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RESEARCH ARTICLE

ADVANCES OF DESERTIFICATION RESEARCH: STATUS, GAP AND FUTURE CHALLENGES (SUDAN STUDY CASE)

Mohammed Ahmed Hag Ali Alzubair[1,*], Motasim Hyder Abd Elwahab[2] and Atiyat Abdalla Fadoul Nuri[3]

[1]Associate Professor, Physical geography, University of Khartoum, Sudan
[2]Associate Professor, Faculty of Agriculture, Omdurman Islamic University, Omdurman, Sudan
[3] Associate professor, Red Sea University, Port Sudan, Sudan

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ABSTRACT

Desertification is a result of complex interactions within coupled social-ecological systems. Thus, the relative contributions of climatic, anthropogenic and other drivers of desertification vary depending on specific socio-economic and ecological contexts. The research aimed in contributing raise awareness, show the current status, future challenges and emphasized on researches that must be done through national strategies starting with determination the top priorities of research. Desertification induced by adverse human activities on agricultural lands creates a real research gap on vegetation degradation, soil erosion, soil crusting and compaction caused by mechanized farming and animals trampling, trends of range land as well as continuous updating of carrying capacity of range lands, depletion of nutrients and organic matter due to excessive land use, accumulation of fertilizers and pesticides that may be toxic to human, plants and animals. Due to limited financial resources for anti-desertification research, there is a gap in combating desertification research generally, and wind erosion particularly such as: Stabilizing soil particles by various natural or synthetic cementing and flocculating materials that increase the non- erodiable soil particles (NEP) on the soil surface; producing a rough and cloddy surface; maintaining sufficient vegetative cover; and establishing barriers or shelter belts barriers to reduce effective field length traveled by the wind. Furthermore there is a lack in studies focused on measuring sand encroaching into the Nile. Still there is urgent need to conduct research on design and implementation of shelter belts and specify type of trees, number of rows, density and distance. The inevitable failure for desertification research that is not integrated with poverty alleviation programs, so there is a critical need to designing ideal planning and sustainable management of natural resources to keep this human mass well and satisfied

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INTRODUCTION

Desertification is land degradation in the arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (UNCCD, 1992). Land in this context includes: soil, land surface, vegetation and local water resources. Degradation refers to reduction of the current and the potential of the land to produce (quantitatively/qualitatively) goods or services by various processes: including soil erosion, reduction in amount or diversity of natural vegetation, salinization, sodication, soil compaction, depletion of nutrients and organic matter, and accumulation of pollutants toxic to plants and animals.

Corresponding author: **Mohammed Ahmed Hag Ali Alzubair,**
Associate Professor, Physical geography, University of Khartoum, Sudan.

Arid, semi-arid, and dry sub-humid areas, together with hyper-arid areas, constitute drylands (UNEP, 1994), home to about 3 billion people (van der Esch *et al.,* 2017). The geographic classification of drylands is often based on the aridity index (AI) (Koutroulis, 2019; Prăvălie, 2016) (Fig. 1). Hyper-arid areas, where the aridity indexes is below 0.05, are included in drylands, but are excluded from the definition of desertification (UNCCD, 1992). AI is not an accurate proxy for delineating drylands in an increasing CO2 environment. The suggestion that most of the world has become more arid, since the AI has decreased, is not supported by changes observed in precipitation, evaporation or drought (Sheffield *et al.*, 2012 and Greve *et al.*, 2014). The difference between desertification and land degradation is not process-based but geographic. Although land degradation processes can occur anywhere across the world, when it occurs in arid and semi-arid and dry sub-humid areas, it is considered desertification processes. Desertification is not limited to irreversible forms of land degradation, nor is it equated to desert expansion, but represents all forms and levels of land degradation occurring in drylands. Data from the Global Land Cover Share (GLC-Share) database, which represents the major land cover classes defined by the FAO, provide the following figures for land cover: 13.0% croplands, 13.0% grasslands (including both natural grasslands and managed grazing lands); 28% "tree-covered areas" (including both natural and managed forests); 9.5% shrub-covered areas; and 1% artificial surfaces (including urbanized areas). It has been argued that land degradation affect all types of land cover (Latham *et al.,* 2014). Over the past 50 years, the world's net cultivated area has grown by 12%, mostly at the expense of forest, wetlands and grassland habitats. At the same time, the global irrigated area has doubled (FAO, 2011). Tropical forests were the primary source of new agricultural land in the 1980s and 1990s, representing about 30% of new agricultural land; 55% is represented by intact forest and 25% by disturbed forest (Gibbs *et al.,* 2010). By 2050, the demand for new agricultural land (due to population pressure, diet change and demand for bio fuels) is expected to increase by about 50%. It is very probable that tropical forests will account for that land; therefore, further deforestation is to be expected, together with an exacerbation of soil degradation (Gibbs *et al.,* 2010 and De Fries *et al.,* 2010). Extreme desert is characterized by absent of vegetation due to lack of rainfall for one year or more (aridity index less than 0.03) (Abdalla *et al*., 2007 and Ibrahim, 2008) Poor population and scarcity of water sources. More hot spot areas are added to this zone from other deteriorated areas annually (Eltoum, 2013). Although there is a recovery by rainfall in some areas as reported by (Hellden, 2003; Ali and Bayoumi, 2004) the effect of biotic and a biotic factors exceeded this recovery (Ali and Bayoumi, 2004; Eltoum and Dafalla, 2014). Fighting desertification is a fight for human being survival in Sudan. Populations of Sudan may diminish dramatically in the next 50 years (Abdalla *et al*., 2007; Ibrahim, 2008; Eltoum, 2013; Hellden, 2003; Ali and Bayoumi, 2004 and Eltoum and Dafalla, 2014).

Study area: The study area was Sudan (1,882,000 Km^2). It is a northeast African country at latitudes 14 and 22° North and longitudes 22° and 38° East. 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 (Taha *et al.,* 2013). Vegetation biomass is seriously affected by this change. 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, 1958) to classify the vegetation zone of Sudan. 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). Aridity index (AI) is defined as a measurement of precipitation divided by evapotranspiration. Five degrees of aridity were defined (0.03 - 0.65) by (Dregne *et al*., 1991) in and become global measure.

Estimation of desertification in Sudan: The third edition of the World Atlas of Desertification (Cherlet *et al*., 2018) indicated that it is not possible to deterministically map the global extent of land degradation, and its subset - desertification, pointing out that the complexity of interactions between social, economic, and environmental systems make land degradation not amenable to mapping at a global scale. Instead, Cherlet *et al.,* (2018) presented global maps highlighting the convergence of various pressures on land resources. Sudan was subjected to different complex disasters such as drought, desertification, famine, floods, pest infestation conflicts and war (Nour, 2007). Most of these disasters are triggered by desertification and climate change Eltoum *et al*., 2014. Recent researches support the evidence of presence of desert and desert like condition more to the south of the northern border of southern Sudan (FEWSENT, 2011). Desertification in Sudan was monitored in few spot areas using remote sensing and geographical information system. Stebbing, 1980, use the desert boundary to monitor the encroachment of the Sahara (desert). The desert boundary 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, (Harrison and Jackson, (1958); DECARB, (1976); Lampery, 1975; Salih, 1994; Ayoub, 1998, 1999; Ali and Bauimi, 2004; Dafalla, *et al.,* 2007; Eltoum and Dafalla, 2014; Dregne, (1991); Mustafa, 2008) and recently Eltoum *et al*., 2015). The last assessment report considered as the first effort for mapping desertification in Sudan Fig. (2).The annual rate of this shift depends on the rate of change of climatic, biotic and a biotic factor. Understanding this shift is very important in monitor desertification, measure required response to prevent, mitigate and/or stop the desert creeping.

Estimation of vegetation degradation in Sudan: Vegetation greenness 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, 2004 and Dafalla, *et al*., 2007) and enhanced vegetation index (EVI) (FAO, 2006; Eltoum and Dafalla, 2014). These indices are important elements in natural resources assessment and monitoring (Silleos *et al.,* 2006). They provide quantitative and qualitative optical measures for assessment of plant canopy cover; patterns and structure (Huete *et al.,* 2011). 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 factor such as soils chemical structures and physical structures, fires and change in climate. Management and conservation of soil and water resources from desertification are critical to human well-being. Their prudent use and management are more important now than ever before to meet the high demands for food production and satisfy the needs of an increasing world population. Despite the extensive research and abundant literature on soil and water conservation, still land degradation remaining high. Still little quantitative data is available due to limited number of studies and projects carried out to cover the whole area of the Sudan and all kinds of desertification processes. Financial resources for anti – desertification are limited therefore any action program or studies will not pave its way to priorities. Moreover there is a lack of efficient public awareness and popular participation mechanisms. Managing soils under intensive use and restoring eroded lands are top priorities to a sustained agronomic and forestry production besides conserving soil and water resources. Monitoring of the extent of land degradation in the affected areas in Sudan is essential for designing control measures for enhancing agricultural development.

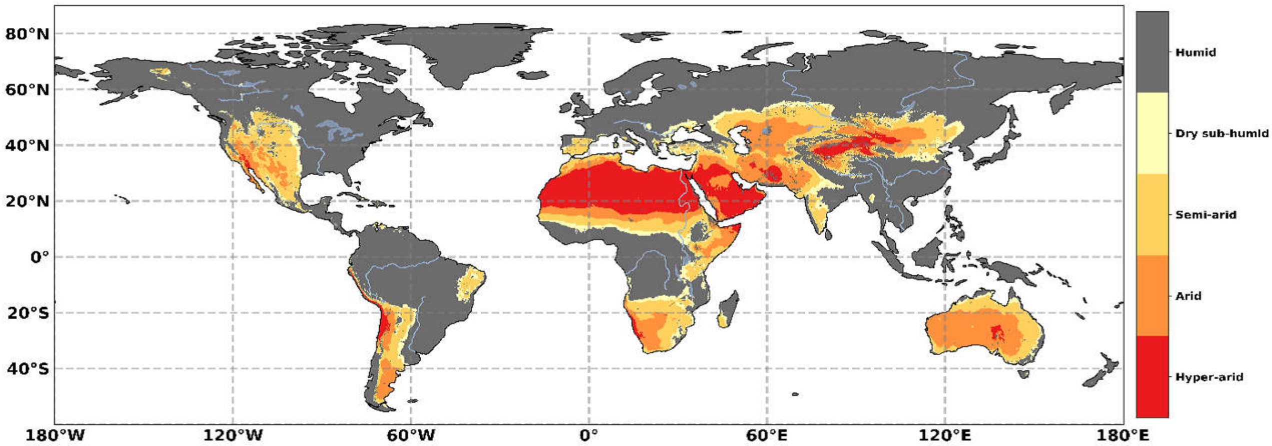

Fig.1. Geographical distribution of drylands, delimited based on the Aridity Index (AI). The classification of AI is: Humid AI > 0.65, Dry sub-humid 0.50 < AI ≤ 0.65, Semi-arid 0.20 < AI ≤ 0.50, Arid 0.05< AI ≤ 0.20, Hyper-arid AI< 0.05. Data: TerraClimate precipitation and potential evapotranspiration (1980-2015) (Abatzoglou *et al.,* 2018)

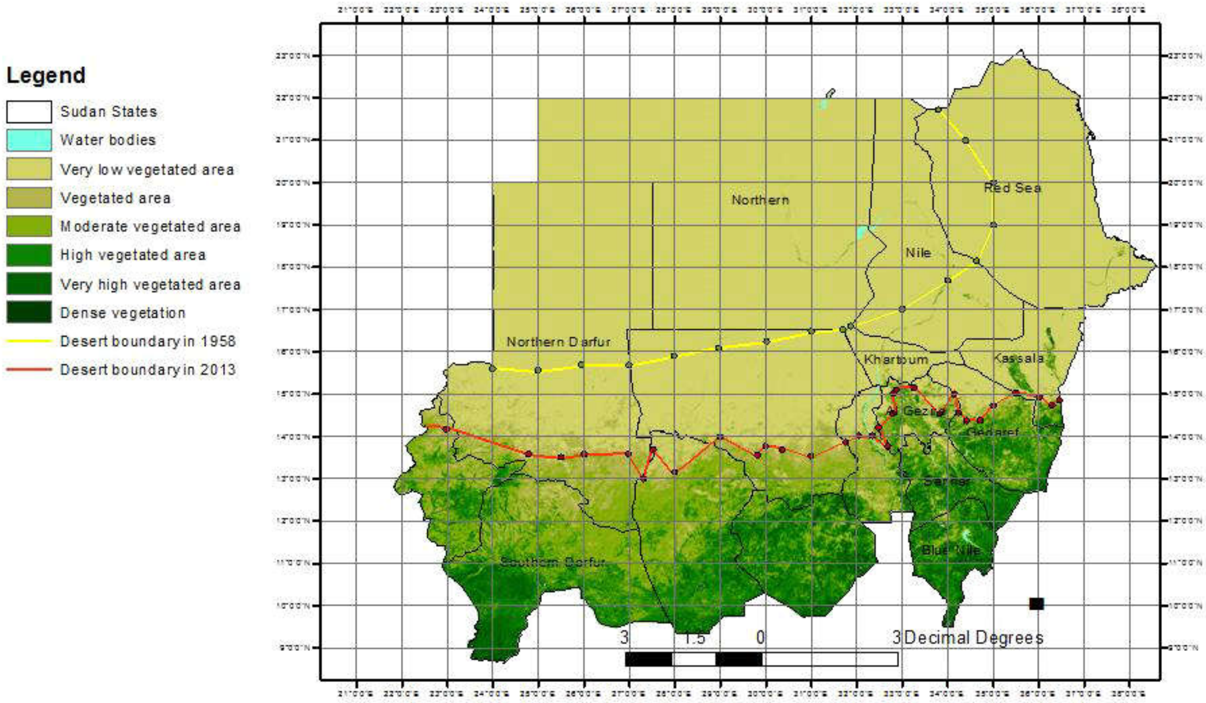

Fig.2. Sudan vegetations map produced from MODIES EVI5 2013 (Eltoum *et al*., 2015).

This paper is an attempt to present casting new light on scientific researches on desertification in Sudan, to achieve the following objectives:

- To encourage and create an initial background to collect the research of some scientific institutions
- To view the current status of problem and raising awareness that may contributes in combating desertification and their harmful impacts.
- To display studies and research that must be carried out to cover the weak areas of desertification research.

Desertification, climate and human activities

Desertification and climate: Desertification is land degradation in the arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (UNCCD, 1992), according to the UNCCD definition desertification caused mainly by climatic and human activities. In central Sudan, the drought periods of 1968 and 1972 were preceded by above average rainfalls (floods) in many parts of the region. In 1962 Lake Chad recorded its highest level in the 20th century and the widespread flooding drove many people from their villages. In contrast the drought conditions after 1965 reduced the Lake's level so low that irrigation was stopped during 1984-1986 (Kolawole, 1987; 1988). Periods of prolonged droughts like the great Sahelian drought (1968-1973) may occur. High aridity is an adverse climatic condition that creates fragile ecosystems, which can easily be upset by adverse human activities. DECARB (1976) it was stated that comparison of the hypothetical vegetation types and location 100 years before the present time with those mapped by (Harrison and Jackson, 1958) are highly suggestive that desertification in Sudan is in part due to climate change. However, it was gutted that the change of Wadi El-malik from desert scrub zone into full desert was thought to be too large to be attributed to climate change only. Recently, climate change is recognized as a factor that enhances desertification (Mustafa, 2007). Climate change as a result of greenhouse effect, reflected in 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. These changes affects on 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) (Eltoum and, Dafalla, 2014). Global warming is an international phenomenon caused predominantly by industrial countries and endured by developing countries. Developed countries contribute heavily to climate change through industrial activities that emit excessive amounts of GHGs.

Desertification and the human being role: 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 (Alhafian,2001) 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 were about 11 person/km^2 .

This density increased to 22 person/ km^2 as the population doubled from 19.6 million in 1983 to (38) million in 2014 (National Censes Report, 2010). Density will be 50person/km^2 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 (FEWSENT, 2011). 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. People can be a major asset in reversing a trend towards degradation. However, they need to be healthy and politically and economically motivated to care for the land, as subsistence agriculture, poverty, and illiteracy can be important causes of land and environmental degradation (Beinroth *et al.,* 1994; Lal, 1994 and Eswaran *et al.,* 2000). In the arid and semi-arid zones in developing countries, e.g. Sudan, the relatively poor population in the rural areas seeks sustenance from the natural resources of their fragile ecosystems. They misuse the land through over and irrational cultivation of marginal lands, overgrazing, wood cutting and deforestation, uprooting of shrubs, burning of grasslands, forests and shrubs, and lowering of the ground water due to excessive water use. These activities cause degradation of the land, which is steadily accelerated due to the exponential increase in human and livestock pressures. These inevitable adverse activities prompted by the poverty of the local communities accentuate desertification, more poverty, and more reliance on the fragile ecosystems; thus completing a poverty vicious circle. The use of heavy machinery in mechanized farming may lead to compaction, which increases soil strength, limit root development, and proliferation, and thereby reduce plant growth and crop yield (Ayoub, 1998, 1999; Izzeldin *et al.*, 2000).

Desertification processes in different land use system: The relation between land degradation processes and land use systems was explained by (Mustafa, 2007) the three major land use systems in the ecosystem vulnerable to land degradation include: rangelands, rain-fed crop lands and irrigated lands.

Desertification in range and forest lands: Osman and Warrag (2009) conducted a research on assessment of vegetation cover changes with special reference to *Acacia senegal* in Bara locality, north Kordofan. They compared the existing cover with past vegetation in terms of tree density and species composition. The results showed that the same tree species in Bara locality were maintained while changes in relative densities were observed especially for A. Senegal, which decreased to 2% as compared with 31% in 1995. The dominant tree species were *Acacia tortilis* followed by *Leptadenia pyrotechnica, Calotrpis procera, Balanites aegyptiaca, Faidherbia albida, Ziziphus spina-christi* and lastly A. Senegal. Fangama (2010) assessed the forest cover changes at Um Gargur refugees' settlement in Gedaref state by using remote sensing techniques. The results revealed that, the was a high degree of change in the forest cover in1999, which is equals to 7.1% of the study area while the ground measurement in 2004 revealed that the degree of change was -100%. Abusuwar and Abdelaziz (2010) evaluated the effect of sowing some range species on the production of desertified range lands in Sinnar state. Dawelbait *et al.* (2013) identified changes in ground cover of endangered range plant species in north Kordofan state. They found changes in range attributes were clearly noticed and some important plants are being endangered so the study recommends a strategy for range land rehabilitation to be adopted in relation to composition of important, palatable endangered plant species. These studies are very important due to determination the trends of range land so as controlling degradation in plant and natural vegetation composition furthermore carrying capacity should be calculated to avoid the negative impact of overgrazing.

Desertification in irrigated lands: Some studies were undertaken in irrigated lands in central Sudan (mechanized farming schemes). As an example (Alamin *et al.*.2006) they established tress for sand settlement in a desertified source area of drifting sand encroaching on parts of the Gezira Irrigation Scheme in Central Sudan, Establishment, survival and growth of *Acacia tortilis*, *Leptadenia pyrotechnica*, *Prosopis juliflora*, *Salvadora persica* and *Panicum turgidum* were investigated. Comparisons were made of the sums of final survivors in the replicates for each treatment to assess the survival trends over time within the measuring periods. Mohammed *et al*. (1995) studied the sand movement from seriously degraded arid land with active sand dunes, northwest of the Gezira irrigation scheme and consequences and a protective shelterbelt. They found more than 10 cm of top soil was eroded by wind during 1977-1987. The scheme suffers from filling of canals with sand, increases in farm level beyond what is necessary for irrigation water to reach it, and changes in the soil characteristics from clay to more sandy conditions. A Eucalyptus shelterbelt was established to protect the scheme from desert encroachment. The approaching wind speed was significantly (>20% ± 2%) reduced within a distance of 20 m, three times the height of the belt. This reduction of wind speed is responsible for the amounts of deposited sand near and inside the belt, forming a dune within and near its edge that at some places is >2.5 m high and >45 m wide. Simple sand catchers were used for measuring saltating sand close to and within the belt. Because of deposition, the amount of moving airborne sand is reduced with distance to the belt. The decreasing ratio of coarser soil particles to the total amount of saltating sand could also be quantified with distance to the belt and height from the soil surface.

Desertification in rain-fed lands: Glover (2005) studied tropical dry land rehabilitation of the Gedaref region and found that the mechanized scheme farmers ranked the indicators of the occurrence of land degradation in the following order: reduced soil fertility, soil erosion, prevalence of pests (53 %), soil erosion, pests (23 %), reduced soil fertility, soil erosion (21 %), and reduced soil fertility (3 %). Smallholder farmers mentioned reduced soil fertility (53 %), soil erosion (27 %), reduced soil fertility, soil erosion/ prevalence of pests (13 %), and reduced soil fertility/soil erosion (7%). The majority of collaborative reserve farmers (83 %) indicated drought as the main indicator of land degradation. The remaining few collaborative farmers (17 %) indicated reduced soil fertility as an indicator of land degradation. Abdi *et al.* (2013) showed that in rain-fed agricultural zones in the Sudan, deep ploughing and leveling of the surface soil caused an increase in its susceptibility to wind erosion, which, in turn, has led to a severe decline in its fertility and in some places,the formation of sand dunes. The implications of these trends on the natural resource base include environmental degradation, food insecurity and aggravation of income inequalities among the Sudanese producers. The study has suggested Agroforestry technology as potential solution to this continued problem of declining rural agricultural production in the Sudan. Considerable research undertaken in Gedaref State this attention is due to the importance of state as a one of the most mechanized rain-fed scheme in Sudan. In the Gedaref region, destruction of the natural vegetation for agricultural expansion is one of the major causes of the degradation of renewable resources and the environment. Sulieman and Buchroithner (2009) assessed degradation and abandonment of mechanized rain- fed agricultural land in the southern Gedarf region: the local farmers' perception. The study identified and analyzed the farmers' attitudes and perceptions towards agricultural land degradation and abandonment. Biro *et al*. (2013) analyzed and monitor the LULC changes using multi-temporal Land sat data for the years 1979, 1989 and 1999 and ASTER data for the year 2009. In addition, efforts were made to discuss the impact of LULC changes on the selected soil properties. For this, a post classification comparison technique was used to detect LULC changes from satellite images. Primarily, three main LULC types were selected to investigate the properties of soil, namely, cultivated land, fallow land and woodland. The results showed that a significant and extensive change of LULC patterns has occurred in the last three decades in the study area. Further, laboratory tests revealed that soil properties were significantly affected by these LULC changes. The change of the physical and chemical properties of the soil may have attributed to the changes in the LULC resulting in land degradation, which in turn has led to a decline in soil productivity.

Hano (2013) assessed the impacts of changes in land use patterns on land degradation/desertification in the semi- arid zone of White Nile State using remote sensing and GIS during the period from 1973 to 2009. He reported that land use change affected soil degradation which led to the movement of sand dunes during the study period. Glover and Elsiddig (2012) studied the causes and consequences of environmental changes. Adam *et al.* (2014) assessed land degradation in Rawashda, area Gedaref State by using remote sensing, GIS and soil techniques. Ali *et al*. (2012) assessed and mapped of soil degradation at Gadambalyia schemes in Gedaref state, related to sorghum productivity. Satellite images and GIS were integrated with soil quality to detect and map the type and degree of severity of soil degradation. Soil quality indicators were determined and compared with the same indicators, determined previously in the same locations in 1976. The System Integration Risk model was used to classify the area of schemes according to soil chemical and physical degradation. The results revealed that the soil qualities in 2005 were significantly affected ($P< 0.001$) both negatively and positively, compared with the 1976 data. Soil chemical degradation ranged from low to severe, while the soil physical properties were not significant degraded. The long term average of the sorghum for all farms was between 1 to 3.5 sac per feddan (1 sac =100 kg; 1 feddan = 0.42 ha). About 1.5% of the total farms (262 farms) had long term average less than 1.5 sacs per feddan. 44.3% of the farms had long term average of 2.5 sacs feddan $^{-1}$, and 34% of the farms had long term average of 3 sacs fed^{-1} and above. Only about 10% of the total area had no yield deterioration while about 57% had low to moderate yield deterioration and 33% had high to severe degradation. This means that, although the soil was highly degraded, it was still possible to obtain some sorghum.

Another cause of desertification in the Sudan is the rangelands cleared for mechanized rain-fed agriculture and shifting cultivation. According to (FAO, 2001b), during the 1980s and 1990s there was a rapid expansion of rain-fed mechanized cultivation with the aim of attaining self-sufficiency in food production. According to Salih (1987), the land area for mechanized agriculture increased from about 2.0 million ha in 1954 to about 14 million ha in 1994, a rate of 300,000 ha per year. Large scale mechanized farming has been the main factor contributing to deforestation and consequent land degradation (FAO, 2001a). In Sudan, land degradation/desertification (LDD) has devastated large areas and consequently, it includes social, economic, and environmental aspects. LDD results from various factors, including climatic variation and human activities. Probably the LU practices and their changes have contributed to an increase of LDD in that area.

Research gab in three different land use system: Desertification is a result of complex interactions within coupled social-ecological systems. Thus, the relative contributions of climatic, anthropogenic and other drivers of desertification vary depending on specific socioeconomic and ecological contexts. Management and conservation of vegetation crop, soil and water resources from desertification processes and reversing the adverse human activities are more important now than ever before to meet the high demands for food production and satisfy the needs of an increasing world population. The three major land use system almost shared the same adverse human activities as well as desertification processes. Semi desert forest was totally removed indifferent 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 overgrazing and expansion of agricultural activities maximized desertification. 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 (Eltoum *et al*., 2015). So conducting more research on vegetation (natural and cultivated) degradation, soil erosion (wind and water), soil crusting and compaction caused by mechanized farming and animals trampling, trends of range land as well as continuous updating of carrying capacity of range lands, depletion of nutrients and organic matter due to excessive land use, accumulation of fertilizers and pesticides that may be toxic to human, plants and animals eventually, evaluating the negative human activities on micro and macro climate beside their contribution to climate change. Inevitable continuous of negative human activities on natural resources unless give them energy alternatives and getting over from their poverty

Research in wind erosion and salts affected soils

Research in wind erosion: Erosion refers to removal of soil by the physical forces of water, wind, or often caused by farming activities such as tillage (Ginoux *et al.,* 2012). There is a significant potential for climate change to increase soil erosion by water particularly in those regions where precipitation volumes and intensity are projected to increase (Panthou *et al.,* 2014; Nearing *et al.,* 2015). Studies conducted in Sudan on wind erosion are limited, despite their importance and diffusion. Wind erosion occurs, naturally, in all lands wherever the surface soil is loose and dry and blown by erosive winds. However, it is predominant and has serious adverse impacts on agricultural lands in the arid and semi-arid lands characterized by low, variable, erratic, and unpredictable rainfall, and high temperature, high wind velocity and consequent high rates of evapotranspiration. In developing countries it is accelerated by environmentally non-sustainable land use and management systems. Wind erosion is affected by two main factors wind erosivity and soil erodibility. Ayoub (1998) studied the contribution of human activities on accelerating wind erosion.

Salih (1996) assessed the total area affected by drought and desertification about 50.5% of Sudan's total area. The indispensable estimate was that made by (Dregne, 1991), while the estimates of (UNEP, 1977 and FAO/UNEP, 1984) were similar. Ayoub (1998) about 64 million ha of soils are degraded in the Sudan, 81% of the total degraded area is in the arid, semi-arid and dry sub-humid; but significant percentages of land are also degraded in the dry sub-humid and moist sub-humid zones. As percent of total area per aridity zone, the dry sub-humid and moist sub-humid zones have figures higher than the semi-arid and hyper zones, 28 % and 29%, respectively. According to the latest synthesis on land degradation at the national level was assembled by (Ayoub, 1999) who examined the status of land resources in the Sudan after over half a century of Unsustainable land use. The author indicated that the dry lands of the Sudan are 234.4 million ha constituting about 94% of the total area of the country (248.8 million ha). Out of this area 31.2%, 25.9%, 31.2% and 6.5% are hyper-arid, arid, semi-arid and dry sub-humid respectively. Dramatic increasing was recorded after nine years, hyper-arid, arid and semi-arid lands constitute 41.2, 33.4 and 25.2% of the total area of Sudan, respectively (Mustafa, 2008).

Ayoub, (1999) attributed food insecurity in North Kordofan, North Darfur, West Kordofan, and West Darfur States to wind erosion and nutrient depletion. Severe food insecurity in the Red Sea Hills area was attributed to wind and water erosion. Desertification being the main environmental problem and major constraint of biological production in Sudan (Mustafa, 2008) deserves top priority in research. Wind erosion is a predominant and a major process of desertification in Sudan, particularly in the northern part of the country due to the predominance aridity. Lamprey (1975) reported that the Sahara desert advanced at a rate of 5 to 6 km/year during the period 1958 –1975, some researcher doesn't agree with Lamprey. It is obvious according to his estimate the whole areas of Sudan must be covered by sand dunes or sand sheet. It is true that the Sahara advanced southward in winter season from November and March by northerly winds acting as prevailing winds whereas, in summer season August and September. the prevailing wind plowing mainly by south and south west which were stronger winds but shorter in duration, that reflected in slowdown the Lamprey rate and opposite effect of northerly winds; e.g (Abdelwahab and Mustafa, 2015 and Abuzied, 2009). Mukhtar (1995) studied wind erosion in southern Khartoum with use of aerial photo interpretation. She recognized three classes of wind erosion: slight, moderate and severe covering areas of about 31.7 km^2, 0.1 km^2 and 1.64 km^2, respectively. Ibrahim *et al*. (2003) evaluated, through aerial photo interpretation the extent and severity of sand erosion in a 760 km^2 area to the south of Khartoum, between the Blue and the White Nile, Sudan. Two sets of aerial photographs, dating back to the years 1960 and 1990 were assembled to compile two mosaics of the area. The results of the field checks indicated a very high (90%) purity of the mapping units and that 26.4% of the total area was affected by slight, moderate or severe wind erosion.

The laboratory analysis indicated that sand was transported mainly in suspension. Comprehensive reviews on intensity wind erosion (IWE) were presented by several research workers in different states (Abdelwahab and Mustafa, 2013; Abdelwahab *et al., 2014;* Abdelwahab and Mustafa, 2015; Abdelwahab and Mustafa, 2016a; Abdelwahab and Mustafa, 2016b; Abdelwahab *et al., 2015;* Abuzied, 2009; Abuzeid *et al.,* 2015a; Abuzeid *et al.,* 2015b; Abuzeid *et al.,* 2017; Rizgalla *et al.* 1999; Farah, 2003; and Haikal, 2005). A national research project on the assessment and mapping of wind erodibility in various states was undertaken in the Desertification and Desert Cultivation Studies Institute (Medani and Mustafa 2003; Mustafa and Medani 2003; Mohammed and Mustafa, 2005; Rehan and Mustafa, 2005; Abdelwahab *et al*., 2009; Mohammed and Mustafa, 2011; Hassan and Mustafa, 2011 and Abdelgadir *et al*., 2013). Soil indicators were recommended for the prediction of non-erodible soil particles (NEP) and wind erodibility (WE) of the soils. For example Mustafa and Medani (2003) recommended the use of (Silt + Sand) / (Clay + $CaCO_3$) ratio for the prediction of NEP and WE of the soils of Khartoum State. WE showed quadratic increase with increase of this ratio. It was concluded that this indicator is a better indicator than the clay ratio alone, which was previously recommended by other authors. Elagib and Martin (2000) assessed the effects of environmental forcing on various climatic patterns over the past few decades, within the frame of the present analysis, the results are quite striking and are in concordance with scientific contentions that such land degradation could result in climatic modification. Higher temperature and less rainfall, sunshine duration and global radiation have been noticed. Evapotranspiration has responded more to the warming and drying conditions, thus showed signs of increasing rates, especially during the wet season. In Sudan very little attention was given to consequent climatic changes in literature.

Research gab in wind erosion: Due to limited financial resources for anti-desertification research, there is a real gap in combating desertification research generally, and wind erosion particularly such as: Stabilizing soil particles by various natural or synthetic cementing and flocculating materials that increase the non- erodiable soil particles (NEP) on the soil surface; producing a rough and cloddy surface; maintaining sufficient vegetative cover; and establishing barriers or shelter belts barriers to reduce effective field length traveled by the wind. Furthermore there is a lack in studies focused on measuring sand encroaching into the Nile, winds data analysis, losses of nutrients and organic matter particularly that caused by wind erosion. Still there is urgent need to conduct researches on design and implementation of shelter belts and specify type of trees, number of rows, density and distance. Unfortunately all that researches on assessment of intensity wind erosion (IWE) conducted in a part of affected states (Abdelwahab and Mustafa, 2013; Abdelwahab *et al., 2014;* Abuzeid *et al.,* 2017; Rizgalla *et al.* (1999); Farah, 2003; and Haikal, 2005).

Research in soil salinity and sodicity: Saline and sodic soils occur naturally in arid, semiarid and dry sub-humid regions of the world. Climate change or hydrological change can cause soil salinisation by increasing the mineralized ground water level. However, secondary salinisation occurs when the concentration of dissolved salts in water and soil is increased by anthropogenic processes, mainly through poorly managed irrigation schemes. The threat of soil and groundwater salinisation induced by sea level rise and sea water intrusion is amplified by climate change About 250,000 hectares in northern Sudan were affected to varying degrees by salinity and sodicity (Mustafa, 1986). Hamed and Mustafa (1975), found that the relative hydraulic conductivity of the Vertisols and other Aridisols was increased while the dispersion index decreased by decreasing the exchangeable sodium percentage (ESP) and increasing the total concentration of salts (C.) There was also a significant decrease in the relative hydraulic conductivity by increasing the dispersion index which indicated 80% variation of soil samples balanced with salts of sodium chloride and calcium chloride. The relationship between the sodium exchangeable ratio and the total salt concentration threshold showed that the saturated gypsum solution was initially active in Vertisols with ESP >9, and in the expandable Aridisols soil with ESP >16. Mustafa and Hamed (1977) found that the large swell of soil increased with increasing ESP and C decrease. The study showed that the swelling caused 87% and 71% variability of the relative hydraulic conductivity for the Vertisols and Aridisols, respectively.

Elmahi and Mustafa (1980) conducted a laboratory experiment to study the effect of the concentration of electricity and the absorption sodium ratio on the phosphorus capture in three surface soil samples from different arid regions, one of which belongs to the Vertisols, and two were Aridisols. Dahab *et al*., (1988) studied the effect of irrigation periods (5, 10 and 20 days) and the amount of irrigation water 120, 240 and 480 mm added at (3 and 6 mm / day) on intermittent evaporation and distribution of soil moisture and redistribution of salt in columns of saline-sodic soil have irregular salinity. Malik *et al.* (1992) found an increase in the swell and dispersion of the Vertisols from the soil of central Sudan and the decrease in permeability and spread of water, by increasing SAR and decreasing C. Awad Elkarim *et al.* (1995) explained the low rate of urea hydrolysis by water due to increased soil salinity in the range of 40-200 meg/L especially at high level of SAR. A study was conducted on the effect of some organic and inorganic amendments on cumulative evaporation, moisture distribution and salt redistribution in saline (Vertic-natargid) (Abd Elrahman *et al.,* 1996). Mohammed and Mustafa (2000) found a very significant increase according to the second-degree polynomial equation in the size of the soil shrinkage by increasing the sodium exchangeable ratio at several fixed values of the total concentration of salts. The direction of these equations explained more than 90% of the variation in shrinkage size. The effect of salts on the physiochemical properties of soil was studied by several researchers (Mohammed and Mustafa 2001; Ishaq and Mustafa 2005; Saeed and Aissa 2002; Mustafa and Abdelmajid 1981, 1982; Dahab, *et al.,* 1988).

Research gab in soil salinity and sodicity: Salinization and sodication is a predominant and a major process of desertification in Sudan, due to the presence of conducive, environment particularly in the northern part of the country. Land productivity directly affected by the amount and type of salts present in the soil, so there is urgent need to insert a program on salinization and sodication in national strategy for scientific research in desertification with determination the affected lands. Furthermore reclamation experiments conducted in demonstrate farm must be carried out in the vast affected lands.

Future challenges and recommendations

Future challenges

The all gabs have been mentioned are regarded as future challenges, beside the following challenges:

- There are knowledge gaps on the extent and severity of desertification at global, regional, and local scales (Zhang and Huisingh, 2018; Zucca *et al.,* 2012). Overall, improved estimation and mapping of areas undergoing desertification is needed. This requires a combination of rapidly expanding sources of remotely sensed data, ground observations and new modeling approaches.
- Despite numerous relevant studies, consistent indicators for attributing desertification to climatic and/or human causes are still lacking due to methodological short comings.
- Climate change impacts on dust and sand storm activity remain a critical gap. In addition, the impacts of dust and sand storms on human welfare, ecosystems, crop productivity and animal health are not measured, particularly in the highly affected regions such as the Sahel, North Africa, the Middle East and Central Asia (e.g. Painter *et al.,* 2018).
- The knowledge of future climate change impacts on such desertification processes as soil erosion, salinisation, and nutrient depletion remains limited both at the global and at the local levels.
- Desertification under changing climate has a high potential to increase poverty particularly through the risks coming from extreme weather events (Olsson *et*

al., 2014). The inevitable failure for desertification research that is not integrated with poverty alleviation programs, so there is a critical need to designing ideal planning and sustainable management of natural resources to keep this human mass well and satisfied

- Desertification in Sudan was monitored in few spot areas using remote sensing and geographical information system.

Recommendation

- The National Scientific Research Forum on Desertification in Sudan held on March, 2004(Mustafa, 2008)in that Forum many papers were presented on desertification with identify research themes, delineate research objectives and propose strategies and methodologies in the various areas related to desertification (sectors). The Forum also addressed proposed research plans of action in the affected States emphasized on a framework networking in different institutions operating in the different areas related to desertification. Papers presented in the forum regarded as starting platforms or gateway to get over desertification trouble through an excellent planning research but unfortunately after fourteen years, there is no progress shown except humility effort from time to time and here and there. So there is need to determine the completed and uncompleted research.
- It is time to commit to a new national strategy for scientific research in desertification starting with determination the top priority research, based on the National Scientific Research Forum on Desertification in Sudan, March-2004.
- The inevitable necessity of spending on scientific research from national income, furthermore adequate funding must be provided by the State, regional and international organizations, knowing that the Government is obliged, under the United Nations Convention to Combat Desertification, to secure adequate funding for anti-desertification research and programs.
- Insert a program on soil and water pollution in national strategy for scientific research in desertification with determination the levels of pollutant and compared with international allowed levels. Furthermore adoption of a fforestation programmers through implementation of Sudan action plan is suggested, strengthening of current institutions to use very advance technologies to cover all the country are recommended.
- Urgent need to collect the scattered research and studies that were undertaken in various academic corporations and research centers to avoid duplicate researches, leading to lose money and time and also the lack of coordination between relevant institutions must be treated.
- Urgent need for carry out interdisciplinary research and community should involve. This highlights the role of agricultural extension and environmental media.
- Promote early warning research to avoid the effects of natural disasters specially, drought as indirect reason caused desertification under irrational land use.
- Till now there is no attention was given to (Environmental impact assessment) studies in Sudan particularly that related to land degradation such as, random mining, forest deforestation for oil exploitation and the effect of Marraw dam on date palm production.
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Conclusion

Before the separation of Southern part of Sudan, Salih, 1996 assessed the total area affected by drought and desertification about 50.5% of Sudan's total area. The dry lands of the Sudan are 234.4 million ha constituting about 94% of the total area of the country (248.8 million ha). Out of this area 31.2%, 25.9%, 31.2% and 6.5% are hyper-arid, arid, semi-arid and dry sub-humid respectively (Ayoub,1999). Dramatic increasing was recorded after nine years, hyper-arid, arid and semi-arid lands constitute 41.2, 33.4 and 25.2% of the total area of Sudan, respectively (Mustafa, 2008), which is prone to different degrees of land degradation. The previous assessment must considering as very dangers warning. Now after separation the whole area of Sudan highly susceptible to all kind of land degradation processes, moreover all these areas are fragile ecosystem. So deterioration will be continuous unless serious measures carried out to reduce it.

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