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Integration of Geo-Spatial Techniques for Desertification Impact Assessment on Agricultural lands In El-Qutaynah Area, Sudan

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Abstract

This study focused on El-Qutaynah area, White Nile State, Sudan. The overall objective of this study was to monitoring, assessment and evaluate of the land degradation and desertification in the area. While the specified aims of this research was to mapping the change that occurred in the agricultural lands during the last century. To achieve these objectives, the research was based on various dataset extracted from satellite images (TM and ETM+) for the period 1987 to 2013, fieldwork and climatic data. Pre-processing methods which includes; geometric and radiometric correction was carried out for the raw images. Change detection method as one of the data transformation was used for the satellite images to detect the change based on the pixel values as indicators for change in land use land cover types in the study area. Image processing methods which includes; supervised and unsupervised classification procedures were performed to the corrected images that to determine the LULC classes for the reference and recent image. The study pointed out that the agricultural land was decreased and increased over time and space. However, a decreased in sand areas was noticed and indicated in the study area by (-18.56%) in 2013, with increases in the agricultural area as general. The study also revealed that the sand movement that comes from others areas outside the state has extremely affected the study area in the past. Finally, the study concluded that the space technologies by means of remote sensing and geographic information system (GIS) are very useful when used as tools for evaluating desertification process in arid and semi-arid areas over the world.

Keywords

Geo-Spatial, Desertification, Sudan, Change Detection, Agriculture

1. Introduction

Desertification is one of the main problems threatening the agricultural production in the Sudan (UNEP, 1992). Most of African countries affected by desertification are poor countries with low living standard. Desertification is global problem but it is one of the most urgent ecological problem in Sudan today (FAO, 1983). This research paper attempts to highlight how the integration between space technology which means remote sensing techniques and GIS can help us to monitor and detect the impact of desertification on the agricultural land. According to El-hag *et al.,* (2007) illustrated that sand movement is one of the main problems threatening the agricultural production in at some parts of Sudan and in particular the Northern States. The White Nile State is one of the State affected by sand encroachment, crawled to it sand from the Western side and covered on many of their areas (El-Qutaynah Area) which clearly appear impacted with and affected by sand creep. However, the onesite impact of land degradation on agricultural productivity are easily masked due to use of additional inputs and adoption of improved technology which have led to some question that the negative effects of desertification (Laurence *et al.,* 2006).

2. Study Area

The study area is located in the White Nile State locality of El- Qutanah, between North Kordofan on the west, El-Gazera on the east, and Sennar States on the south east. It covers approximately 11,227 km^2, lying between latitudes 32° 55´ E and 14° 51´ N and longitudes 32° 9´ E and 15° 10´ N, (Figure 1). The climate of the study area according to Osman, (2005) is tropical climate that varies between the continental shelf in the north and savannah ecosystems in the tropical regions in the Southern part of Sudan. Temperature in all parts of the Sudan in the period from March to July is rated 42°C, at daytime and 23°C at night. Low temperature in the period from November to February are up to 30°C at noon and 16°C at night, especially in the north.

Rainfall rate ranges between 75 mm to 300 mm in the central regions, 400 mm to 800 mm in the tropics Figure (2) showed the rainfall distribution in average in the study area for the period of 1966-2012, which depicted that the minimum rate of rainfall was 8.0 mm in 1984, and the maximum one was 50 mm in 2007 (Field work, 2014). The main soil in the study area are alluvial, subtropical and tropical (fluvial)-Darc vertsols Brown of semi desert savannah and shrub land (calcic), Osman, (2005). Rainfall Variability analysis (Figure 3) showed the variation over time during the last four decades. The variability involves changes in the average state of rains over durations ranging from decades to millions of years. Rainfall variability means the degree to which rainfall amounts vary across an area or through time. There are two types of variability (spatial and temporal). The temporal variability means the variation of rainfall amounts at a given location across a time interval, which is important in understanding climate change.

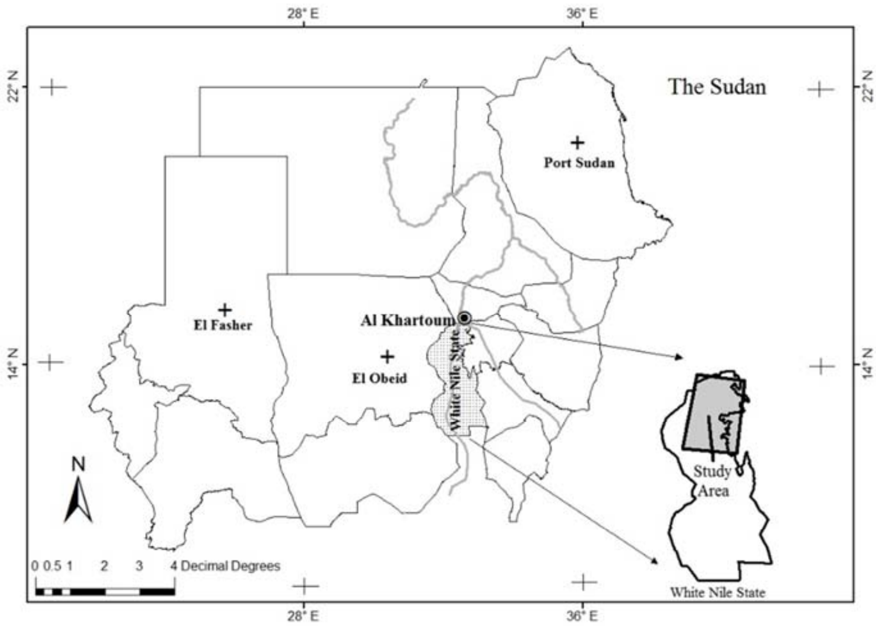

Figure 1. *Location map of the study area.*

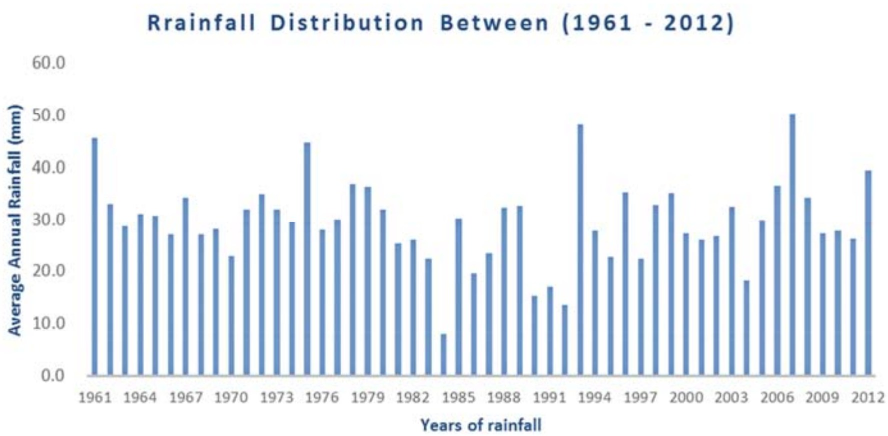

Figure 2. *Annual Rainfall Pattern Distribution (Source: Kusti Metrological Station, 2014).*

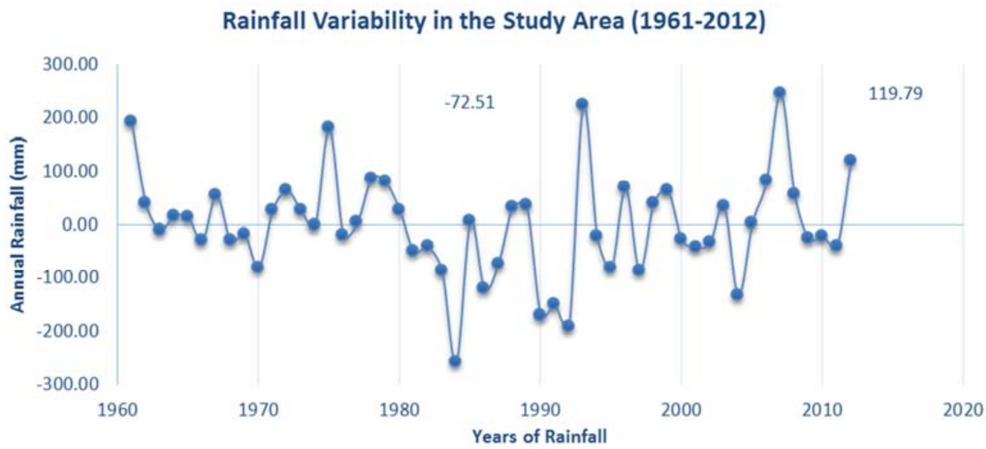

Figure 3. *Rainfall Variability in the study area of the years (1961-2012).*

3. Methodology

Thematic Mapper (TM), and Enhanced Thematic Mapper (ETM+) digital images were acquired for the study area (Path 173/ Raw 50) for the dates 1986 and 2013 respectively. The 1986 TM is 28.5m spatial resolution, while 2013 ETM+ images is 30m spatial resolution. The images were acquired after the rainy season (October and November) of each year to minimize cloud cover. The 1986 TM image was obtained from Global Land Cover Facility (GLCF), while the 2013 ETM+ image was obtained from Landsat 8 the USGS Global Visualization Viewer (GloVis).

Application of atmospheric correction is essential for the current study for two reasons .Firstly, the study compares the relationship between field-based data and spectral information of a time series of the imagery. Secondly, the imagery was acquired in dates with different atmospheric condition and collected by different types. Removing atmospheric effects involves calibration and atmospheric correction. Calibration adjusts the image by converting raw radiance values of each pixel to top-of-atmosphere absolute radiance) or relative (reflectance) values. Atmospheric correction then adjusts these values to ground radiance or reflectance at each pixel based on sun-ground-sensor geometry and atmospheric composition.

The digital number (DN) values of the geometrically corrected TM and ETM+ data were converted to at-satellite radiance using equation (1)

$$L\lambda = \mathrm{L\ min}\lambda + \left(\frac{L\ max\lambda - Lmin\ \gamma}{DN\ max}\right) * DN$$

Where:

Lλ Spectral radiance (i: band)

Lmaxλ Maximum spectral radiance (mW cm-^{2}$_{sr}$-$^{1\mu m-1}$)

Lminλ Minimum spectral radiance (mW cm-^{2}$_{sr}$$^{-1}$μm^{-1})

DN Absolute calibrated digital number

At-satellite radiances were then converted to surface reflectance by correcting both solar and atmospheric effects. At-satellite radiance was converted to surface reflectance using FLAASH (Fast Line-of-sight-Atmospheric Analysis of Spectral Hypercube) module in ENVI 4.8 software.

The geometric correction by means of image to image registration was made to resample TM image of 1986 image using about 15"fixed" point locations, known as Ground Control Points (GCPs). The RMSEs was 0.34 pixels. False Colour Composite (FCC) were used to determine the main land use/ land cover classes. Change detection method was applied to figure out the change in percentages between the two dates, where the TM 1986 image were used as reference image, while the ETM+ 2013 image was used as recent image.

Image classification was used as techniques to convert the digital number to real feature by using supervised classification method in ERDAS Imagine 2014, where spectral signature files were generated to be used in the classification method using a maximum likelihood algorithm. The spectral signatures included both image and tasseled-cap bands created for each image of each analysis year. LC maps were produced for each of the three years containing 6 LULC types in each of the resulting maps.

Additional image processing included the derivation of tasseled-cap indices for image TM 1987 and ETM+ 2013. Tasseled-cap transformed spectral bands 1, 2, and3 (indices of brightness, greenness, and wetness, respectively),(Lunetta, 2004), were calculated for the TM images using Landsat-5 coefficient published by Crist *et al.,* (1986). Although Huang *et al.,* (2002) recommended using reflectance-based tasseled-Cap coefficients for Landsat 7. Tasseled-cap 1 and 2 (brightness and greenness) were calculated for the TM image using coefficients published by Kauth and Thomas (1976). These investigators have shown tasseled-cap indices to be useful in differentiating vegetation types on the study area.

Normalized Difference Vegetation Index (NDVI) is a data transformation, which reduces data dimensionality. NDVI is the most widely used of all vegetation indices because it requires data from only the red and near-infrared portion of the electromagnetic spectrum, and it can be applied to virtually all remotely sensed multi-spectral data types (Lunetta, 1999). NDVI analysis was used in the study to easily differentiate between vegetated areas from un-vegetated areas, which is derived through the equation (2):

$$NDVI = \frac{NIR - R}{NIR + R}$$

Where:

NIR = Near-infrared band. R = Red band

Accuracy assessment was carried out for each of the three LULC maps using a proportional sampling scheme based on the distribution of the validation sample points for each of the cover types in the study area.

4. Results and Discussions

The overall accuracy of the classification results is summarized in Tables 1, and 2 respectively. The increase in overall map accuracy in 2013 was attributed to spectral resolution of the sensor and the GCPs data collection was in 2014. Overall accuracy was between 90.9% and 94.9% for 1987 and 2013 respectively.

Table 1. *Error Matrix for Land-cover Map in the study area for year1987.*

	Reference Data								
Classified Data	**Bare Soil**	**Water**	**Rocky Land**	**Sandy Soil**	**Rain-fed**	**Cultivated Land**	**Vegetation**	**Total**	**User's Accuracy**
Bare Soil	6	0	0	1	0	0	0	7	85.7%
Water	0	3	0	0	0	0	0	3	100%
Rocky Land	0	0	3	1	0	0	0	4	75%
Sandy Soil	0	0	0	8	0	0	0	8	100%
Rain-fed	0	0	0	0	0	0	0	0	-
Cultivated Land	0	0	0	0	0	10	0	10	100%
Vegetation	0	0	0	0	0	2	10	12	83.3%
Total	6	3	3	10	0	12	10	44	
Producer's accuracy	100%	100%	100%	80%	-	83.3%	100%		

Note: Overall classification accuracy = 90.9% Kappa statistic = 0.9%

Table 2. *Error Matrix for Land-Cover Map in the study area for year 2013.*

	Reference Data								
Classified Data	**Bare Soil**	**Water**	**Rocky Land**	**Sandy Soil**	**Rain-fed**	**Cultivated Land**	**Vegetation**	**Total**	**User's Accuracy**
Bare Soil	7	0	0	0	0	0	0	7	100%
Water	0	3	0	0	0	0	0	3	100%
Rocky Land	1	0	3	0	0	0	0	4	75%
Sandy Soil	0	0	0	6	2	0	0	8	75%
Rain-fed	3	0	0	0	5	0	0	8	62.5%
Cultivated Land	0	0	0	0	0	9	2	11	81.8%
Vegetation	0	0	0	0	0	0	12	12	100%
Total	11	3	3	6	7	9	14	53	
Producer's accuracy	63.6%	100%	100%	100%	71.4%	100%	85.7%		

Note: Overall classification accuracy = 94.9%. Kappa statistic = 0.8%

From the satellites images analysis and interpretation, it was possible to state that sand moved from Western Kordofan and North Western parts from Goz Abu Dolua towards the study area. Table (3) and Figure (4) showed that sand was moved from western and North Western part to East of the study area and covered about 2346.54 km^2 which equal 20.91% of the total area. The cultivation as main occupation in the study area it consist two types of agricultural activates one of them rain-fed. In 1987 because the area covered by sand dunes, therefore, ran-fed it was possible, so it classified as zero in the 1987. The other agricultural activities was the irrigated cultivation from the River Nile, which cover about 4015.83 km^2 which represent about 35.79% of the total area. The natural vegetation cover was scatter in different parts of the study area which cover about 379.27 km^2 which constituted 3.38% of the total area. The most dominant vegetation cover which classified as mixed woody land in this year was *Acacia Senegal, and Acacia millifera* (kitir). While the most dominant grass land in this year was *Cenchrus biflorus Roxb localy called Haskaneet, and Eragrostis tremula Hochst ex Steud which locally called El-Banu* (Figure 5 and 6) respectively.

Table 3. *LULC classes in 1987.*

Class name	Pixel Count	Area(meter)	Area(km^2)	Percentage (%)
Unclassified Pixels	243	197376.75	0.19737675	0.002
Rocky Land	243	197376.75	0.19737675	2.60
Water Body	358946	291553888.5	291.5538885	3.78
Bare Soil	522102	424077349.5	424.0773495	33.54
Rain-fed Agriculture	0	0	0	0
Sandy Soil	2888940	2346541515	2346.541515	20.91
Vegetation Cover	466941	379272827.3	379.2728273	3.38
Cultivated Land	4944082	4015830605	4015.830605	35.79

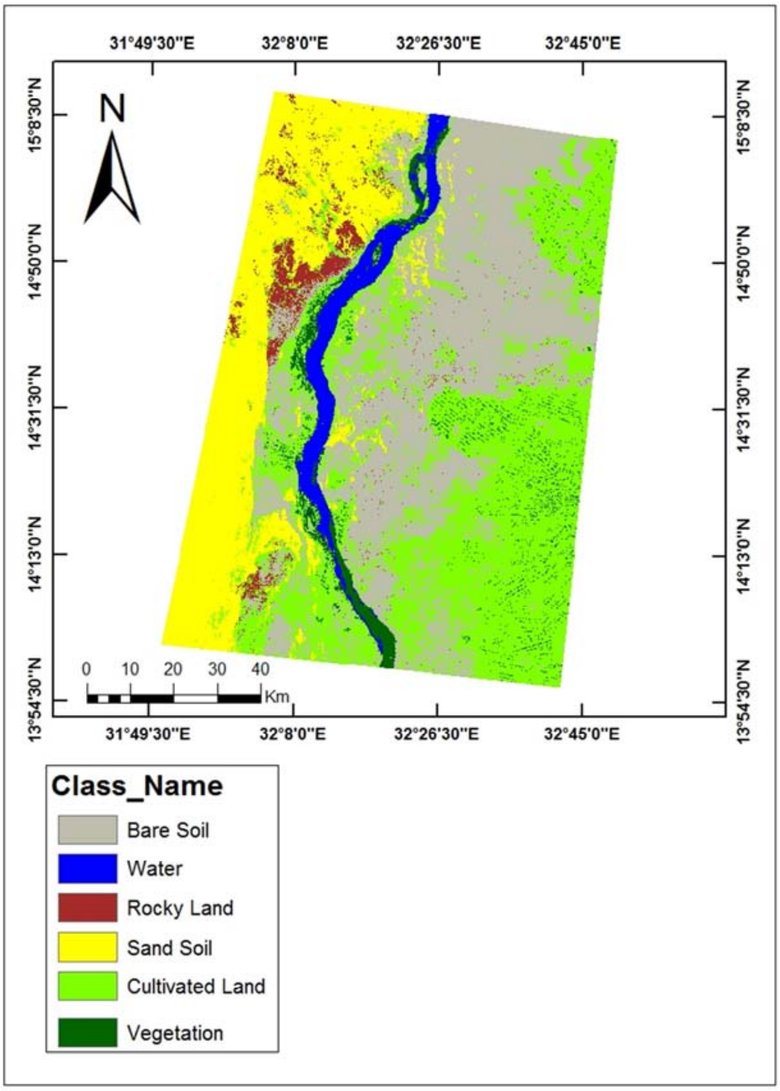

Figure 4. *Land Use/Land Cover classes in year 1987.*

Figure 5. *Dense vegetation cover in the study area.*

Figure 6. *Dense vegetation cover in the study area.*

As showing in Table (4) and figure (7), the sand covered about 263.39km^2 which constituted 2.35% of the total area as illustrated in figures (8a/b) respectively. The vegetation covered about 285.36 km^2 which constituted 2.54% of the total area. The traditional rain-fed agriculture covered about 5411.41 km^2 which constituted 48.22% from the total area, where this area was covered by sand in 1987, which interpret the local contribution effort by the population to control the sand movement by planted of the *Prosopis juliflora* (Mesquite) Trees in large area around the locality. The irrigated cultivated land covered about 3868.65 km^2 which constituted 34.47% of the total area.

Table 4. *LULC classes in 2013.*

Classes Name	Pixel COUNT	Area (Meter)	Area (km2)	Percentage (%)
Unclassified Pixels	424	381600	0.38	0.003
Rocky	112672	101404800	101.40	0.90
Water Body	631621	568458900	568.46	5.07
Bare Soil	802831	722547900	722.55	6.44
Rain-fed Agriculture	6012674	5411406600	5411.41	48.22
Sandy Soil	292657	263391300	263.39	2.35
Vegetation Cover	317072	285364800	285.36	2.54
Cultivated Land	4298496	3868646400	3868.65	34.47

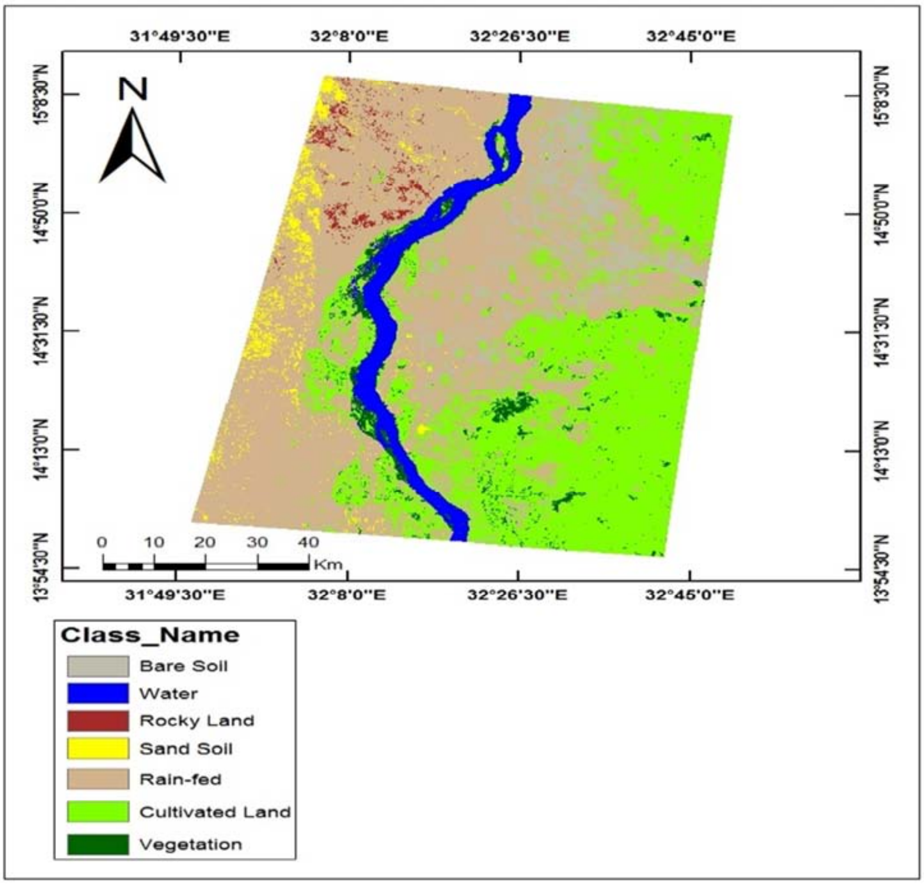

Figure 7. *Land Use/Land Cover classes in year 2013.*

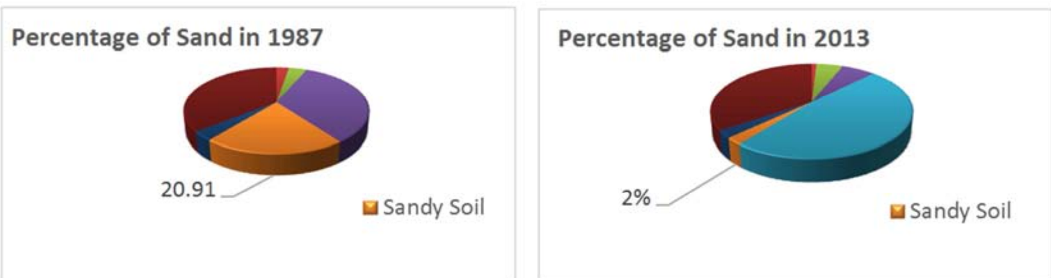

Figure 8. *The percentage of the sand cover in the study area of the year 1987 and 2013.*

NDVI image for the years 1987 and 2013 (Figures 9) showed that dense vegetation covered an area of 350.12 km^2 in year 1987 and area of 686.91 km^2 in the year 2013, the area increased to 336.79 Km^2 in year 2013, that because the traditional rain-fed agriculture. Bare area covered about 9097.47 km^2 in year 1987 and about 6663.63 km^2 in the year 2013, which mean decreased in this class to about 2433.84 km^2. Generally, the vegetation cover showed clear improvement during the period of the study, which might be due to increasing in rainfall and the development mining specially Gold.

Change in Land Use/Land Cover classes between 1987 and 2013 to assess the impact of desertification on agricultural activates in the study area was carried out. Figure (10) illustrate the changed area between the two dates. The area covered with sand was decreased from 1987 to 2013; there was reduction in area counted to -18.5%. This is attributed to the increased amount of rainfall (Figure 2) and traditional rain-fed agriculture during year 1987 to 2013 from 291.55 to 568.46 km^2 in water sector and from 0 to 5411.41 km2 in traditional rain-fed agriculture. This might be due to increases in rainfall, which led to sand fixation, this finding was agreed with study of (Edirs *et al.,* 2013). Area covered by water was increased by 1.28% during the period of 1987 to 2013. Traditional rain-fed agriculture was increased by 5411.41 km^2, which represent about 48.2% of the total area during the same periods. The vegetation cover and irrigated cultivated area was decreased by -0.837% in vegetation cover to -1.315% in irrigated agriculture respectively. This was unexpected cover cultivated area, but might be due to un-cultivated land, which locally called "Bur lands".

Salih (1996), Wedad (2012), and El-Hag (2005) found that sand moved from the Sahara desert towards the river Nile in the Northern Sudan. This study showed that the sand moved from the Northern Kordofan, across the White Nile State to the study area "El-Qutaynah Area" due to the drought and human activates through deforestation. Nevertheless, according to fieldwork study, which made in the last of April 2014 to the study area, it was found that, the movement of sand was mostly stopped, that due to tree plantation around the locality boundary.

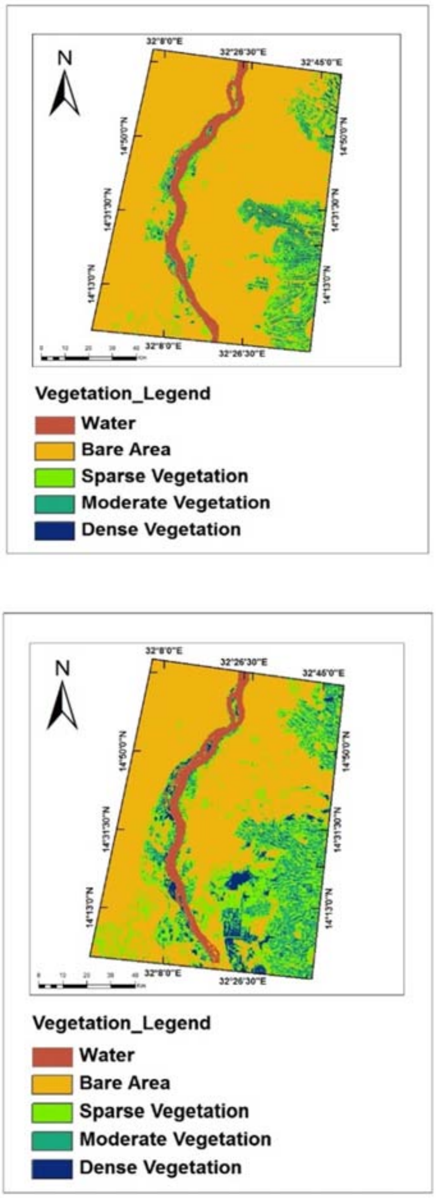

Figure 9. *The Land Use/Land Cover Analysis based on NDVI analysis results according to image 1987 (above) and image 2013 (below).*

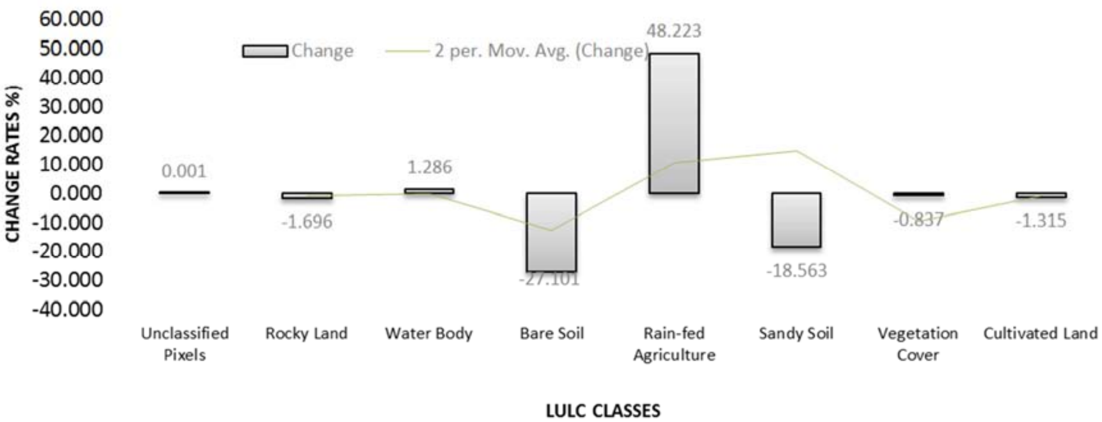

Figure 10. *Land Use/Land Cover Change Detection between 1987 and 2013.*

5. Conclusion

The study revealed different signs of desertification and land degradation in the study area during the year of 1987 as judged by change in patterns of land use/cover types, this change indicated: increase of farming land, water bodies and decreases of sandy soil inside the study area. These signs could be revised with the use of agricultural indicators. Based on these finding the study concluded that:

a Sand movement threatens the highly productive agricultural land, in the study area and the Gezira-Schemes project area.
b Sand movement threatens the traditional agricultural land in the all-White Nile State, which led to endanger the crop production and livelihood of inhabitants in these areas.
c Mesquite trees have become a source of threat to the future of agriculture in the locality.

Based on these findings, the study recommended that:

a Improving the level of awareness of the inhabitants about sand movement problem.
b Encourage the people to plant trees around the area, which helps to stop the Creep of sand.
c Conduct more research on how to address the problem of sand encroachment is not only about the study area, but also in all the Arab world countries.
d Monitor the evolution of the problem using space technologies.

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