Quantification of Sand Encroachment on Abu–Habil Valley in the Southern Fringe of the Sahara, Sudan: 2000 – 2020

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Abstract:

This research objects to quantify desert encroachment on Abu- Habil valley in a semi arid environment of Sudan. The research focuses on tracing this encroachment using GIS techniques based on Landsat 5 (TM) and Landsat 8 (OLI_TIRS) images which were downloaded from USA Geological Survey website. They are multi-temporal with high geographical coverage. Three indices were used, the Normalized Difference Vegetation Index "NDVI", the Soil Adjusted Vegetation Index (SAVI), and the Normalized Differential Sand Areas Index (NDSAI). NDSAI depends on the assumption that, sandy areas have less water content (humidity) within other earthy covers. SAVI is used to correct the index of natural differences of vegetation due to soil brightness in areas with low vegetative cover. Encroachment of sand on the watershed of Abu-Habil valley was also examined to further justify sand encroachments on the valley. Techniques of detecting changes were used to compare changes in sandy areas during these two decades. Results confirmed the encroachment of sand dunes on Abu-Habil by 4% and 13% by the two indices used and the diminishing of its watershed by 3%. These main results were discussed within the context of climate change and human pressure. A national strategy is needed to restore the areas of fragile environment of Sudan.

Key words: Desert fringe, Sand dunes, Sand encroachment, Environmental degradation.

قياس تقدم الرمال على خور ابو حبل في الحد الجنوبي للصحراء الكبري في السودان: 2000- 2020

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المستخلص:

يهدف هذا البحث إلى قياس تقدم الرمال على خور أبو حبل الواقع في بيئة السودان شبه الجافة. ركز البحث على تقفي هذا التقدم باستخدام تقنية نظم المعلومات الجغرافية بالاعتماد على المرئيات الفضائية 5 (TM Landsat 8 (OLI_TIRS) التي تم تحميلها من موقع هيئة المساحة الجيولوجية الأمريكية. وتتميز هذه المرئيات بالتغطية الجغرافية العالية والتعددية المتغيرة. استخدمت ثلاثة مؤشرات هي “NDVI Normalized Difference Vegetation Index”، و the Soil Adjusted Vegetation Index (SAVI) **و** Normalized Differential Sand Areas Index (NDSAI).. يعتمد **NDSAI** على افتراض أن المناطق المغطأة بالرمال لها محتوى مائي اقل (رطوبة) بين الأغطية الأرضية الأخرى. ويستخدم SAVI لتصحيح مؤشر التغيرات الطبيعية للنبات بسبب لمعان التربة في المناطق ذات الغطاء النباتي المنخفض. كما تم تقصي تقدم الرمال على المستجمع المائي لخور أبو حبل لزيادة التبرير لتقدمات الرمال على هذا الخور. استخدمت الطرق لرصد التغيرات لمقارنة التغيرات خلال هذين العقدين من الزمان. وقد أكدت النتائج تقدم الرمال على خور أبو حبل بنسبة 4 % و 13 % بالمؤشرين الذين تم استخدامهما وتقلص مستجمع مياهه بنسبة 3%. تم مناقشة هذه النتائج الاساسية في محتوى التغير المناخي والضغط البشري. هناك ضرورة لاستراتيجية قومية لإعادة- بناء المناطق ذات الهشاشة البيئية في السودان.

كلمات مفتاحية: حد الصحراء، كثبان رملية، تقدم الرمال، تدهور بيئي

1- Introduction

Literature on sand encroachment in savannah region confirmed its wide and rapid expansion and discussed climate change and human pressure as responsible factors. Climate change as manifested in temperature rising, rainfall fluctuations and recurring onsets of droughts is a cause for devastating impacts on lives (Nadeau, et al. 2007; . Ye, et al. 2018); different regions, and economic sectors and social groups (. Watson, et al. 1996). This has become common in parts of Asia and Africa (Dore,2005) and has resulted in decreased vegetation coverage, accelerating desertification (Fu, et al. 2017) and causing environmental degradation and loss of biodiversity (Wang, et al. 2017), change in flora composition and land cover (Klein, et al. 2007), particularly in the in arid regions (Chen, et al. 2015; Xie, et al. 2016). Desertification is a phenomenon referring to “land degradation in arid, semi-arid, and dry sub-humid regions due to climatic variations and human activities

(UNCCD, 1994). Desertification is much more complex in nature than drought and causes greater and more lasting damage. Droughts are an inherent part of arid and semi-arid climates, while desertification is triggered off and controlled by man. Desertification signifies the extension or intensification of desert like conditions through the destruction of the regeneration ability of the vulnerable ecosystems of semi arid regions (Ibrahim, 1978). From eco-geographical view desertification could be defined as decrease in land surface phenology caused by biotic and a biotic factors (Eltom et al. 2015).

A watershed is an area of high ground that divides two or more river systems so that all streams flow into one river. Streams in a watershed are organized as a network, and the stream order indicates the level of branching in a river system. Both river basins and watersheds are areas of land that drain to a particular water body, such as a lake, stream, river or estuary. In a river basin, all the water drains to a large river. The term watershed is used to describe a smaller area of land that drains to a smaller stream, lake or wetland.

This research objects to quantify desert encroachment on Abu- Habil valley in a semi arid environment of Sudan. The core of investigation as depicted by the results will be in the reversed relationship of vegetation areas versus sandy areas as well as changes occurred in its watershed.

Materials and methods

2.1. Study area

Flowing from the heights of the Nuba Mountains in southern Kordofan State, Abu Habil valley directs northwards to form the Rahad Water Bond, and then eastwards to form a huge Delta on the reachings of the White Nile at eastern Tendelti town (Figure 1). By so, it emerges from a semi-humid environment to a semi- arid environment in the southern fringe of the Sahara to hold the characteristics of poor savannah with sparse vegetation and medium to low rainfalls. This study also assumed that climatic conditions are similar in the area of interest in the summer season and the highest temperature of the sandy area in the day is at 12 and reaches its peak about 1 pm at the local time while the highest annual temperature is in August (Zhang et al., 2012).

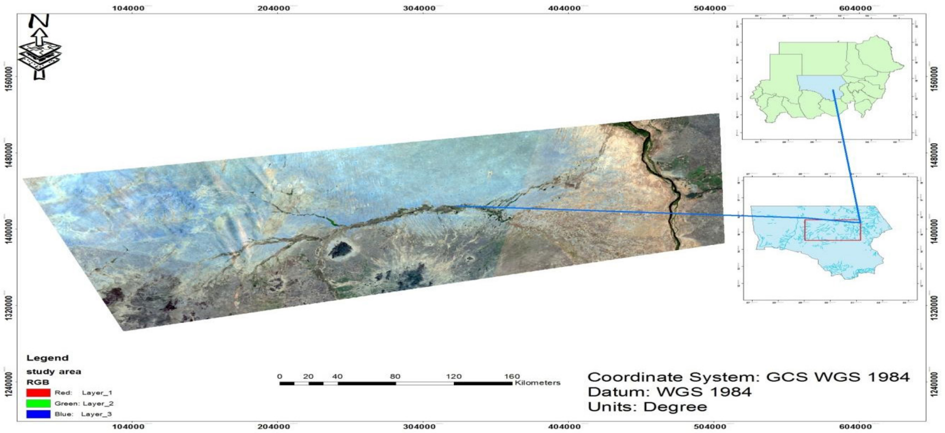

Figure 1: Location of the study area

Source (GSUS-GLOVIS) improved

2.2. Assessment methods

2.2.1. Data sources

Landsat 5 (TM) and Landsat 8 (OLI_TIRS) images were downloaded for the years 2000 and 2020 respectively from USA Geological Survey website. They are multi-temporal with high geographical coverage and temporal accessibility. Their spectral band characteristics were presented in table 1.

Table1: Characteristics of the Landsat images utilized in this study

satellites resolution	Sensors	Data	Path/Row	Level	Spatial
Landsat-4&5	TM	14/2/2000	(173/51) (173/52) (174/51) (174/52) (175/51) (175/52)	Level 1	30m/Multispectral bands 60m/ Thermal bands
Landsat-8	ETM	14/2/2020	(173/51) (173/52) (174/51) (174/52) (175/51) (175/52)	Level2	15m/Panchromatic band 100m/ Thermal bands

2.2.2. Data analysis

An integrated approach was applied for data processing (Fig. 2). The satellite imageries were analysed using ERDAS Imaging 2014 and Arc Map 10.7, where the images were pre-processed through radiometric and geometric correction image enhancement, and supervised classification with aid of remote sensing and geospatial software. In addition, Microsoft Excel 2016 was used in computing the changes on sand dunes encroachment on Abu-Habil valley. The accuracy assessment was systematically performed for each satellite image.

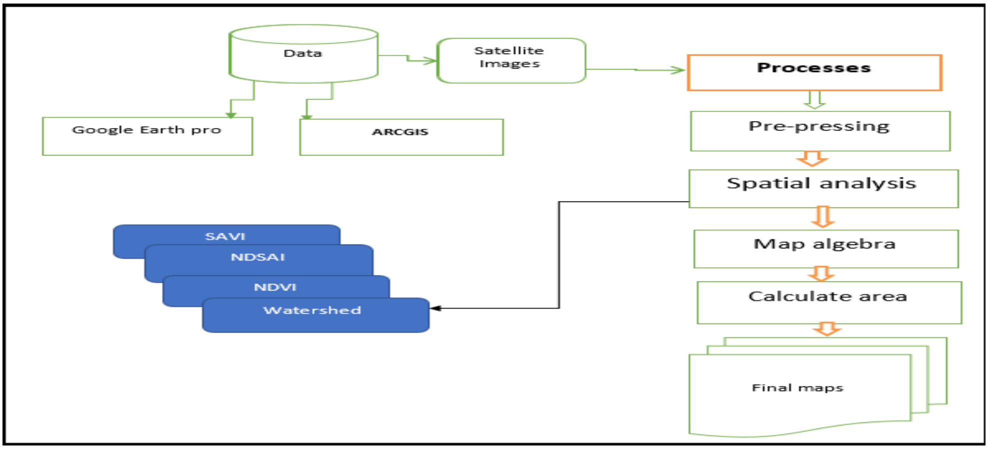

Fig.2. Steps of data processing

Three indices were used to quantify desert encroachment in the study area which were, the Normalized Difference Vegetation Index "NDVI", the Soil Adjusted Vegetation Index (SAVI) and the Normalized Differential Sand Areas Index (NDSAI). The Normalized Difference Vegetation Index "NDVI" was initially proposed by the reference and was derived from the ratio of band 3 (Red) and band 4 (NIR) of the Landsat TM image data set. It was used to monitor the changes in the vegetation cover using the formula:

$$\mathbf{NDVI = (NIR - R) \backslash (NIR + R) \quad (1)}$$

Soil Adjusted Vegetation Index (SAVI) was used to correct the Normalized Difference Vegetation Index (NDVI) for the influence of soil brightness in areas where vegetative cover is low. SAVI could account for assortments of soils and unearthly lists may be calibrated in such a way that the assortments of soils are normalized and do not affect estimations of the vegetation canopy. The Landsat Surface Reflectance-derived SAVI is calculated as a ratio between the R and NIR values with a soil brightness correction factor (L) defined as 0.5 to accommodate most land cover types. The SAVI formula is:

$SAVI = (NIR - R) / (NIR + R + L)) * (1 + L)$ (2)

The red band has been used in the negative sign of Equation 2 so that the sandy areas have a positive value since their reflectivity in the SWIR1 band is higher than in the red band, extreme from higher heat retention and therefore exhibit progressively higher thermal inertia values. Moreover, the drought of the sandy areas and its inability to conserve water is one of the factors that heat the sandy area more quickly than other materials.

One of the problems concerns SAVI was associated with its cursor that was not accurate in identifying sandy areas where some mixed pixels were classified as sandy areas and others as non-sand ones. Also, it did not recognize some sandy areas close to watersheds and agrarian areas that shrink due to high temperature in the surroundings.

The Normalized Differential Sand Areas Index (NDSAI) was developed by using the red and short-wavelength infrared "SWIR1" bands as "SWIR1", which is more sensitive to the moisture content of soil than "SWIR2" (Jasim AL-a'araage, 2012). Therefore, the areas of sand can be well distinguished from the rest of the soils and vegetation areas since they are free of moisture in dry regions, or they rapidly lose water content in humid regions. The NDSAI formula is:

$NDSAI = (SWIR1 - R) \backslash (SWIR1 + R)$ (3)

Where:

R: the reflectance of the red band (0.63–0.69 µm)

SWIR1: the reflectance of the short-wavelength infrared1 band (1.57–1.65 µm)

The values of NDSAI range between ($-1 \leq NDSAI \leq 1$). The sandy areas and the different kinds of soil as well as vegetation areas have values often higher than zero (>0). Water has values less than zero (<0).

3. Results

3.1. Sand encroachment on vegetative cover

Table (2) presents statistics of sand encroachment on Abu-Habil valley from 2000 to 2020 which was calculated from figures 3 A, B). Based on the Normalized Differential Sand Areas Index (NDSAI), sand coverage of the total area was 53% in the year 2000, and increased to 56% in 2020. This means that, sand encroachment was 3% for whole the period with an annual percent of 0.15% coverage. The Soil Adjusted Vegetation Index (SAVI) calculated a sand coverage by 77% in 2000 and 90% in 2020 which means a 13% encroachment of sand area for whole the period and 0.65% annual sand encroachment. The Normalized Differential Sand Areas Index (NDSAI) confirmed the loss of nearly 148, 563 hectares of non- sandy areas by 2020 while the Soil Adjusted Vegetation Index (SAVI) confirmed the loss of 884 hectares (Table 2). The loss of non sandy area was more in the northern parts surrounding Abu- Habil valley.

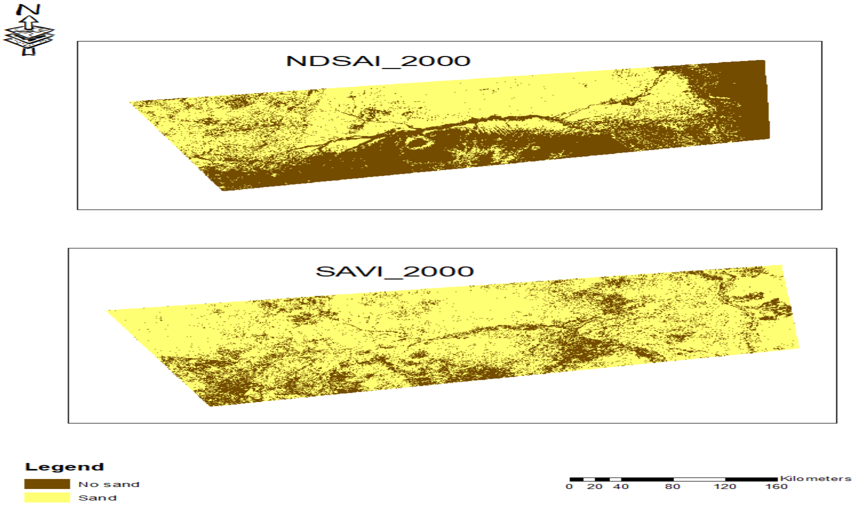

Figure (3,A) determination of sandy and non sandy areas by NDSAI and SAVI indices in the year 2000

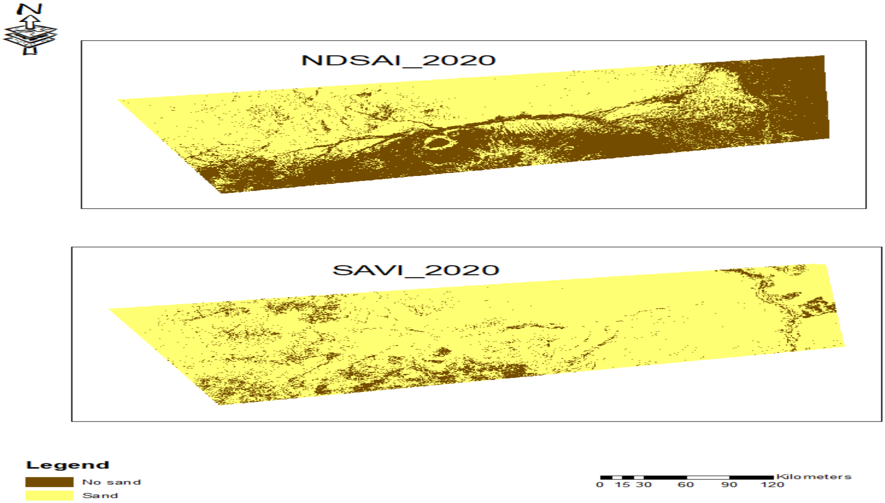

Figure (3, B) determination of sandy and non sandy areas by NDSAI and SAVI indices in the year 2020

Table (2) measurement statistics of sandy and non sandy areas by **NDSAI** and **SAVI** indices (Km^2) in the years 2000 and 2020

NDSAI	Sandy area	Non-sandy area	Total area
Year: 2000	3576952	3180131	67,583,924,622
%	**53**	**47**	(100)
Year: 2020	3783966	2973116	67,583,924,622
%	**56**	**44**	(100)
SAVI	Sandy	Non-sandy	Sum
Year: 2000	5087867	1552539	67,583,924,622
%	**77**	**23**	(100)
Year: 2020	5966853	667957.3	67,583,924,622
%	**90**	**10**	(100)

The statistics of the Normalized Vegetation Index (NDVI) (table 3 and figure 4: A,B) shows the decrease of the area covered by vegetation by 4% during two decades with an average annual sand encroachment on the vegetative cover by 0.2%. Area covered by vegetation constituted 43% of the total area in the year 2000 and decreased to 39% by the year 2020.

Table (3) statistics by NDVI index for Determination of sand encroachment on the vegetative cover in the years 2000 and 2020

NDVI	Area covered by vegetation (km^2)	Area uncovered by vegetation (km^2)	Total areas (km^2)
Year: 2000	2891381	3851998	67,583,924,622
%	43	57	100
Year: 2020	2681790	4076622	67,583,924,622
%	39	61	100

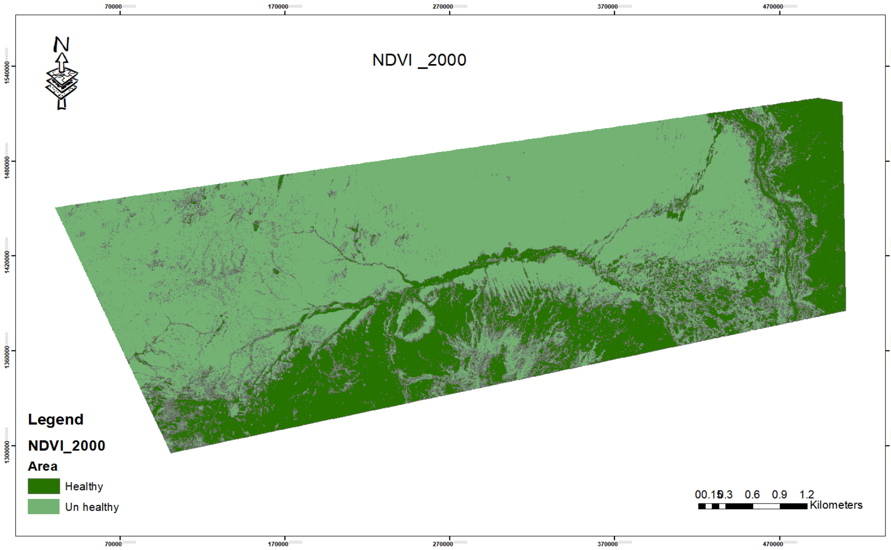

Figure (4, A): **NDVI** index for Determination of sand encroachment on the vegetative cover in the year 2000

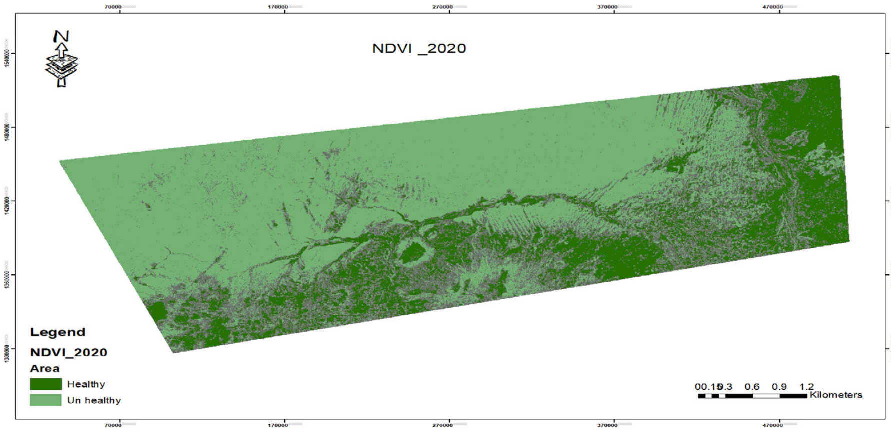

Figure (4, B): **NDVI** index for Determination of sand encroachment on the vegetative cover in the year 2020

3.2. Sand encroachment on Abu-Habil watershed

Reference to figure (5) the watershed of Abu-Habil valley in 1984 is distinctive was its three ordered valleys of first, second and third orders. Third order valleys include some other valley flowing from nearby catchment areas around Abu- Habil valley. They flow into Abu-Habil and considerably contribute into its water budget to enhance its flow eastwards to drain into its delta east of Tendelti town.

In the year 2000 sands have covered tributary branches of first order of the basin and have jumped to the southern part of the valley (figure 6). In the year 2020 the sandy area expanded in the northern part around the valley and has covered the first and second ordered valley eastwards of Abu Habil valley (Figure 7). Comparing the years 2000 and 2020 gives a 3% sand encroachment of the watershed of Abu Habil valley.

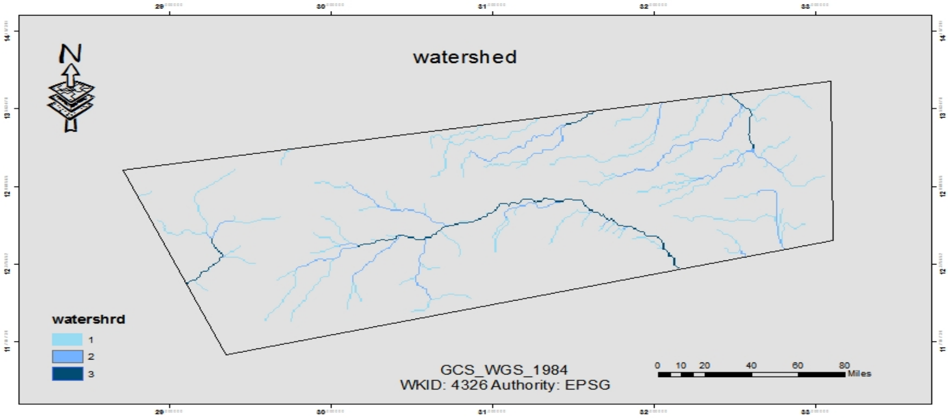

Figure 5: the watershed of Abu Habil valley in the year 1984

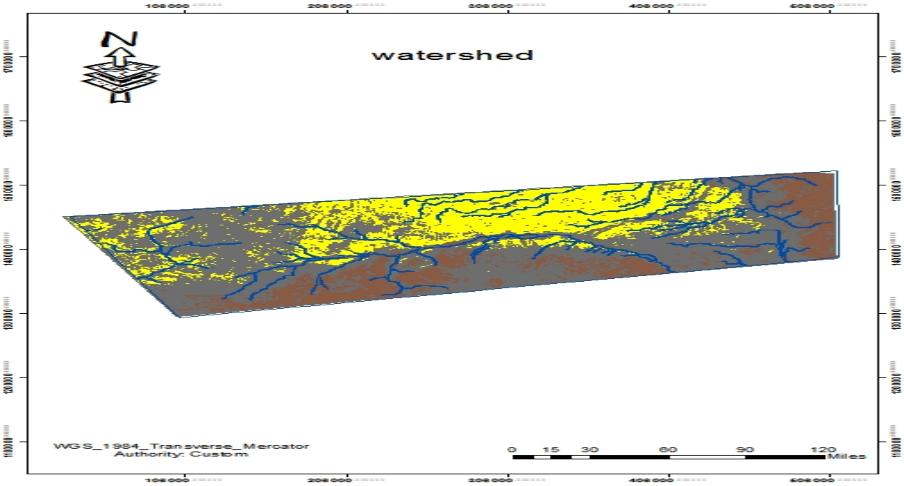

Figure 6: Sand encroachment of the watershed of Abu- Habil valley in the year 2000

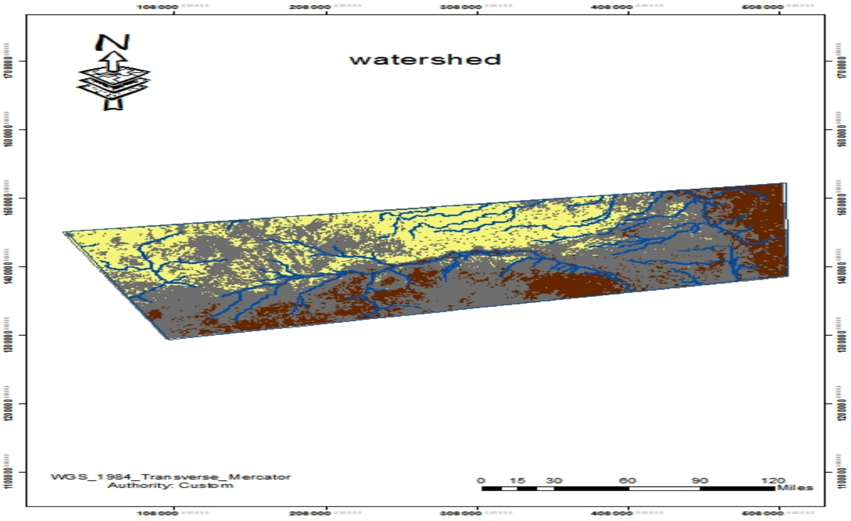

Figure 7: Abu Habil watershed in the year 2020

4. Discussion

The results of sand encroachment on Abu-Habil valley as experimented by the vegetation cover index and shrinking of its watershed could be discussed within the context of climate change and human pressure as responsible factors for deterioration of the vegetation cover which excessively decreased the area of the basin and its watershed. The impacts of climate change on vegetation have been documented worldwide. There is evidence that in the 20th century, warming was faster than the shifts in species ranges (Houghton, 1990), what may lead to extensive biodiversity losses (IPCC, 1996). Increases of 2 to 3°C are predicted for Armenia's climate, along with declines in rainfall, resulting in increased risks of desertification. This is likely to severely affect wetland habitats and associated species, while changes in the distribution of habitats may affect the range and viability of a number of species (Liddle, 1975). Precipitation regimes determine oceanity or continentality, which in turn influence plant distribution. Timberline is very likely growth-determined, with a lower thermal threshold defined by seasonal values of mean air temperature between 5.5 and 7.5°C. The decrease of mean air temperature with elevation appears to be in close correlation with the general decrease of species richness with elevation (Grabherr et al., 1995).

Drought area in East Africa is likely to increase at the end of the 21st century by 16%, 36%, and 54% under Representative Concentration Pathways (RCPs) 2.6, 4.5, and 8.5 respectively, with the areas affected by extreme drought increasing more rapidly than severe and moderate drought. Spatially, drought will increase in Sudan (Gebremedhin et al. 2020) as the observed climatic modification in Sudan has exaggerated the insidious drought conditions (Elagib et al. 2000). Meteorological data for a period of 30 to 50 years in Sudan confirmed that temperatures are rising and rainfall declining. There is a changing pattern in the trend of relative humidity, clouds, radiation and evaporation which may accelerate environmental degradation and desertification in Sudan (Alvi, 1994). According to Hulme (1990) rainfall depletion has been most severe in semi-arid central Sudan between 1921 to 1950 and 1956 to 1985 annual rainfall has declined by 15%, the length of the wet season has contracted by three weeks, and rainfall zones have migrated southwards by between 50 and 100 km. This depletion has been due more to a reduction in the frequency of rain events rather than to a reduced rainfall yield per rain event. Ayoub (1999) compared long-term rainfall in four sub regions in Sudan and showed that rainfall decline had been in the magnitude of 30-40%. The western parts of the Sudan (Kordofan and Darfur) experienced extreme rainfall anomalies than the eastern and central parts (Gedarief ‘’Butana’’ and Damazin), and had suffered greater periods of desiccation than the eastern and central parts. The decadal rainfall means showed below average rainfall for the last three decades in all these sub regions.

The area in north desert boundary predicted as risk areas was converted into desert like conditions (Eltom et al. 2015). Early several studies depicted the ecological deterioration of vegetation cover in Sudan were used to cover most areas of the country (Stebbing, 1972). Decreased shrub abundance in the year 2020 in south of Port Sudan area could be due to significantly higher temperature after 1998. The overall increase in temperature and decrease in precipitation from 1985 to 2015 indicate a potential threat to vegetation in this area in the future (Loh et al. 2020). In central North Kordofan State long-term desertification/re-growing of vegetation cover over time and space were estimated where over the last 21 years, desertification significantly prevailed over vegetation re-growth particularly in areas around rural villages (Dawelbait et al. 2012). Generally, land degradation, and desertification processes in arid and semi-arid environment were increased in the last four decades, especially in the developing countries like Sudan (Salih et al. 2017).

The fate of seasonal river ecosystem habitats under climate change essentially depends on the changes in annual recharge of the river, which are related to alterations in precipitation and evaporation over the river basin, therefore, the change in climate conditions is expected to significantly affect hydrological and ecological components, particularly in fragmented ecosystems. Climate over the Diner River Basin will become warmer and wetter and the projected strenflow is quite sensitive to rainfall and temperature variation, and will likely increase to affect ecosystems in Diner National Park positively and promote the ecological restoration for the habitats of flora and fauna (Basheer et al. 2016).

Human activities such as land use and deforestation are participating factors. Human pressure at the national level in Senegal show moderate change, with a modest decrease in savannas from 74 to 70% from 1965 to 2000, and an expansion of cropland from 17 to 21%. However, at the eco-region scale, rapid change in some and relative stability in others was observed (Tappana et al., 2004). Also, the land use by its various interests, and including man, in Târgoviste Plain, Romania led on the one hand to restrict the areas occupied by natural plant formations (replaced by crops, secondary plant formations or 184 J. Geogr. Reg. Plann. become unproductive due to land degradation), and on the other hand, changes more or less pronounced in the composition and structure of vegetation cover in parts where the natural vegetation was maintained. This is all the greater as an agricultural activity has attracted the circuit area where the initial spontaneous vegetation was replaced by different other cultures (Mihaela et al., 2010). In addition, Michael et al. (2003) identified the human induced pressure and their impacts on water resources in Wtirm catchment in the Neckar River basin in southwest Germany that the impacts detected are much more severe in this catchment compared to assessment results, which were derived in other catchments with lower degrees of human pressures. The potential impacts of human activity-induced climate change on natural vegetation in China confirmed northward shift of vegetation types, with an increase in the areal extent of tropical rain forests and decrease of cold temperate coniferous forest and tundra (Wang and Zhao, 1995). In Israel, biodiversity in urban development and agriculture cause rapid habitat destruction, fragmentation into smaller habitats and loss of connectivity between populations all leading to species extinction (Guy and Uriel, 2000).

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 (Abdi et al. 2013), (see figure 8). In Umm-Ruwaba district, where a part of Abu-Habil valley flows there, desertification has been attributed largely to a shortening of the soil-renewing fallow period, carried out in an attempt to make up for declining crop yields per unit area, and also to overexploitation of the protective tree cover, largely for the making of charcoal, as a source of needed cash income (Khogali, 1991).

Figure 8: Desert encroachment in northern Sudan

Drought, deforestation, overpopulation and overgrazing have accelerated desert encroachment and have exerted huge pressure on the ecology of southern Darfur (Robinson, 2005) particularly in areas around rural villages. Changes in land use and mismanagement of natural resources were the main driving factors affecting degradation. More than 120,000 km^2 were estimated as being subjected to a medium-high desertification rate (Dawelbait et al. 2012). Waugh (1999) attributed 70% of the problem of desertification to many factors among which is uncontrollable population growth.

5. Conclusions

The main results of this research could be summarized as follows:

1- NDSAI index shows an increase in sandy area by 3% during the two decades, while SAVI index shows an increase by 13%. The difference in the results given by the two indices could be attributed to that, SAVI index depends on determining sandy area as based on vegetative cover while NDSAI index is more precise since it depends on wave length which determine soil types more obviously (SWIRI)

2- These moving sands have encroached on Abu-Habil watershed. In the year 2000 sands have covered the first ordered branch of the basin accompanied by jumping of sands into the southern part of the basin. In the year 2020 sands have covered the first and the second order branches in the northeastern watershed. During these two decades the area of the basin has diminished by 3%.

These results confirm the high vulnerability of Abu – Habil valley to the threats of sand encroachment as it neighbors the Sahara and the witnessed repercussions of climate change and excessive human pressure due to factors outlined here. This problem is not restricted to Abu-Habil valley alone; however, it impacts on many parts of Sudan. Therefore, a national strategy is needed to restore the areas of fragile environment of Sudan.

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