0.03 |
| *Combretum hartmannianum* | | | | | | | | | | | | | | | |
| 2691 | 0.201 | 0.002 | 46.430 | 12.310 | 0.072 | 30.420 | 0.039 | 0.001 | 99.360 | 0.470 | 0.266 | 0.005 | 99.364 | 3.241 | 12.17 |
| *Dalbergia melanoxylon* | | | | | | | | | | | | | | | |
| 211 | 0.148 | 0.004 | 36.960 | 10.090 | 0.149 | 21.390 | 0.019 | 0.001 | 77.724 | 0.019 | 0.110 | 0.006 | 77.724 | 0.105 | 0.95 |
| *Dichrostachy scinerea* | | | | | | | | | | | | | | | |
| 449 | 0.124 | 0.002 | 35.120 | 9.986 | 0.100 | 21.260 | 0.014 | 0.001 | 80.192 | 0.028 | 0.076 | 0.003 | 80.192 | 0.155 | 2.03 |
| *Diospyros mespiliformis* | | | | | | | | | | | | | | | |
| 26 | 0.225 | 0.018 | 41.160 | 16.750 | 0.208 | 6.332 | 0.046 | 0.007 | 79.534 | 0.005 | 0.434 | 0.068 | 79.534 | 0.051 | 0.12 |
| *Ficus microcarpa* | | | | | | | | | | | | | | | |
| 38 | 0.521 | 0.036 | 43.050 | 14.490 | 0.522 | 22.210 | 0.252 | 0.033 | 79.934 | 0.043 | 2.047 | 0.265 | 79.934 | 0.352 | 0.17 |

**Table 3: (con…) Forest Stand Table**

| Trees | DBH(m) | | | Height(m) | | | BA/t ($m^2$) | | | BA/h | Tree volume($m^3$) | | | V/h | D/h |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SE | CV% | Mean | SE | CV% | Mean | SE | CV% | | Mean | SE | CV% | | |
| *Ficus religiosa* | | | | | | | | | | | | | | | |
| 2 | 0.480 | 0.040 | 11.790 | NA | NA | NA | 0.182 | 0.030 | 23.408 | 0.002 | 1.235 | 0.204 | 23.408 | 0.011 | 0.01 |
| *Hyphaene thebaica* | | | | | | | | | | | | | | | |
| 73 | 0.322 | 0.008 | 22.310 | 10.990 | 0.547 | 42.500 | 0.085 | 0.004 | 44.323 | 0.028 | 0.525 | 0.027 | 44.323 | 0.173 | 0.33 |
| *Lanchocarpus laxiflorus* | | | | | | | | | | | | | | | |
| 291 | 0.212 | 0.005 | 40.100 | 10.650 | 0.214 | 34.250 | 0.041 | 0.002 | 95.569 | 0.054 | 0.244 | 0.014 | 95.569 | 0.321 | 1.32 |
| *Lannea fruticosa* | | | | | | | | | | | | | | | |
| 1905 | 0.202 | 0.002 | 37.880 | 11.600 | 0.078 | 29.460 | 0.037 | 0.001 | 94.622 | 0.316 | 0.238 | 0.005 | 94.622 | 2.050 | 8.61 |
| *Parkinsonia aculeate* | | | | | | | | | | | | | | | |
| 8 | 0.143 | 0.010 | 19.390 | NA | NA | NA | 0.017 | 0.002 | 36.799 | 0.001 | 0.112 | 0.015 | 36.799 | 0.004 | 0.04 |
| *Pterocarpus lucens* | | | | | | | | | | | | | | | |
| 217 | 0.311 | 0.009 | 42.320 | 12.530 | 0.257 | 30.190 | 0.089 | 0.005 | 81.000 | 0.088 | 0.625 | 0.034 | 81.000 | 0.613 | 0.98 |
| *Sterculia Africana* | | | | | | | | | | | | | | | |
| 91 | 0.568 | 0.028 | 47.350 | 17.150 | 0.351 | 19.500 | 0.310 | 0.028 | 86.322 | 0.128 | 2.976 | 0.269 | 86.322 | 1.224 | 0.41 |
| *Sterculia setigera* | | | | | | | | | | | | | | | |
| 282 | 0.505 | 0.014 | 45.180 | 13.400 | 0.211 | 26.380 | 0.241 | 0.091 | 84.062 | 0.310 | 1.809 | 0.091 | 84.062 | 2.310 | 1.27 |

**Table 3: (con…) Forest Stand Table**

| Trees | DBH(m) | | | Height(m) | | | BA/t($m^2$) | | | BA/h | Tree volume($m^3$) | | | V/h | D/h |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SE | CV% | Mean | SE | CV% | Mean | SE | CV% | | Mean | SE | CV% | | |
| *Strychnos innoua* | | | | | | | | | | | | | | | |
| 7 | 0.14 | 0.01 | 27.16 | NA | NA | NA | 0.02 | 0.00 | 59.32 | 0.00 | 0.10 | 0.02 | 59.32 | 0.00 | 0.03 |
| *Tamarindus indica* | | | | | | | | | | | | | | | |
| 5 | 0.50 | 0.10 | 42.78 | 10.50 | 0.86 | 18.24 | 0.22 | 0.07 | 65.28 | 0.01 | 1.32 | 0.38 | 65.28 | 0.02 | 0.02 |
| *Terminalia laxifora* | | | | | | | | | | | | | | | |
| 94 | 0.27 | 0.01 | 36.73 | 12.11 | 0.35 | 27.98 | 0.06 | 0.00 | 67.90 | 0.03 | 0.43 | 0.03 | 67.90 | 0.18 | 0.42 |
| *Xeromphis nilotica* | | | | | | | | | | | | | | | |
| 31 | 0.12 | 0.01 | 34.89 | NA | NA | NA | 0.01 | 0.00 | 74.18 | 0.00 | 0.09 | 0.01 | 74.18 | 0.01 | 0.14 |
| *Ziziphus abyssinica* | | | | | | | | | | | | | | | |
| 100 | 0.16 | 0.01 | 39.14 | NA | NA | NA | 0.02 | 0.00 | 81.31 | 0.01 | 0.16 | 0.01 | 81.31 | 0.07 | 0.45 |
| *Ziziphus spina_christi* | | | | | | | | | | | | | | | |
| 148 | 0.14 | 0.00 | 32.35 | NA | NA | NA | 0.02 | 0.00 | 67.39 | 0.01 | 0.12 | 0.01 | 67.39 | 0.08 | 0.67 |

### 3.2 Vegetation Dynamics

**Table 4: Forest Dynamics**

| Species | A | RA | D | RD | F | RF | IV |
|---|---|---|---|---|---|---|---|
| ***Acacia Senegal*** | 0.085 | 3.192 | 0.002 | 1.285 | 0.230 | 4.540 | 9.020 |
| ***Acacia seyal*** | 0.072 | 2.694 | 0.002 | 1.311 | 0.190 | 3.710 | 7.710 |
| ***Acacia sieberana*** | 0.002 | 0.066 | 0.000 | 0.102 | 0.010 | 0.270 | 0.440 |
| ***Adansonia digitata*** | 0.002 | 0.075 | 0.000 | 0.218 | 0.010 | 0.200 | 0.500 |
| ***Aegle marmelos*** | 0.001 | 0.019 | - | - | 0.002 | 0.030 | 0.050 |
| ***Albizia amara*** | 0.002 | 0.056 | - | - | 0.005 | 0.100 | 0.160 |
| ***Anogeisus leiocarpus*** | 0.467 | 17.535 | 0.025 | 18.863 | 0.680 | 13.100 | 49.500 |
| ***Balanites aegyptiaca*** | 0.239 | 8.965 | 0.011 | 7.986 | 0.550 | 10.720 | 27.600 |
| ***Bauhinia rufesens*** | 0.002 | 0.085 | - | - | 0.005 | 0.100 | 0.180 |
| ***Bombax coslatum*** | 0.002 | 0.075 | - | - | 0.001 | 0.030 | 0.100 |
| ***Boswellia papyrifera*** | 0.122 | 4.572 | 0.009 | 6.805 | 0.310 | 6.070 | 17.400 |
| ***Combretum adenogoniam*** | 0.002 | 0.066 | - | - | 0.003 | 0.060 | 0.130 |
| ***Combretum hartmannianum*** | 0.672 | 25.260 | 0.026 | 19.333 | 0.880 | 16.800 | 61.490 |
| ***Dalbergia melanoxylon*** | 0.053 | 1.981 | 0.001 | 0.765 | 0.060 | 1.240 | 3.990 |
| ***Dichrostachy scinerea*** | 0.112 | 4.215 | 0.002 | 1.138 | 0.280 | 5.370 | 10.700 |
| ***Diospyros mespiliformis*** | 0.007 | 0.244 | 0.000 | 0.224 | 0.020 | 0.410 | 0.880 |

A ≡ Abundance, RA ≡ Relative Abundance, D≡ Dominance, RD ≡ Relative Dominance, F ≡ Frequency and RF ≡ Relative Frequency

**Table 4: (Cont...): Forest Dynamics**

| Species | A | RA | D | RD | F | RF | IV |
|---|---|---|---|---|---|---|---|
| *Ficus microcarpus* | 0.010 | 0.357 | 0.002 | 1.782 | 0.030 | 0.720 | 2.800 |
| *Ficus religiosa* | 5E-04 | 0.019 | - | - | 0 | 0.06 | 0.08 |
| *Hyphaene thebaica* | 0.018 | 0.685 | 0.0016 | 1.157 | 0.08 | 1.7 | 3.54 |
| *Lanchocarpus laxiflorus* | 0.073 | 2.732 | 0.003 | 2.212 | 0.17 | 3.33 | 8.27 |
| *Lannea fruticosa* | 0.476 | 17.88 | 0.0175 | 12.98 | 0.74 | 14.2 | 45.15 |
| *Parkinsonia aculeate* | 0.002 | 0.075 | - | - | 0.01 | 0.24 | 0.317 |
| *Pterocarpus lucens* | 0.054 | 2.037 | 0.0048 | 3.602 | 0.15 | 3.01 | 8.65 |
| *Sterculia Africana* | 0.023 | 0.854 | 0.0071 | 5.242 | 0.09 | 1.83 | 7.93 |
| *Sterculia setigera* | 0.071 | 2.647 | 0.017 | 12.64 | 0.25 | 4.85 | 20.14 |
| *Strychnos innoua* | 0.002 | 0.066 | - | - | 0.01 | 0.17 | 0.23 |
| *Tamarindus indica* | 0.001 | 0.047 | 0.0003 | 0.208 | 0 | 0.06 | 0.32 |
| *Terminalia laxifora* | 0.024 | 0.882 | 0.0015 | 1.103 | 0.12 | 2.39 | 4.37 |
| *Xeromphis nilotica* | 0.008 | 0.291 | 0.0001 | 0.076 | 0.02 | 0.48 | 0.85 |
| *Ziziphus abyssinica* | 0.025 | 0.939 | 0.0006 | 0.451 | 0.08 | 1.56 | 2.95 |
| *Ziziphus spina_christi* | 0.037 | 1.389 | 0.0007 | 0.491 | 0.11 | 2.25 | 4.13 |

## 3.3 Environmental factor (Rain fall):

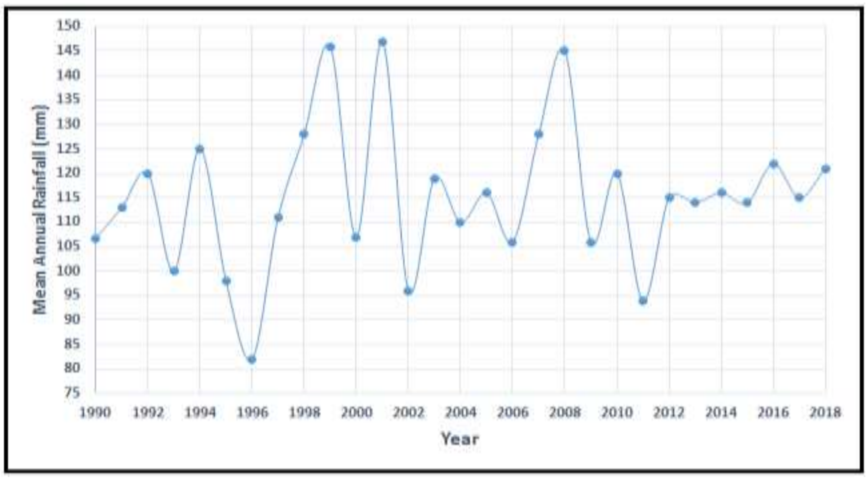


**Figure3: Mean Annual Rainfall**

## 3.4 Land covers classification for year 1990

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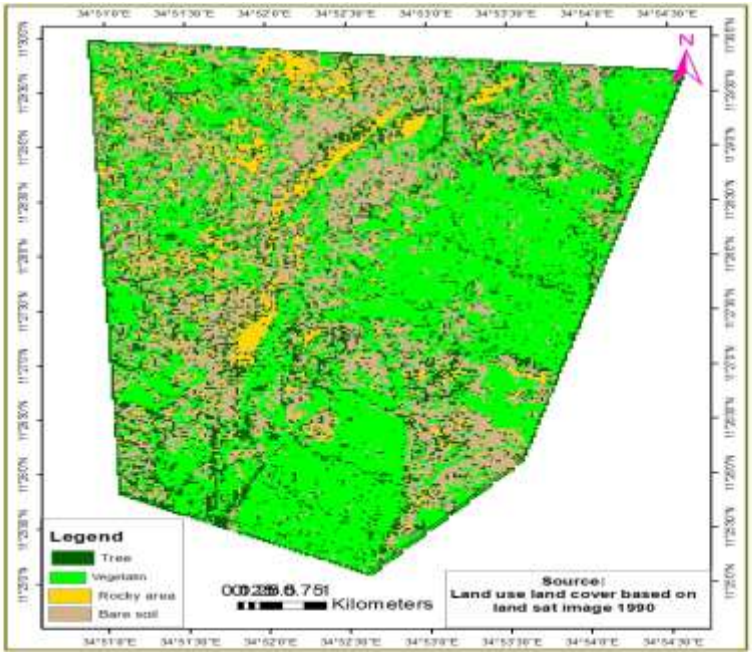


**Figure 4: land covers class year (1990).**

**Table 5: Land use / Land cover Distribution (1990 - 2018)**

| **Classes** | **1990** Area(ha) | Area (%) | **2000** Area(ha) | Area (%) | **2010** Area(ha) | Area (%) | **2018** Area(ha) | Area (%) | **Trend** |
|---|---|---|---|---|---|---|---|---|---|
| Trees | 1347.495 | 29.4 | 1782.978 | 38.9 | 437.3 | 9.55 | 302.4 | 6.60 | (-ve) |
| Bare Rocky | 851.135 | 18.6 | 712.8875 | 15.6 | 1788.3 | 39 | 1973.4 | 43.08 | (-ve) |
| vegetation | 1550.095 | 33.8 | 1626.278 | 35.5 | 1863.31 | 40.79 | 994.41 | 21.71 | (-ve) |
| Bare soil | 831.785 | 18.2 | 458.3675 | 10.00 | 491.6 | 10.7 | 1310.3 | 28.61 | (-ve) |
| Total | 4580.51 | 100 | 4580.51 | 100 % | 4580.51 | 100 | 4580.5 | 100 | |

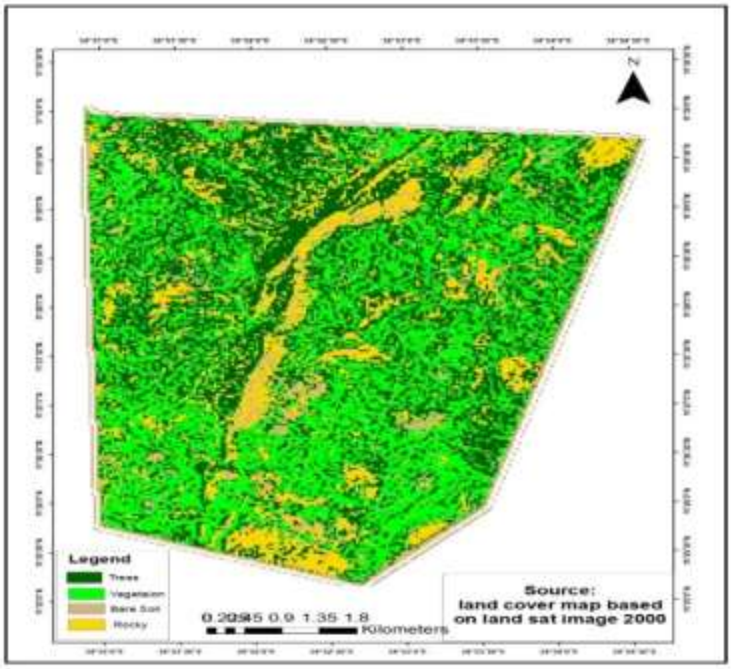


**Figure 5: land covers classification system 2018**

**Change detection**

**Table 6: Periodical change of land cover**

| Land Cover | **1990-2000** | | **2000-2010** | | **2010-2018** | | **1990-2018** | |
|---|---|---|---|---|---|---|---|---|
| | **Change (ha)** | **Change (%)** | **Change (ha)** | **Change (%)** | **Change (ha)** | **Change (%)** | **Change (ha)** | **Change (%)** |
| **Forest** | 435.48 | 32.32 | -1345,68 | -75,47 | -134.90 | -30.85 | -1045.10 | -77.56 |
| **Bare rock** | -138.25 | -16.24 | 1075.41 | 150.85 | 185.10 | 10.35 | 1122.27 | 131.86 |
| **Vegetation** | 76.18 | 4.91 | 237.03 | 14.58 | -868.90 | -46.63 | -555.69 | -35.85 |
| **Bare soil** | -373.42 | -44,89 | 33.23 | 7.25 | 818.70 | 166,54 | 478.52 | 57.53 |
| **Total** | 0 | | 0 | | 0 | | 0 | |

**Table 7:Periodical change of land cover**

| Land Cover | 1990 | 1990 - 2000 | | 1990 - 2010 | | 1990 - 2018 | |
|---|---|---|---|---|---|---|---|
| | Original (ha) | Change (ha) | Change (%) | Change (ha) | Change (%) | Change (ha) | Change (%) |
| **Trees** | 1347.50 | 435.48 | 32.32 | -910.20 | -67.55 | -1045.10 | -77.56 |
| **Bare Rock** | 851.14 | -138.25 | -16.24 | 937.17 | 110.11 | 1122.27 | 131.86 |
| **Vegetation** | 1550.10 | 76.18 | 4.91 | 313.22 | 20.21 | -555.69 | -35.85 |
| **Bare soil** | 831.79 | -373.42 | -44.89 | -340.19 | -40.90 | 478.52 | 57.53 |
| **Total** | 4580.51 | 0 | | 0 | | 0 | |

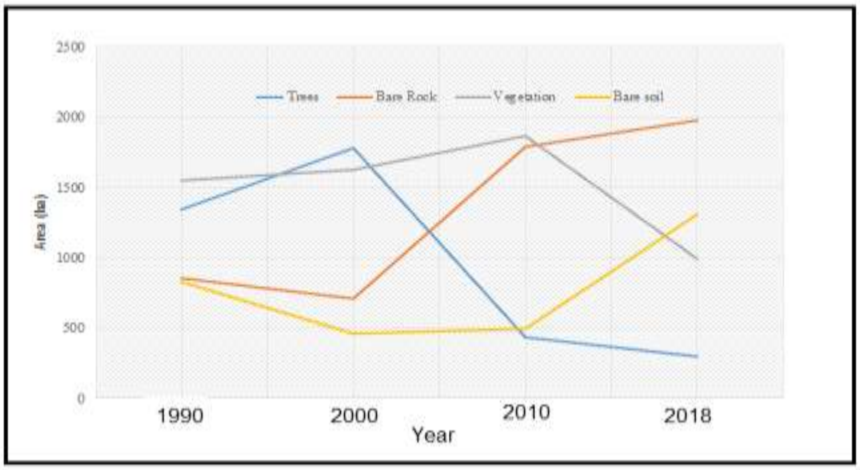


**Figure 6: Trend of land cover Change**

## SUMMARY AND CONCLUSIONS

The study with the help of remote sensing facilities has succeeded to highlight the condition and development of the study area during the period 1990 – 2018 based on the information provided by the type of satellite images and actual field measurements conditions. The study concluded that, although there were some fluctuations in the amount of annual rainfall in the area, there are no enough evidences to support their direct effect on the growth of vegetation cover. The study also indicated that the availability of other vegetation cover, such as grasses, in the forest can reduce the pressure on mature forest tress and seedlings by domestic animal herders. In the last decade of the study period, the decrease of forest cover is mostly associated with decrease or absence of vegetation cover as in that case forest trees and young seedlings become the main source of animal feeding. If other forest destruction agents are added due to the absence of management control, the present forest will disappear within the coming five years.

It is therefore, recommended that similar studies are necessary in such types of forests to avail up to date forest inventory data for managers to support management plans with acceptable costs and periodic flow of information. Exerting full control on such reserved forests will not be possible in the absence of suitable logistic support and the availability of up-to-date forest inventory data. Such type of data could be obtained precisely and regularly with acceptable costusing remote sensing and GIS techniques. New policies and practices of forest extension should be adapted to alert local communities to the threats of land and forested gradation.

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