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Using Remote Sensing Applications (Vegetation Indices) to Estimate the Land Use and Land Cover in Semi-Arid Areas of Sudan

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Abstract

Vegetation is one of the most dynamic elements of the ecosystem. Hence, monitoring vegetation degradation through the use of various vegetation indices plays an important role in the quantitative assessment of its vigour, which can be used for detecting land use change pattern and vegetation density in semi-arid region. In Sudan where fragile ecosystems are dominant, the vast majority of the rural population depends solely on agriculture, and pasture as a means of living, the ecological pattern had been greatly impaired, resulting into loss of vegetation cover coupled with variation in climate. This study describes the use of normalized difference vegetative index (NDVI) to quantitatively examine the vigour of vegetation in Sudan through different vegetation indices. Cloud free multi-spectral remotely sensed data from LANDSAT Thematic Mapper (TM) and Enhance Thematic Mapper plus (ETM+) for the dry season months of 1985 and 2010 were used in this study. In this study, vegetation indices (NDVI, SAVI, GSI) comprising of two or more spectral bands were used to examine vegetation degradation over 25 years. The normalized difference vegetation index (NDVI) was used to assess areas, which had been undergoing changes over time. The results of this study shows conversion of vegetation cover to other land use type, which is an indication of vegetation degradation. The results of the NDVI in 1985 (vegetated area) showed that an area of about 21% was covered by vegetation while 50% of the area were covered with vegetation in 2010. Similar increases in vegetated area were observed from the results of SAVI and GSI for 2010 respectively. Variation in the results of bare and cultivated land was observed from the results of this study. An increase in area covered by sand land was observed from the results of soil adjusted vegetation index (SAVI) and topsoil grain size index (GSI).

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The result of SAVI showed that about 30% of the total area was covered with sand land in 2010 as compared to that of 1985 in which the area covered with sand land accounts for 27%. In addition, the results of GSI showed an increase of about 40% in the area covered with sand land in 2010 and 53% in 1985. The results obtained from SAVI and GSI is an indication of loss in vegetal cover due to conversion of land such as agricultural activities and extensive rangeland expansion. Although, increase in vegetated area were observed from the result of this study, this increase has a negative impact as the natural vegetation are degraded due to human induced activities which gradually lead to the replacement of the natural vegetation with invasive of tree species (Mesquite). The results of this study shows that vegetation degradation in the semi arid region of Sudan is associated with increase in sand land on expense of cultivable land. Hence, the study therefore suggest the use of different imagery with high resolutions to further analyse vegetation degradation in order to increase the validity and accuracy of vegetation change patterns and their relation to climatic variability in the semi-arid lands of Sudan.

Keywords: Remote sensing; Vegetation; NDVI; SAVI; GSI; Sudan.

1. Introduction

Vegetation indices means; some mathematical combination or transformation of spectral bands that accentuates the spectral properties of green plants so that they appear distinct from other image features. Vegetation Indices (VIs) obtained from remote sensing-based canopies are quite simple and effective algorithms for quantitative and qualitative evaluations of vegetation cover, vigour, and growth dynamics, among other applications ([1,2]).

Since the 1960’s scientists have extracted and modelled various vegetation biophysical variables using remotely sensed data. Much of the effort has gone into the development of vegetation indices – defined as dimensionless, radiometric measures that function as indicators of relative abundance and activity of green vegetation, often including leaf-area-index (LAI), percentage green cover, chlorophyll content, green biomass, and absorbed photosynthetically active radiation (APAR) [3].

Estimation of vegetation parameters for various purposes has a long history of research in remote sensing literature. The estimators - or vegetation indices - have commonly used a two-dimensional data space represented by the Red and NIR spectral range. Land cover analysis was done using different slope and distance based vegetative indices (VI’s). This helps in identifying observed physical cover including vegetation (natural). VI is computed based on the data grabbed by space borne sensors in the range 0.6-0.7 (red band) and 0.7-0.9 (Near-IR band), which helps in delineating the area under vegetation and non-vegetation areas. Vegetation degradation has resulted from various factors including human-induced activities and severe prolonged drought under poor land resource management [4]. Its assessment and monitoring entail the use of remote sensing data that offers the possibility of gaining environmental data over both large areas and relatively long

time-periods. Hence, various ecological studies, including that of the polar environment, are now using the remotely sensed NDVI, e.g. MODIS-NDVI as a proxy of vegetation productivity rather than performing direct vegetation ([5,6]). One of the major applications of remote sensing data is the detection and quantification of green vegetation. However, Vegetation indices (VIs) are based on digital brightness values; they attempt to measure biomass or vegetative vigour. The analysis of vegetation and detection of changes in the vegetation pattern on spatial and temporal scales, are keys to monitoring and assessment the natural resource. Thus, the detection and quantitative assessment of vegetation is one of the major applications of remote sensing for environmental resource management and decision-making. However, over the years, new vegetation index models have been developed to detect sparse green vegetation and simultaneously minimize the effects of soil background brightness, topographical distortion (primarily aspect and slope), and atmospheric “noise”. The two main groups of vegetation indices (either vegetation or soil) are referred to as slope-based and distance-based. The slope-based Vegetation Indices are simple arithmetic combinations of two or more spectral bands. Distance-based Vegetation Indices require the plotting of a soil line using regression of soil values for the red and near infrared bands. The main objective of the distance based vegetation index is to cancel the effect of soil brightness in cases where vegetation is sparse and pixels contain a mixture of green vegetation and soil background. This is particularly important in arid and semi-arid environment. Therefore, vegetation indices can be used as degradation and desertification monitoring Indicators to monitor land desertification and dynamic changes ([7,8]).

Arid and semi-arid lands cover approximately one third of the continental surface of the earth. They include the deserts, their semi-arid and sub-humid dry margins, and the subtropical Mediterranean latitudes. Because of the vast area covered these lands play a major role in energy balance and hydrologic, carbon and nutrient cycles. The dry land areas are characterized by irregularity and shortage of rainfall, prolonged dry seasons, high temperature and high evaporation. Such variation in climatic factors makes drylands more fragile and prone to land degradation and desertification.

2. Materials and methods

The Gash Agricultural Scheme (GAS) in Kassala State eastern Sudan is place where this research was conducted,which is located in the arid and semi-arid region.Gash is a river coming from the Eritrean Ethiopian highlands, it runs along a watercourse (wadi) (where the study area is located) carrying water directly to a very fertile inland delta (the Gash Die). Gash agricultural scheme (GAS) is considered the first scheme in Kassala state for the livelihood of the people in and around the Gash river area. The scheme was established in 1930 with a total area approximately 900,000 acres between altitudes 15.3 and 16.3 N and longitude 35.5 and 36.3 E, using irrigation by the Gash river and rainfall for 750,000 acres or more depending on the flood of the river and rainfall during the season. However, the scheme was constructed for poverty reduction by cash economy improvement through cotton and caster cultivation as cash crops, Sorghum as the main staple crop, using the flooding for irrigation ([9,10]). Figure1, shows the of the study area location.

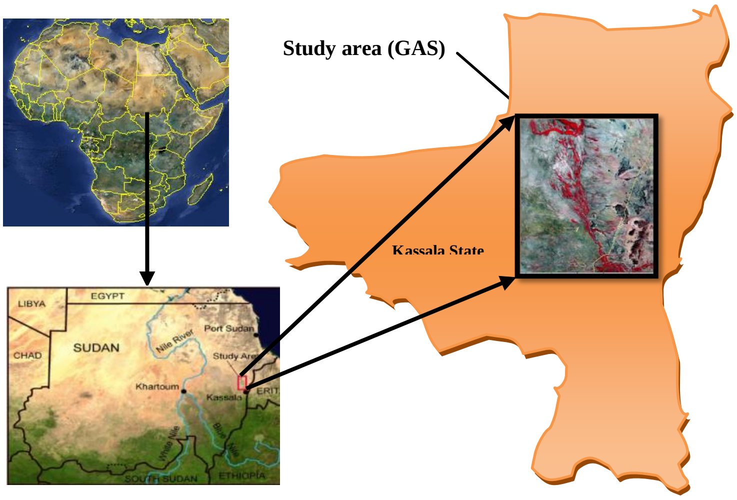


Figure 1: The study area location (modified by author, ETM+ image 2010)

2.1. Methodology

Remote sensing is a methodology of multi-disciplinary approach. Therefore, the traditional methods for monitoring land-cover change relying on field data and aerial photography can be costly and time-consuming for relatively large areas ([11,12]). However, in recent years the application of remote sensing techniques in many thematic areas (e.g., Earth Sciences) has been extended and supplements the conventional methods of data collection [13].The methodology adopted for this study takes into consideration; the data acquisition, different image correction techniques including georeferencing and geometric, radiometric and atmospheric corrections and image enhancement. Vegetation indices and supervised classification techniques based on maximum likelihood classifier were used to achieve the aim of the study that attempt to quantitatively examine the vigor of vegetation in semi-arid land of Sudan. To extract the information for overall condition of vegetation and its status in the study area, free cloudy Multi-temporal Landsat data i.ethematic mapper (TM) 1985 and enhance thematic mapper plus (ETM+) 2010was ordered free of charge from the United States Geological Survey (USGS)via Global Visualization Viewer (GLOVIS) as illustrated in figure 2. These data sets were acquired in dry season to mitigate the seasonal fluctuation in the study area. To remove distortions and differentiation in the geographical location of the data, some corrections and enhancements methods were done e.g. histogram, stretching, resembling and rectification, radiometric, geometric and atmospheric corrections ([14,15]) using both ENVI and ERDAS imagine 9.2. The reasons for selecting Landsat imagery are due to the free access, appropriate spatial and spectral resolution, coupled with its relevant to the objectives of the study. Figure1 shows the methodology (Flow chart) for this study. The characteristics of remotely sensed imagery are illustrates in Table 1. The ancillary data such as GPS training samples (ground truth points) were also used to facilitate and enhance the classification process. In addition to visual interpretation, SPSS package were applied to analyse and finalize the results and creating the maps. Three vegetation indices methods were applied in this study in order to examine the vigour of vegetation in semi-arid land of Sudan; these are Normalized difference vegetation index (NDVI),

Three vegetation indices methods were applied in this study in order to examine the vigour of vegetation in semi-arid land of Sudan, these are Normalized difference vegetation index (NDVI), Soil adjusted vegetation index (SAVI) and Grain size index (GSI) as shown in table 2. Vegetation indices are considered one of the major applications of remote sensing data in detecting change and quantification of green vegetation (Kumar and his colleagues 2010). Actually, these indices are useful in identifying areas of healthy vegetation based on the difference between the maximum absorption of radiation in the red due to the chlorophyll pigments and the maximum reflection of radiation in the NIR due to the leaf cellular structure [3]. NDVI as expressed by [3] provide useful information for detecting and interpreting vegetation of land cover,it is also used for classification, evaluation and change detection assessment. The formula for NDVI is as follows;

$$NDVI = (NIR - RED) / (NIR + RED)$$

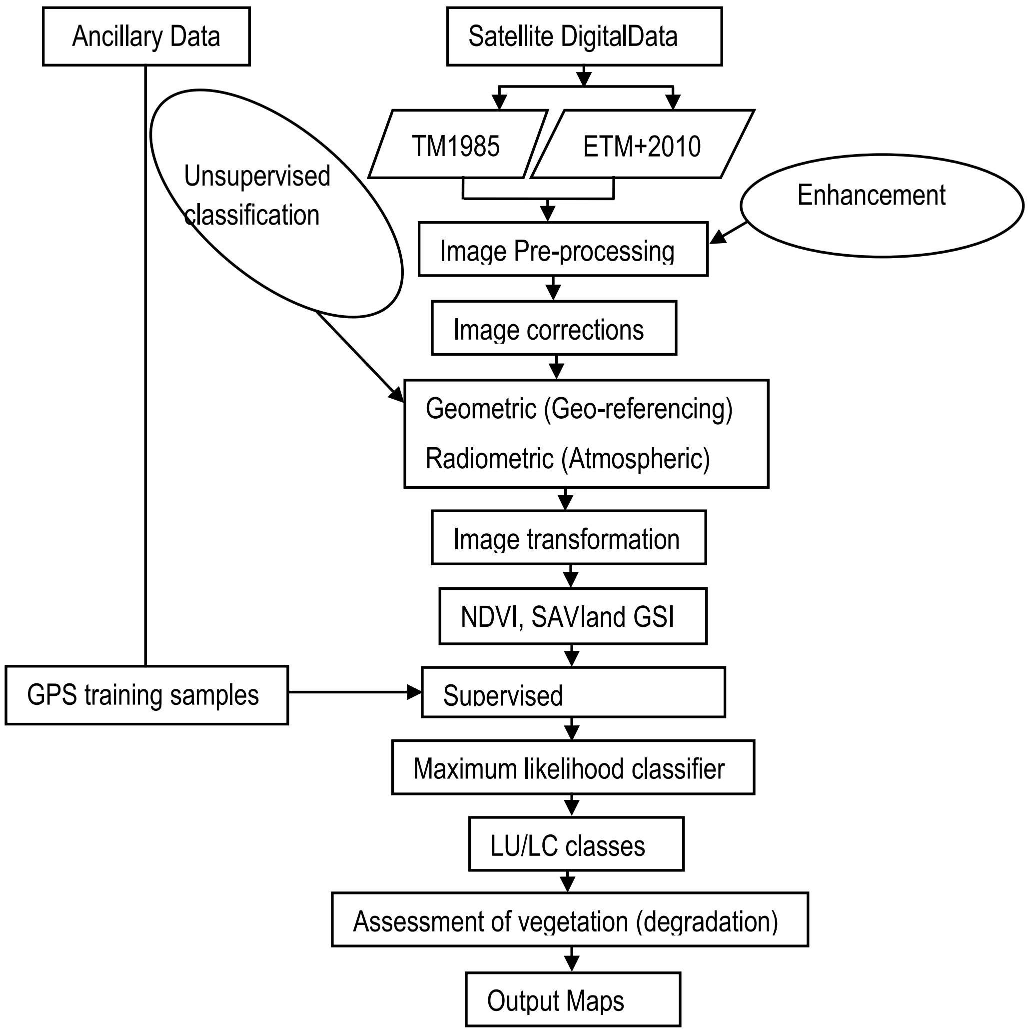


Figure 2: Flow chart of work approach

Table 1: Properties of the database used in the study

Satellite	Acquisition date	Spectral bands	Ground resolution
Landsat Thematic Mapper TM	05.Nov.1985	7 bands	30 m
Landsat Enhance Thematic Mapper plus ETM+	17.Nov. 2010	7 bands	30 m

Table 2: Specifications of the vegetation indices used in the study

Indices	Specifications
NDVI	***NDVI = (NIR – RED) / (NIR + RED)*** NIR= Near Infrared Band RED= Red band
SAVI	$\mathrm{SAVI} = \frac{(\mathrm{NIR} - \mathrm{RED}) * (1 + \mathrm{L})}{(NIR + RED + L)}$ (1+L) is the multiplication factor added so that the index can conform to the maximum and minimum NDVI range. For most purposes and in this study, the value of L is 0.5, corresponding to intermediate vegetation canopy cover.
GSI	R, G and B= red, green, and blue visible bands of the remote sensing data. GSI value is close to 0 in vegetated area, and for a water body, it is a negative value. For sand = 0.0075-0.0425um.

SAVI as expressed by [16] reduces the effect of soil brightness background on NDVI and is calculated by shifting the NIR and red channels towards a negative origin by adding a constant factor (L) to the NDVI formula is;

$$\mathrm{SAVI} = \frac{(\mathrm{NIR} - \mathrm{RED}) * (1 + \mathrm{L})}{(NIR + RED + L)}$$

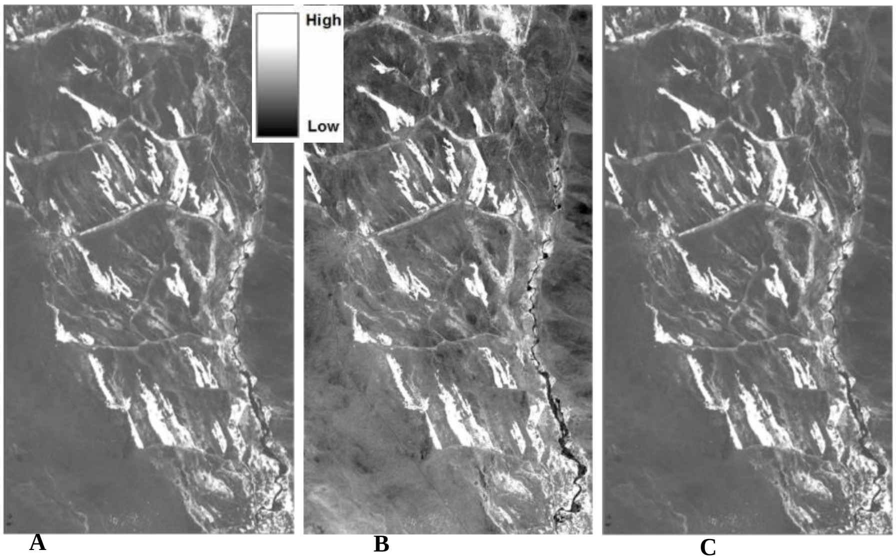
The (GSI) was developed by [17] to determine the upper soil texture and the assessment of land degradation in semi-arid regions of Asia (China Mongolian). The formula for GSI is;

$$GSI= (R-B) * (R+B+G)$$

In order to calculate the amount of vegetation quantitatively and qualitatively, supervised classification using maximum classifier was applied to images produced by vegetation indices to get the final map of vegetation for the study area.

3. Results and discussion

The results of the applied NDVI, SAVI and GSI to the images of TM 1985 and ETM+2010 produced two vegetation maps as shown in figure3 and 4. In order to calculate the amount of vegetation, which were produced, by NDVI, SAVI and GSI, the maximum likelihood classifier (MLC) was applied (figure 5 and 6) which calculates the values of NDVI for each class over time for the two images. The extracted NDVI values were categorized into five types of land use land cover classes explicitly as shown in table 3.2. However, due to the high NDVI value it is easily to distinguish woodland from grass and shrubs.



A B C

Figure 3: Vegetation map for TM 1985 using (A) NDVI, (B) GSI and (C) SAVI

By using visualization interpretation and comparison of classifications maps of MLC and NDVI, the results shows that, there are high differentiations in vegetation distribution during the 25 years of the study period.Table 4, represents the percentages of the real areas of vegetation cover (*High dense of mesquite trees, Low dense of mesquite trees*), bare and cultivated land and the sand area (*stabilized sand and mobile sand*) from the total area based on the analysis of the NDVI. The results of the NDVI in 1985 (vegetated area) showed that about 21% was covered by vegetation while 50% of the area were covered with vegetation in 2010, other classes significantly were increasing or decreasing during this period.

Table 3: Land use and land cover classes

No	Class Name
1	High dense mesquite trees
2	low dense mesquite trees
3	Bare and Cultivated land
4	Stabilized sand
5	Mobile sand

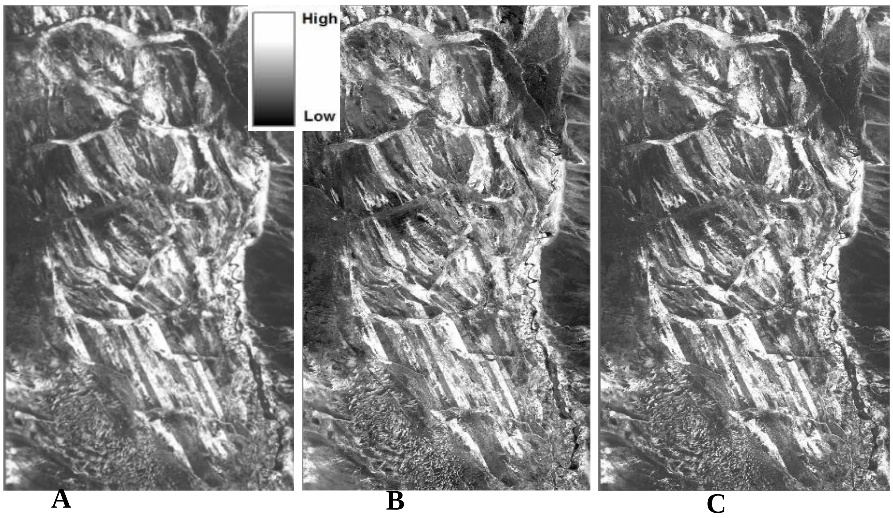
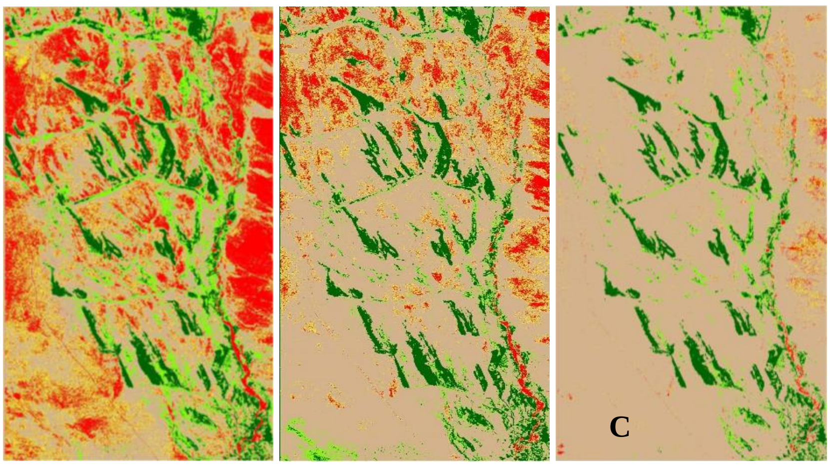


Figure 4: Vegetation map for ETM+ 2010 using (A) NDVI, (B) GSI and (C) SAVI



High dense mesquite trees
Low dense mesquite trees
Bare and cultivated land
Stabilized sand
Mobile sand

Figure 5: Vegetation classified map of TM1985 using MLC for (A) NDVI (B) GSI and (C) SAVI

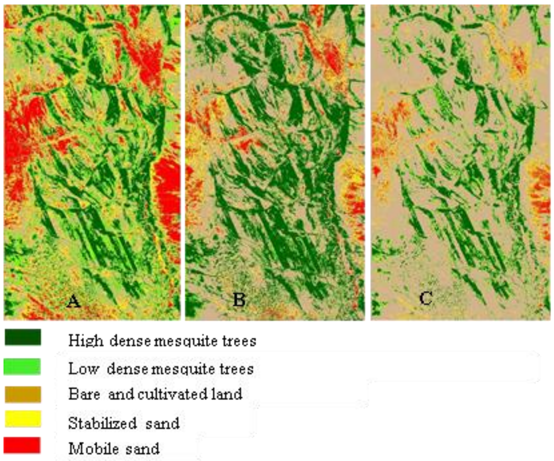


Figure 6: Vegetation classified map of ETM+2010 usingMLC for (A) NDVI (B) GSI and (C) SAVI

In table 5, the results showed that vegetated areas observed by SAVI in1985is about 39% while 46% of the area were covered by vegetation in 2010, significant reduction in the area covered by bare and cultivated area was observed in 2010.The class sand area observed also was a little increased. The results in table 6 showed that, vegetated area by GSI is about 24% in1985 while the areas covered with vegetation in 2010 were 45%. Hence, similar increases in vegetation areas were observed by either NDVI, GSI and SAVI between 1985 and 2010 respectively.

Table 4: percentage of the areas change during the study period using NDVI

NDVI / years	Vegetation area%	Bare and cultivated land%	Sand land %
TM 1985	20.5	22.12	57.67
ETM+2010	50.03	07.04	43.00

Table 5: percentage of the areas change during the study period using SAVI

SAVI / Years	Vegetation area%	Bare and cultivated land%	Sand land %
TM 1985	38.23	35.10	26.71
ETM+ 2010	45.75	25.05	29.2

Table 6: percentage of the areas change during the study period using GSI

GSI / Years	Vegetation area%	Bare and cultivated land%	Sand land %
TM 1985	23.92	23.65	52.62
ETM+ 2010	44.44	15.18	40.53

Variation in the results of bare and cultivated land was observed from the results of this study. A decreased in area covered by sand land was observed from the results of soil adjusted vegetation index (SAVI), while an increase by topsoil grain size index (GSI). The result of SAVI showed that about 30% of the total area was covered with sand land in 2010when compared to that in1985, which the area covered with sand land accounts for 27%. In addition, the results of GSI showed an increase of about 40% in the area covered with sand land in 2010 and 52% in 1985. The results obtained from NDVI and GSI is an indication of loss in vegetal cover due to conversion of land for other purpose such as agricultural activities and extensive rangeland expansion. The results of this study shows conversion of vegetation cover to other land use type, which is an indication of vegetation degradation in the study area. Although, an increase in vegetated area were observed from the result of this study, this increase has a negative impact as the natural vegetation are degraded due to human induced activities which gradually lead to the replacement of the natural vegetation with invasive of tree species (Mesquite trees). The results of this study show that vegetation degradation in the semi-arid region of Sudan is associated with increase in sand land on expense of cultivable land.

4. Recommendations

Simple VIs combining visible and NIR bands have significantly improved the sensitivity of the detection of green vegetation. Therefore, the study recommended the use of different imagery with high resolutions to further analyze vegetation degradation in order to increase the validity and accuracy of vegetation change patterns and their relation to climatic variability in the semi-arid lands of Sudan. The study also recommended integrating the socio economic with remote sensing data for more accurate results and enhancements.

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