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The Role of Ecological Factors in Causing Land Surface Desertification, the Case of Sudan

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Authors' contributions

This work was carried out in collaboration between all authors. Author MAAE designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors MSD and ISI managed the literature searches, analyses of the study performed the structural equation modeling and discuss the conclusion. All authors read and approved the final manuscript.

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ABSTRACT

Desertification is a serious socio-economic and environmental disaster that affecting many parts of the world. From eco-geographical view desertification could be defined as decrease in land surface phenology (LSP) caused by biotic and a biotic factors. These factors caused several changes in different geographical locations of the earth planet surface, specifically north and south of desert boundary reported by Harisson and Jakson [1] in Sudan. The aim of this study is to investigate the possible factors related with desertification cause or behind this phenomenon in Sudan. The specific objective is to diagnose the role of biotics and a biotics factors in causing desertification so that recommendation remedy will be given. Using eco-geographical analysis the study revealed that the area in north desert boundary predicted in previous study by Eltoum and Dafalla [2] as risk

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areas was converted in to desert like condition. These changes are continuing and moving south as discovered by Stebbing [3] and suggested by Lampery [4] and Salih [5]. The study concluded that slow onset complex desertification disaster creeping to Sudan. Populations of Sudan may be disappearing within the next 50 years. There for, an urgent need of immediate afforestation program is present.

Keywords: Ecological; land surface; desert creeping; RS; GIS.

1. INTRODUCTION

Desertification is global environmental problem. One fifth of the productive land of the earth planet surface will be desertified with in the coming ten years ONU [6]. The number of people threatened by severe desertification increased three times from 80 in 1977 to 250 million in 2001 [7]. This has an adverse impact on people income, health and livelihood. Described desertification as deterioration of ecosystem in arid, semi arid and dry sub humid regions. The (UNCCD) define Desertification as land degradation in arid, semi- arid and dry sub – humid areas resulting from various factors, including climatic variation and human activities [8]. Land degradation in this definition means reduction or loss, in arid semi arid and dry sub–humid areas, of the biological or economical productivity.

2. LITERATURE REVIEW

2.1 Desertification of the Earth Planet Surface

Land surface desertification of the earth planet surface extended all over the continents. Many set of variables and indicators were used to monitor land surface desertification in the past. After the geo informatics revolution exists, Environmental sensitivity test method was used to produce sensitivity maps of different geo locations of the earth planet surface. According to Izzo [9]. 48.4% of the Dominkan Republic is sensitive to desertification and 16.4% are high sensitive. Recently desertification of Karst rocky in China refer to population growth and un sustainable land use practice [10,11]. Jafari and Bakhshandehmehr [12] use environmental sensitivity method to study desertification in Iran.

2.2 Desertification Phenomena in Sudan

Sudan was subjected to different complex disasters such as drought, desertification, famine, floods, pest infestation conflicts and war [13]. Most of these disasters are triggered by desertification and climate change [14]. Recent researches support the evidence of presence of desert and desert like condition more to the south of the northern border of southern Sudan [15]. Desertification in Sudan was monitored in few spot areas using remote sensing and geographical information system. Stebing [3] use the desert boundary to monitor the encroachment of the Sahara (desert). The desert boundary (response factor) is an artificial boundary that separates the grate Sahara of Africa from the Sudano Sahelian vegetation zone (semi desert area) in Sudan. Due to anthropogenic and climate change, an annual shift was reported by many researchers, Historically, Lampery [4], Salih, [5], Ali and Bauimi, [16], Dafalla, [17], and recently Eltoum and Dafalla, [2]. The annual rate of this shift depends on the rate of change of climatic, biotic and a biotic factors. Understanding this shift is very important in monitor desertification, measure required response to prevent, mitigate and/or stop the desert creeping.

2.3 Eco Geographical Analysis

Eco geographical studies provide information on ecological region; adaption, genetic resources, habitat, distributions and land cover [18], Elements for the analysis includes biotic variables (associated species, co-occurrence with competitors, pest, disease, herbivores and mutualisms), Anthropogenic (landuse) and a biotic variables (climatic, temperature, rainfall, geophysical, latitude, slope, aspect, edaphic, soil type, soil pH, organic matter and salinity).

2.4 Observation of Vegetation Biomass

2.4.1 Vegetation indices indicators

Vegetation greenness (response factor) is measured through satellite observation to estimate biomass in desertification researches using different indices (algorithms) such as simple index (VI), normalized index (NDVI) Ali and Bauimi, [26], Dafalla, [17], and enhanced vegetation index (EVI) Eltoum, [19], Eltoum and

Dafalla, [2]. These indices are important elements in natural resources assessment and monitoring [20]. They provide quantitative and qualitative optical measures for assessment of plant canopy cover; patterns and structure [21]. Canopies have varied interaction degrees with sensed electromagnetic spectrum depending on its chlorophyll content. Chlorophyll content is affected by biotic factors (grazing animals, wild life, human being, insect, pest, diseases) and a biotic factors such as soils chemical structures and physical structures, fires and change in climate. The change in climate measures include (Rain, wind and temperature). Monitoring greenness at regional and national level still a challenge in Remote sensing (RS) and Geographical information system (GIS) Science. The information mentioned in literature regarding vegetation observation was distribution of vegetation type, biophysical and structural properties (biome types), spatial and temporal variation. Thus the graded green colors (dark green for high biomass areas and light green for low one) in (MODIES EVI5) satellite images color composite, represent the vegetation cover greenness state of specific land surface. This could be used to study land surface phenology.

2.4.2 Land surface phenology (LSP)

Land Surface Phenology (LSP) (response factor) is the spatio -temporal patterns of vegetation in a given land surface. LSP is affected by response of vegetation to change and variation in ecosystem this could be due to change of chlorophyll as affected by biotic and a biotic factors. To understand the change and variation, LSP could be divided into three main periods, start of growing season (SOS), end of growing season (EOS) and duration of growing season (DOS). Land surface could be classified into, vegetated area, non vegetated area, low vegetated area, very low vegetated area and highly vegetated area depending on scales and frequency of vegetation during these periods [22] Reduction of LSP results from reduction of vegetation biomass density (amount of plant material per unit area). It is also an indicator of degradation of vegetation cover.

2.5 Abiotic Factors (Soil)

2.5.1 Soil physical and chemical proprieties indicators

Soil (response factor) is a micro ecological system for living organisms. Physical properties indicators of soil in desertefied areas include, high surface soil temperatures during summer, low clay and organic matter content and low water holding capacity these factors determine its biological activity [23]. Plants, animals, human beings, insects and microorganisms could not survive easily under these conditions. Soil chemical properties indicators are Soil pH which is affected by acidity and alkalinity and determine availability of the nutrient elements for plants species, Accumulations of salts and toxic elements in the plants root zone.

2.6 A Biotic Factor (Climate Measures)

2.6.1 Rain fall

Rain (response factor) control is impossible. There is a high variation in spatial and temporal distribution of rainfall in Sudan. Lines of equal rain fall depth (isohyets) were used by Harison and Jakson in 1958 [1] to classify the vegetation zone of Sudan. Adam [24] used Sylianinov index to determine the climatic zones in Sudan.

2.6.2 Wind

Sudan is dominated by two types of winds, the dry north easterly wind in winter (October, November, December, January and February) and the humid southerly wind in rainy season during (may, June, July, august and September). The inter tropical convergence zone (ITCZ) separate the dry northerly wind from the humid southerly wind. ITCZ moves north and south during the year seasons (winter, summer and rainy season). The rate of wind speed is increasing up in Sudan.

2.6.3 Temperature

Increasing temperature as a result of greenhouse effect (global warming) is an important factor in climate change. Sudan is getting warmer. A change of 0.5-3ºC temperature was recorded [25]. Vegetation biomass is seriously affected by this change.

2.6.4 Aridity index

Aridity index (response factor) is defined as a measurement of precipitation divided by evapo transpiration. Five degrees of aridity were defined (0.03 - 0.65) by Dregnee et al. [26] in and become global measure.

2.7 Biotic Factors (Cause Factor)

2.7.1 Human being population biomass

After independent in 1956 Sudan population enumerated was 10.1 million. Population increased to 14.8 million in 1973. In 1983 census 19.6 million was reported. Population densities was about 11 person/km² .This density increased to 22 person/ km² as the population doubled from 19.6 million in 1983 to (38) million in 2014 [27]. Human beings population described as one of the environmental changes elements. Human beings populations' density increased very fast after global industrial revival. About 90% of this increased was in the past 350 years. it represent 1% of predicted human beings survival on earth plant [28]. Estimated global population will be 10-11thouthands billion. Adverse changes in Biosphere will be expected. After independent in 1956 Sudan population enumerated was 10.1 million. Population Increased to 14.8 million in 1973. In 1983 census 19.6 million reported. Population densities about 11 person/km². This density increase to 22 person/km² as the population increase about tow times (38) million in 2014 [27]. Economic factors control population distribution within the country. Stated that limited production and poor environmental resources of geographical areas posed population to migrate. Land productivity will not be enough to support the increased human beings populations as the case of Asia continent.

2.7.2 Grazing animal biomass

Animal units were used to estimate carrying capacity of ecological zone of Sudan. Basher [29] estimated 7-14 animal units in the semi desert zone. FAO later describe the semi desert zone as over stoked areas (+3) and more than (+25).

2.7.3 Wild life (response factor)

Several historical reports indicated the presence of wildlife in northern parts of Sudan. Indigenous Falcon was used as national government themes. Images of wildlife animals were present in national coins since independent of Sudan in 1956.

2.7.4 Insect biomass

As every living organism have benefits and drawback, insects do. It's found everywhere for specific unknown object. Role of insect biomass in Land surface phenology could be answered through this example; Flowering plants, water availability and temperature are very deterministic factors for selecting site of bee hives. Traditional bee keeping activities, honey and wax trades were found before in many states of Sudan as indicator of health forest eco system.

2.7.5 Soil microorganisms' biomass

Microorganisms could not survive easily under dessert conditions. Some geographical areas of different land surface of Sudan states exhibit symptoms of absent of biological activity of living organisms Plants vegetation, animals, human beings, insects and microorganisms due to lack of moisture content in soil regime and presence of synthetics chemicals Fertilizers residue, pesticide, fungicide and pollutant chemicals [30]. Decrease in soil micro organisms' biomass affect soil fertility and availability of nutrient to plants vegetation biomass.

3. MATERIALS AND METHODS

3.1 Study Area

The study area was Sudan. It is a northeast African country at latitudes 14 and 22° North and longitudes 22° and 38° East. Selected points were monitored for desertification symptoms.

3.2 Data

Data acquired by the Multi-spectral Moderate Resolution Imaging Spectral-radiometer Satellite (MODIS). Satellite images were correlated with historical ground survey data and maps related to other research parameters (biotics and abiotics factors).

3.3 Methods

The MODIS Enhanced Vegetation Index (EVI) images version 5 were used in this study for vegetation studies (the main response factor). MODIS images were freely downloaded from the website of International Research Institute for Climate and Society (IRI) at University of Colombia.
http://www.iridl.ldeo.columbia.edu/maproom/Food Security

Supervised classification was carried out using points of interest located in the desert boundary

in 1958.The edge of the similar desert vegetation was traced at selected new groups of points and converted to vector data described as desert boundary in 2013. To map areas under desertification process several maps were produced and the tow boundary were plotted over grid layer of one degree. The set of maps were compared using eco-geographical analysis method.

4. RESULTS AND DISCUSSION

4.1 Source of the Problem

Climate change as a result of greenhouse effect, global warming due to increasing temperature of the earth surface, fluctuated rain fall in amount and distribution, High wind speed and change in aridity index of Sudan eco zones. As result of these changes, the plants vegetation biomass, grazing animals' biomass, wild life biomass, insect biomass and human being biomass will be affected simultaneously. The outcome of desertification which exists in several states of Sudan is food insecurity problems and socio economic problems (hunger, famine, conflicts and war) [2].

4.2 Degradation of Vegetation Covers (Response Factor)

Vegetation biomass is an important measure for depicting eco geographical changes and response of phenomena to biotic and a biotic cause factors. The change in vegetation biomass affects environment, biodiversity, eco system service, hydrology, desertification, poverty, natural resources, carbon cycle and ozone layer. Satellites images easily register the vegetation response to these changes in (the past, present and future). These facilitate extraction of information for sustainable management, planning and maintenance of bio diversity. In typical forest eco - system vegetation cover (strata) consists of tree layer, shrub layer, herb layer and micro substrates. Presence and absence of one of these layers reflect a change in its ecosystem. Fig. 1 show this change and represents absence of shrub layer in initial stage of desertification in land surface. Main indicators of vegetation cover degradation are decrease of land covered by vegetation and decrease of forage (change to less productive types of vegetation) resulting from selection pressure due to livestock intensity.

Semi desert forest was totally removed in different parts of the countries as the case of Sudan. The sub tropical forest was partially affected. Removal of trees layer strata beside removal of low vegetation biomass layers by over grazing and expansion of agricultural activities maximized desertification in Sudan Fig. (2). The result of these changes is natural resources deterioration indicated by absence of wildlife, absence of useful insect and predators beside pest invasion. Deterioration of natural resources is always followed by decrease in land productivity and soil degradation.

Fig. 1. Open trees system in low rainfall savannah with annual dry vegetation and absent of perennials (Start of clearing for agriculture, 2002)

4.3 The Role of a Biotic Factors (Soils)

4.3.1 Soil physical and chemical proprieties

Soil in some areas of different land of Sudan states exhibit symptoms of absence of this biological activity. Low nitrogen content is a general characteristic of deteriorated soil as a result of absent of organic matter and biological activity. Nitrogen content is a limiting factor of crop yield indicated by low yield, small fruits and pale green poor forage. Moreover salinity and sodicity affect different soils of irrigated and rain fed agriculture in Sudan causing failure of seed germination and stunted plant growth [31]. Soil degradation is the main cause of decreasing yield of agricultural crops and pastures. This process force farmers and nomads to move more south for better agricultural crops yield and pastures.

4.4 The Role of a Biotic Factors (Climate Measures)

4.4.1 Role of rainfall

In recent century rainfall fluctuated in amount and distribution in several parts of Sudan. Decline of up to 20 percent of rainfall were reported. The vegetated areas follow the same pattern of rainfall in it is spatial and temporal distribution. Diminished rainfall can cause drought. Prolonged drought can cause famine as the great famine of 1931 which is indicated by adverse decrease of total land surface phenology (LSP) plants, human beings and animals. Due to diminished rainfall which caused failure of agricultural crops and poor pastures. More over prolonged drought can cause desertification and expansion of desert affected areas. In other meaning it is a permanent decrease of LSP.

4.4.2 The role of wind

The movement of soil particles by wind force could be classified into three mechanisms (saltation, creep and suspension). Wind with speeds exceeding 5.4 m/sec are classified as erosive wind [32]. Adverse effect of wind erosion on soil, crops, human and animals were studied by Mustafa, [31].

4.4.3 The role of temperature

Survival of plants species in specific vegetation biomass zone depends on temperature. As example exceeding 30ºC temperature level could cause damage to several vegetables crops of cool- season and 40ºC temperature level for warm season vegetable. Increasing soil temperature by 1ºC up optimum temperature could delay vegetables seed germination about 15 days. Sorghum crop germination is sensitive to increase in soil temperature. Acceptable

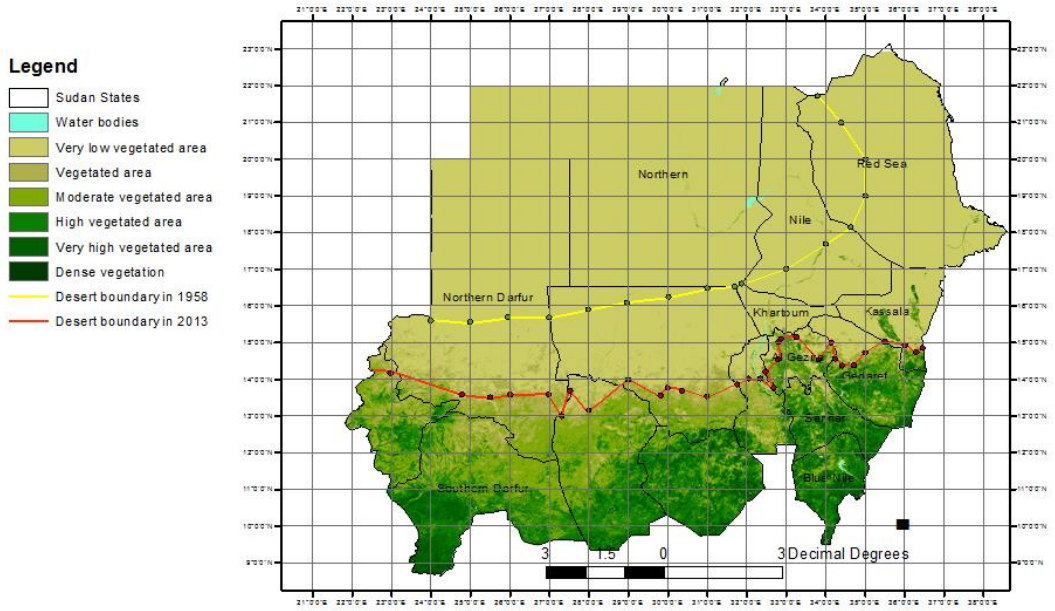

Fig. 2. Sudan vegetations map produced from MODIES EVI5 2013

germination is defined as 85% during 6 days [33]. Sorghum crop is the staple food in most of the country .In recent years the crop represent the backbone of economic agricultural crops of Sudan. Decrease of yield could be the reason behind expansion of economic sorghum production more south. Unfortunately this decrease will continue. Prediction of production losses due to heat stress associate with decreasing rainfall by 2025 is upsetting [15]. Taha [42] predicted 5-25% losses of sorghum crop production in Sudan by year 2000 to 2050.

4.4.4 The role of aridity index

FAO in 1997 prepared world atlas of desertification depending on aridity index. Sudan environmental characteristics of each arid zone were classified by Salih [5]. Proposed action plan to be implemented in each zone was prepared by desertification and Desert Cultivation Institute (DADACSI) [34] and recommended by Eltoum et al. [14].

4.5 The Role of Biotic Factors

4.5.1 The role of human being population biomass

If the density takes the same rate of change, the population may exceed 100 million. Density will be 50 person/km² by year 2050. To feed this huge population Sudan will import everything considering (prediction of 5-25% crops losses by 2050) otherwise the ghost of famine will exist as output due to decrease in yield productivity and increase population. Eight million people northern and southern Sudan faced moderate to high levels food insecurity in 2010 [35]. This requires careful planning and sustainable management of natural resources to keep this human mass well and satisfied. Absence of nomadic (pastoralisim) activities in River Nile state and some localities in Kassala and North Darfur states indicated sever deterioration of vegetation in these states Fig. (3). Because nomads move with their animals to target well vegetated areas seasonally (High LSP). Absent of human beings population in some localities is alarming.

4.5.2 The role of grazing animal biomass

Over grazing practice resulted in exceeding the carrying capacity of the range land in several states of Sudan. Over stoking and under stoking is used to describe the difference between estimated present use and potential current capacity in animal unit/year/mile². Ayoub in [36] reported that 46.9% of soil degradation was caused by over grazing in Sudan. Absence of nomads (pastorals) in River Nile state and some localities in Kassala and North Darfur states indicated the decrease of grazing activities (pastoralisim) due to diminished vegetation [27].

4.5.3 The role of wild life

When Lampery visited Sudan in 1975 and after extensive air craft survey 1500/km² he reported that no single Ostrich was seen. The total sighting animals were 46 gazelles as one/35km² with varied density between 14° - 16° N. In addition no Addax or Oryx was found (nomads sow it before 1973). Lampery visited Sudan again in 1976 he reported after the second visit that the only sign of wildlife animals in Sudan country was a falcon in the sky or snakes in barrow; the desertification extincted all wildlife animals. Recently seasonal vegetation in these areas could not support animals' survival. For gazelles, Addax and Oryx single gazelles could not be found outside the zoo and natural protected areas in Sudan. Addax and Oryx extincted before Lampery came to Sudan. Even so, not far from natural protected areas you can find signs of natural resources deterioration. Fig. 4 indicate the last stage in forest eco zone degradation. Desert like conditions started from this stage and end with complete desert.

Healthy forest regularly consists of varieties of wild animals. Monkeys, amphibians, reptiles, birds and small mammals consume alive and dead insects.

4.5.4 The role of insect biomass

Fig. 5 represent honey bee hive hanged in mahogany tress forest in Sudan. Insects are excellent pollinators for many forest plants. Dung beetles and flies larvae associate with animals herd movement by decomposing dung and enriching soil with organic matter. High density of these insects indicates animals herd concentration or trampling around specific areas. During drought period insect beetles and ants are capable to survive while others fail. Ants store sorghum inside nests to be used during shortage periods. Drought period of 1986 in Sudan was very severing. Dead animals were scattered around the capital city (Khartoum). Peoples of affected states destroy ants nest to collect sorghum.

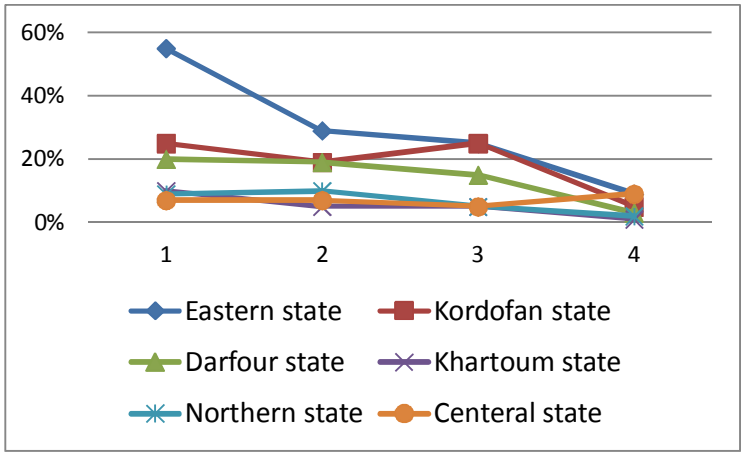

Fig. 3. Decrease of total nomads in Sudan, Census of nomads in Sudan in 1956, 1973, 1983 and 1993

Fig. 4. Removal of trees, building huts, shelters and clearing annual vegetation for agriculture (2002)

Dura "antad" associated with milky stage of sorghum cultivation were reported at the end of growing season (EOS) usually after rainfall. Goats consume dura antad also some Sudanese tribes enjoy it. Presence of annual vegetations at start of growing season (SOS) in desert and semi desert areas triggered desert locust out breaks after rainy season. Sever vegetation damage caused by desert locust in these areas of Sudan was reported [37]. Desert locusts provide a well known food source for some tribes and nomads. Fig. 6 show termite mound in deteriorated low vegetation areas bordering to Dinder national park. Termites are active wood and vegetation biomass decomposer. It is a good source of carbohydrates and monkeys like it. In some Sothern parts of Sudan there is high vegetation phenology. Presence of Tsetse flies (vector of sleepiness disease) in these high vegetated areas prevents forest eco-system from human beings activity and grazing animal attacks [38]. Even insect biomass are not far away from human beings activity, simply they eat some insect species and destroy the rest of it. These interactions seem to be the answer for why insects are member of the earth planet.

4.5.5 The role of micro organisms

The role of micro organisms in soil is to release nutrient from soil materials for plants roots, fixation of nitrogen, root aeration and substance exchange. In agricultural science Soil defined as micro climate media for plant growth and yield,

this reflects the importance of micro organism biomass activities in the ecological zone surrounding plant vegetation roots zone. Pseudomonas and Bacillus affectd ozone layer as result of it is activities denitrifictaion of urea (NO3) and release of (N2), (NO2) gases (Mahadi, 2006).

4.6 Desert Creeping

Extreme desert is characterized by absent of vegetation biomass due to lack of rainfall for one year or more (aridity index less than 0.03) Abdalla et al. [39] Ibrahim [23]. Poor population and scarcity of water sources. More hot spot areas are added to this zone from other deteriorated areas annually [37] Fig. 7.

Although there is a recovery by rainfall in some areas as reported by [40], Ali and Bayoumi, [16] the effect of biotic and a biotic factors exceeded this recovery [16,14]. Fighting desertification is a fight for human being survival in Sudan. Populations of Sudan may diminish dramatically in the next 50 years.

Fig. 5. Honey bees hive hanged in mahogany trees forest

Fig. 6. Termite mound decomposed wood biomass and vegetation (2002)

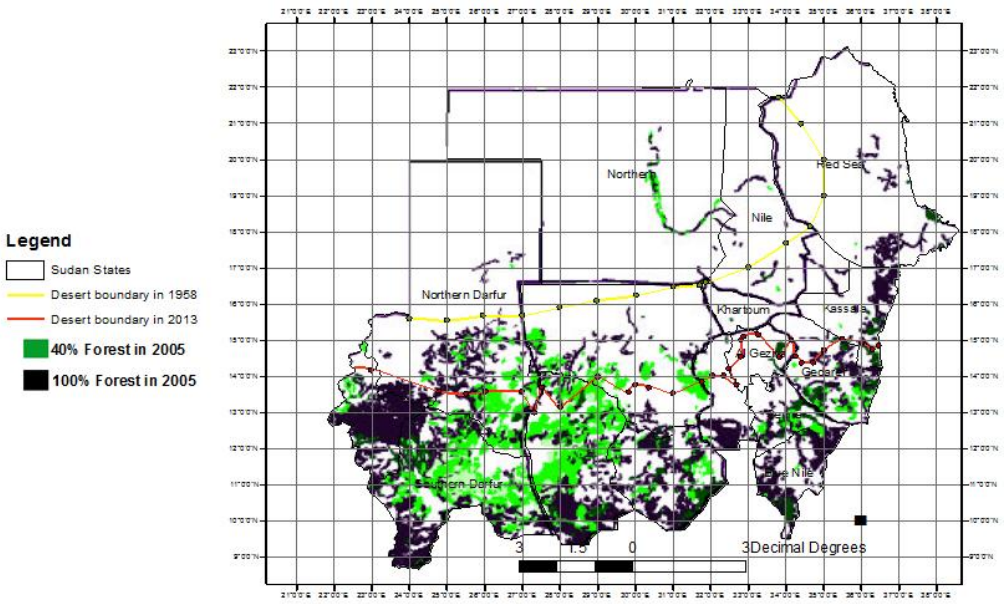

Fig. 7. Decrease of Sudan forest cover, modified from (FAO, 2005)

5. CONCLUSION AND RECOMMENDATIONS

This paper is the first effort to map desertification in Sudan (all the country). Based on this fact, the information mentioned in this paper could be used as base for producing Sudan desertification susceptibility maps using environmental sensitivity test. The outputs maps of this research could be used in monitoring desertification and ecological changes of the land surface specifically in Sudan. Ground truth and validation of these facts could be easy for several researchers and institutions. Afforestation programme through implementation of Sudan action plan is suggested, strengthening of current institutions to use very advance technologies to cover all the country are recommended as well as connection of these institutions under a separate entity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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