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Remote sensing -based vegetation indices for monitoring vegetation change in the semi-arid region of Sudan

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ABSTRACT

Land degradation, a phenomenon referring to (drought) in arid, semi-arid and dry sub-humid regions as a result of climatic variations and anthropogenic activities most especially in the semi-arid lands of Sudan, where vast majority of the rural population depend solely on agriculture and pasture for their daily livelihood, the ecological pattern had been greatly influenced thereby leading to loss of vegetation cover coupled with climatic variability and replacement of the natural tree composition with invasive mesquite species. The principal aim of this study is to quantitatively examine the vigour of vegetation in Sudan through different vegetation indices. The assessment was done based on indicators such as soil adjusted vegetation index (SAVI). Cloud free multi-spectral remotely sensed data from LANDSAT imagery for the dry season periods of 1984 and 2009 were used in this study. Results of this study shows conversion of vegetation to other land use type. In general, an increase in area covered by vegetation was observed from the NDVI results of 2009 which is a contrast of that of 1984. The results of the vegetation indices for NDVI in 1984 (vegetated area) showed that about 21% was covered by vegetation while 49% of the area were covered with vegetation in 2009. Similar increase in vegetated area were observed from the result of SAVI. The decrease in vegetation observed in 1984 is as a result of extensive drought period which affects vegetation productivity thereby accelerating expansion of bare surfaces and sand accumulation. 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 led to the replacement of the natural vegetation with invasive tree species. The results of the study shows that NDVI perform better than by SAVI.

Keywords: Vegetation degradation, NDVI, SAVI, GSI, Sudan

1. INTRODUCTION

Estimation of vegetation is an important factor for determining what the vegetation type would be without human perturbation. One third of the continental earth surface is covered by arid and semi-arid lands (Manal, 2007), these lands plays an important role in energy balance and hydrology, carbon and nutrient cycles because of the vast area covered in arid and semi-arid lands of Sudan where dependency on vegetation for various uses is continuous, assessment of vegetation vigour through the use of remotely sensed data in necessary. Monitoring of vegetation change using remote sensing is providing an improved understanding of the health and condition of vegetation as well as rates of conversion of natural vegetation to other land uses (Adam, 2011). In Sudan however, anthropogenic activities in different parts of the country had resulted in vegetation cover change. One out of the several factors causing vegetation degradation in the study area (Sudan) is agriculture. The sector (agriculture) is considered as the mainstay of Sudan's economy and it accounts for about 38.9% of the GDP between 2004 and 2005 (CBS, 2005). This study therefore describe the use of Normalized Difference Vegetative Index (NDVI) to quantitatively examine the vigour of vegetation in Sudan through different vegetation indices. The assessment was done based on indicators such as soil adjusted vegetation index (SAVI), topsoil grain size index (GSI) and NDVI. However, monitoring vegetation degradation in these ecological sensitive zone will help provide information which can be used for proper land use management.

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2. DESCRIPTION OF STUDY AREA

This research was conducted in the Gash Agricultural Scheme (GAS) in Kassala state eastern Sudan, 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 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 castor cultivation as cash crops, Sorghum as the main staple crop, using the flooding for irrigation (Hateboer, 1989; IFAD, 2003). Figure 1 illustrated the location of the study area.

Figure 1: Location of the study area

Source: www.wfp.org (accessed in July, 2016)

3. METHODOLOGY

Traditional methods for monitoring land-cover change relying on field data and aerial photography can be costly and time-consuming for relatively large areas (Peterson et al., 2004). Remote sensing is a methodology of multi-disciplinary approach (Theilen-Willige, 1993). 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 (Badawy, 2008). The methodology adopted for this study takes into consideration; data acquisition, different image correction techniques including georeferencing and geometric, radiometric and atmospheric corrections and image enhancement. Vegetation indices and supervised classification techniques were used to achieve the aim of the study that attempt to quantitatively examine the vigour 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.e thematic mapper (TM) 1984 and enhanced thematic mapper (ETM⁺) 2009 was ordered free of charge from the USGS Global Visualization Viewer (GLOVIS). These data set 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, resampling and rectification, radiometric, geometric and atmospheric corrections (Lillesand et al., 2008; Shah et al., 2008) 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. Figure 2 shows the methodology (Flow chart) for this study. The characteristics of remotely sensed imagery are illustrates in Tables 1. Ancillary data such as GPS training samples (ground truth points) were also used to facilitate and enhance the classification process.

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-5 TM	21.Nov.1984	1 – 7 bands	30 m
Landsat-7 ETM+	22.Nov. 2009	1 – 7 bands	30 m

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). Vegetation indices are considered one of the major applications of remote sensing data in detecting change and quantification of green vegetation (Kumar et al., 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 (Jensen, 2000).

NDVI as expressed by Jensen, 2000 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;

$$\text{NDVI} = (\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED}) \quad (1)$$

SAVI as expressed by Huete, 1988 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;

$$\text{SAVI} = (\text{NIR} - \text{RED}) * (1 + L) / (\text{NIR} + \text{RED} + L) \quad (2)$$

The (GSI) was developed by Xiao et al. (2006) to determine the upper soil texture and the assessment of land degradation in semi-arid regions of Asia (China Mongolian). Which used as indicator for land degradation (Pandey et al. (2013); Mfondoum et al., 2016). The formula for GSI is;

$$\text{GSI} = (\text{R} - \text{B}) / (\text{R} + \text{B} + \text{G}) \quad (3)$$

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.

4. RESULTS AND DISCUSSION

The results of the applied NDVI, SAVI and GSI to the images of TM 1984 and 2009 produced two vegetation maps as shown in figure 3 and 4.

Figure 3. Vegetation map for TM 1984 using NDVI, GSI and SAVI

Figure 4. Vegetation map for ETM 2009 using NDVI, GSI and SAVI

In order to calculate the amount of vegetation which were produced by NDVI, SAVI and GSI, the maximum likelihood classifier (MLC) was applied to produced map (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 2. However, due to the high NDVI value it is easily to distinguish wood land from grass and shrubs.

Table 2. Land use and land cover classes

No	Class Name
1	woodland dominated by dense mesquite trees
2	Grass and shrubs dominated by low dense mesquite trees
3	Bare and Cultivated land (Clay soil)
4	Stabilized Fine sand
5	Mobile sand

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 26 years of the study period. Table 3 represents the percentages of areas covered by vegetation (*wood land dominated by dense of mesquite trees, grass and shrubs land dominated by low dense of mesquite tree*), bare and cultivated land and the sand (*stabilized fine sand and mobile sand*) based on the analysis of NDVI. The results of the NDVI in 1984 (vegetated area) showed that about 21% was covered by vegetation while 49% of the area were covered with vegetation in 2009, other classes significantly drooped during this period.

Figure 5. Vegetation classified map of 1984 using MLC for NDVI GSI and SAVI

Figure 6. Vegetation classified map of 2009 using MLC for NDVI GSI and SAVI

In table 4, the results showed that vegetated areas observed by SAVI in 1984 is about 39% while 46% of the area were covered by vegetation in 2009, significant reduction in the area covered by bare and cultivated area was observed in 2009. The class sand land observed also was a little increased. The results in table 5, showed that the vegetated area of GSI is about 24% in 1984 while areas covered with vegetation in 2009 were 46%. Hence, similar increase in vegetation areas were observed by the results of the VI used in this study between 1984 and 2009 respectively.

Table 3. Percentage of the areas that changes during the study period using NDVI

NDVI	Vegetation	Bare and cultivated	Sand land
Years	area%	land%	%
1984	20.5	22.03	57.47
2009	48.74	7.04	44.22

Table 4. Percentage of the areas that changes during the study period using SAVI

SAVI	Vegetation	Bare and cultivated	Sand land
Years	area %	land %	%
1984	38.53	35.10	26.37
2009	45.75	25.05	29.20

Table 5. Percentage of the areas that changes during the study period using GSI

GSI	Vegetation	Bare and cultivated	Sand land
Years	area%	land%	%
1984	23.73	23.65	52.62
2009	46.34	10.13	43.53

Variation in the results of bare land /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). The result of SAVI showed that about 29% of the total area was covered with sand land in 2009 as compared to that of 1984 in which the area covered with sand land accounts for 26%. Also, the results of GSI showed an increase of about 43% in the area covered with sand land in 2009 and 52% in 1984. The results obtained from SAVI 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, 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 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.

5. CONCLUSION

Normalized Difference Vegetation Index is an important tool for assessing the vegetation status of a particular location on a regular basis. This study uses vegetation indices for assessing vegetation degradation in the semi-arid land of Sudan for 1984 and 2009 using Landsat imagery. The results of the VI used in this study showed that there is an increase in vegetated areas. This increase is as a result of invasive species which replaces most of the natural vegetation due to its use as shelterbelt in the region. This study suggest that more research with high resolutions imagery should be carried out in this region to look at the effect of population growth and climatic factors of vegetation degradation in such ecological sensitive zone.

6. SUMMARY

Vegetation is one of the most dynamic element 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 the semi-arid region. In Sudan where fragile ecosystems are dominant and the vast majority of the rural population depend 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) for the growing season months of 1984 and 2009 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 26 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 vegetation indices for NDVI in 1984 (vegetated area) showed that an area of about 21% was covered by vegetation while 49% of the area were covered with vegetation in 2009. Similar increase in vegetated area were observed from the results of SAVI and GSI for 2009 respectively. Variation in the results of bare land /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). The result of SAVI showed that about 29% of the total area were covered with sand land in 2009 as compared to that of 1984 in which the area covered with sand land accounts for 26%. 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 tree species. The results of this study shows that vegetation degradation in the semi-arid region of Sudan is associated with increase in sand 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 dry lands of Sudan.

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