Assessing the Impacts of Land Use Changes on Vegetation Cover in Eastern Sudan

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INTRODUCTION

Climate Change is a global threat to natural resources and livelihoods of human societies, compounded by increase in anthropogenic activities. It was calculated that the increase of fossil fuel use will increase global warming and lead to the extinction of civilizations over the coming centuries [1]. The findings of the Intergovernmental Panel on Climate Change (IPCC) [2] reported that the climate change is already having strong impacts on human societies and the natural world, and is expected to do so for decades to come. More severe and longer droughts have been observed since the 1970s over tropical and subtropical areas according to [2], as such drying trend has been linked to higher temperatures and increased evaporation.

A plausible warmer world with longer and more severe droughts could lead to rapid collapse of tropical forest communities converting them from a net carbon sink into a large carbon source with cascading ecosystem effects affecting global climate-vegetation feedbacks [3]. Sudan is one of the driest but also the most variable countries in Africa in terms of rainfall. Extreme years (either good or bad) are more common than average years [4]. Recently, [5] defined that the climate changes as a change of climate elements which is attributed directly or indirectly to human activities (e.g. industrialization) which consequently alter the composition of the global atmosphere. Also natural climate variability has been observed over comparable time period. Noticeably, these changes in the climate have already caused many crises in natural ecosystems including Savanna arid lands of Sub-Saharan Africa.

In Gadarif State, Sudan, the Ministry of Agriculture documented that the cultivated areas were substantially increased and the productivity was dramatically decreased over the last few decades due to the effect of elevated temperature and variability and shortages in rainfall. The vegetation cover in these areas has also been affected by such harsh conditions and change in the climate. These effects included certain areas and species vulnerable to these changes, which has led to decline in their abundance and diversity. Given these agricultural expansions in forest areas and drought occurrences, it became of high priority to assess the rate of changes in vegetation cover over time in these dry lands. The findings of these assessments are very essential and useful in planning for conservation and rehabilitation efforts.

Therefore, the main objective of the present study is to evaluate the changes in LULC in Gadarif state during the last three decades using remote sensing techniques. Specific period covered and satellite images used in this study were for the years 1986, 1994 and 2013.

DATA AND METHODS

A. Study area

Gadarif state, located in eastern Sudan between latitudes 12° 48’ and 15° 50’ N and longitudes 33° 40’ and 36° 47’ E, covers an area of about 6225794.91 ha, as shown in Fig. 1. The state is characterized by semi-arid climatic conditions with an aridity index ranging from 0.2 to 0.4, as reported by [6]. The vegetation of the study area largely depends on rainfall. According to [7] Gadarif area lies in the low rainfall woodland savannah belt on clay soil and the vegetation composed of great diversity of trees, shrubs and grasses. The average temperature of this region varies between a mean minimum of 22 °C in winter and a mean maximum of 37 °C in summer. The highest temperature in the study area is reported between April and May. Given
the availability of temperature and rainfall measurements both temporally and spatially, these data are commonly used to characterize the climatic state of the territory (e.g. [8-11]).

![Study area map](http://srtm.csi.cgiar.org/)

**Fig. 1** location of the Study area - Gadarif state, Sudan Source of DEM data: http://srtm.csi.cgiar.org/, resolution of 90 m * 90m

### B. Satellite images

Thematic Mapper (TM) and Operational Land Imager and Thermal Infrared Sensor (OLI/TIRS) multi-spectral images are the main remote sensing data used in current study. Multi-temporal Landsat imagery for Gadarif state for the years 1986, 1994 and 2013 was used in this study. The technical details of Landsat 4-5 TM and Landsat 8 OLI/TIRS bands have been provided in Table 1. For other specification of Landsat satellite; refer to the official portal of Landsat (Landsat Program, NASA web). The Landsat TM and OLI/TIRS scenes of path and row of Gadarif state was downloaded from USGS web http://earthexplorer.usgs.gov/ then analyzed including classification to different land use categories. Post-classification is a term describing the comparative analysis of spectral classifications for different dates produced independently [12].

Despite criticisms focusing on accumulation of the inherent errors of each individual classification, this is the most appropriate method for comparing multi-source data, as each data layer can be generalized to a common LULC scheme before being compared [13]. In order to quantify changes of certain LULC type during certain time period, we used the following formula:

$$ LULCC = \frac{LULC_b - LULC_a}{LULC_a} \times \frac{1}{T} \times 100\% $$

Where $LULCC$ is the rate of change of a certain land use and land cover ($LULC$) type for a certain time period; the subscripts $a$ and $b$ denote the beginning and the end of a time period for $LULC$ change investigation, respectively; and $T$ is the time period. A positive value means that there is an increasing trend for a specific time period for an area of a certain $LULC$ type; otherwise, negative values implies deceasing trend for the area assessed.

**Table 1. Properties of the data used in the study**

<table>
<thead>
<tr>
<th>Acquisition Date (Satellite) Sensor Spectral bands</th>
<th>Ground resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986 Landsat 4-5 TM</td>
<td>30</td>
</tr>
<tr>
<td>1994 Landsat 4-5 TM</td>
<td>30</td>
</tr>
<tr>
<td>2013 Landsat 8 OLI/TIRS</td>
<td>30</td>
</tr>
</tbody>
</table>

- TM= thematic mapper; OLI= Operational Land Imager and TIRS and Thermal Infrared Sensor

In this study the ERDAS IMAGINE 9.2 image and Arcgis 9.3 software's were used for overall image processing. Using the nearest neighbour method, images were resampled into a pixel size of 30 * 30 m. An multi-date PCC based change detection algorithm is used to determine the LULC changes in four periodic intervals: 1986 to 1994, 1994 to 2013 and 1986 to 2013.

Post-classification comparison (PCC) is a quantitative method that used for independent classification of individual images for these three years for the same geographic location. It is the most commonly used method for LULC change detection mapping [18-19]. For LULC classification scheme, six level classes were adopted in table 2. In order to identify and quantify areas of changes, PCC procedure compares corresponding pixels (thematic labels) for each of the two times under consideration (e.g. [14-17]).

**Table 2. Description of LULC classes identified in the study area**

<table>
<thead>
<tr>
<th>LULC classes</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>All wooded areas with (75-300 trees/ha). This class includes trees and shrubs.</td>
</tr>
<tr>
<td>MRA</td>
<td>Areas currently under crop or land being prepared for raising crops. Agriculture field with no such regular pattern like irrigated land.</td>
</tr>
<tr>
<td>Irrigated land</td>
<td>A regular pattern of land, and can be seen very clearly in the image.</td>
</tr>
<tr>
<td>Rangeland</td>
<td>This class includes grazing land, area with no vegetation such as bare soil, sand (excluding MRA and Irrigated land), where soil is clearly apparent</td>
</tr>
<tr>
<td>Settlement</td>
<td>Area with man-made structures and activities.</td>
</tr>
<tr>
<td>Water</td>
<td>Reservoirs and Rivers.</td>
</tr>
</tbody>
</table>

### III. RESULTS AND DISCUSSION

#### A. Classification Accuracy Assessment and LULC Mapping

In this study, the image-processing approach is found to be effective in producing compatible LULC data over time, irrespective of the differences in spatial, spectral and radiometric resolution of the satellite data. According to
the produced LULC map, Fig. 2 shows that the Forest, MRA, Irrigated land, Rangeland, Settlement and water the dominate types of LULC classes for the years 1986, 1994 and 2013.

Table 3 shows the percentages of LULC classes in the year 1986. Forest, MRA, Irrigated land, Rangeland, Settlement and water have occupied 4, 24.7, 1.2, 69.7, 0.1 and 0.2 per cent of the study area, respectively. In 1994 same types occupied 3.5, 30.4, 1.2, 64.5, 0.2 and 0.3 per cent of the study area, respectively. In 2013 occupied 2.5, 39.5, 1.4, 55.8, 0.6 and 0.3 per cent of the study area, respectively. Noticeably, there is significant increase in the area of MRA from 24.7 per cent in 1986, to 30.4 in 1994, to 39.5 in 2013. Oppositely, forest area has witnessed dramatic decline as its area reduced from 4 per cent, to 3.5 per cent to 2.5 per cent in the years 1986, 1994 and 2013, respectively.

This significant increase in the area of MRA coincidently with shrinking in forest area indicates deforestation and clear-cutting for trees for agricultural expansion, which has been a continuing trend in the study area. In addition to MRA expansions, also in fact, many people in Sudan including Gadarif state remove considerable number of trees for firewood and building materials. [20] Reported that agriculture is the main economic activity, followed by livestock raising in the traditional seasonal pattern. Also as shown in table 3, a large decrease in Rangeland 69.7, 64.5 and 55.8 per cent is observed, respectively in 1986, 1994 and 2013 of the study area which it may risks livestock raising in the area. On the other hand, human Settlements is observed in the study area from 0.2, 0.3 and 0.6 per cent during these three periods. Overall, during the period of the study, natural vegetation (i.e. forests and rangelands) have been significantly cleared and disadvantaged for the MRA and crop supply.

<table>
<thead>
<tr>
<th>LULC classes</th>
<th>1986</th>
<th>1994</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area (hectare)</td>
<td>Area (%)</td>
<td>Area (hectare)</td>
</tr>
<tr>
<td>1 Forest</td>
<td>249245</td>
<td>4</td>
<td>215689.2</td>
</tr>
<tr>
<td>2 MRA</td>
<td>1538596.6</td>
<td>24.7</td>
<td>1890756.3</td>
</tr>
<tr>
<td>3 Irrigated land</td>
<td>72742.4</td>
<td>1.2</td>
<td>74034.7</td>
</tr>
<tr>
<td>4 Rangeland</td>
<td>4342154.2</td>
<td>69.7</td>
<td>4014748.1</td>
</tr>
<tr>
<td>5 Settlement</td>
<td>8657.8</td>
<td>0.1</td>
<td>13317.5</td>
</tr>
<tr>
<td>6 Water</td>
<td>14398.8</td>
<td>0.2</td>
<td>17249.1</td>
</tr>
<tr>
<td>Total</td>
<td>6225794.91</td>
<td>100</td>
<td>6225794.91</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LULC classes</th>
<th>Forest</th>
<th>MRA</th>
<th>Irrigated land</th>
<th>Rangeland</th>
<th>Settlement</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Forest</td>
<td>50</td>
<td>6</td>
<td>0</td>
<td>44</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2 MRA</td>
<td>0</td>
<td>99</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3 Irrigated land</td>
<td>0</td>
<td>1</td>
<td>95</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>4 Rangeland</td>
<td>2</td>
<td>8</td>
<td>0</td>
<td>90</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5 Settlement</td>
<td>1</td>
<td>19</td>
<td>11</td>
<td>16</td>
<td>53</td>
<td>0</td>
</tr>
<tr>
<td>6 Water</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>95</td>
<td>0</td>
</tr>
</tbody>
</table>

Data in bold represent unchanged fractions of each class.

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Table 5. Change detection (per cent) of LULC for the period 1994 - 2013

<table>
<thead>
<tr>
<th>LULC classes</th>
<th>Forest</th>
<th>MRA</th>
<th>Irrigated land</th>
<th>Rangeland</th>
<th>Settlement</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Forest</td>
<td>39</td>
<td>10</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2 MRA</td>
<td>1</td>
<td>98</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3 Irrigated land</td>
<td>0</td>
<td>0</td>
<td>96</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>4 Rangeland</td>
<td>1</td>
<td>15</td>
<td>0</td>
<td>84</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5 Settlement</td>
<td>0</td>
<td>12</td>
<td>3</td>
<td>7</td>
<td>78</td>
<td>0</td>
</tr>
<tr>
<td>6 Water</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>0</td>
<td>91</td>
<td>0</td>
</tr>
</tbody>
</table>

Data in bold represent unchanged fractions of each class

Table 6. Change detection (per cent) of LULC for the period 1986 - 2013

<table>
<thead>
<tr>
<th>LULC classes</th>
<th>Forest</th>
<th>MRA</th>
<th>Irrigated land</th>
<th>Rangeland</th>
<th>Settlement</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Forest</td>
<td>33</td>
<td>13</td>
<td>0</td>
<td>54</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2 MRA</td>
<td>1</td>
<td>97</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3 Irrigated land</td>
<td>0</td>
<td>0</td>
<td>96</td>
<td>1</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>4 Rangeland</td>
<td>1</td>
<td>21</td>
<td>0</td>
<td>77</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5 Settlement</td>
<td>1</td>
<td>16</td>
<td>8</td>
<td>14</td>
<td>61</td>
<td>0</td>
</tr>
<tr>
<td>6 Water</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>0</td>
<td>92</td>
<td>0</td>
</tr>
</tbody>
</table>

Data in bold represent unchanged fractions of each class

B. LULC change analysis

There are several methods exist to study LULC change [21-22]. Using PCC method [23], images for the three years were classified separately for change detection in the study area based only on the information contained in each image. With the help of this method thematic maps of two dates are compared on pixel-by-pixel basis to extract the change that may have occurred between certain time periods. There exist four LULC classes in classified maps and every class is represented by one unique code (i.e. pixel value) range from 1 to 4. To detect the change from 1986 to 1994, the LULC 1986 map is multiplied with 10. Then both images for 1986 and 1994 added together. All other pixel values show the change that occurred in the image. Same procedure was adopted to detect the change from 1986 to 1994, 1994 to 2013 and 1984 to 2013.

In the study area, LULC classes have changed significantly. Changes are normally quantified per pixel counts, areas or percentages. Different classes are represented as different colors in each image, making it easy to identify not only where changes have taken place but also the class into which the pixels have changed. The change detection statistics for three decades of the study area is presented in tables 4-6.

Fig. 3 captured the post classification change analysis for 1986 to 1994, 1994 to 2013 and 1986 to 2013 image classification. The statistics in tables 4-6 show that the MRA areas have increased significantly, covering approximately 6, 10 and 13 per cent of the Forest for the year 1986 to 1994, 1994 to 2013 and 1986 to 2013, respectively. [24] reported that the Trees class in El Rawashda forest, that is that the largest forest in Gadarif state is decreased, while MRA category is increased. Also MRA areas have increased significantly, covering approximately 8, 15 and 21 of the Rangeland for the year 1986 to 1994, 1994 to 2013 and 1986 to 2013, respectively.

[25] reported that the present natural forest in Sudan is estimated to have declined to approximately 0.8 billion m² standing crop, while it was 2.4 billion m² in mid seventies. Since the time when reservation of natural forests started in 1932, the policy was to concentrate on the management of forests reserves under government control, to organize felling program, protection, conservation, development and management. [26] mentioned over-grazing is among the causes of desertification in Sudan. Land degradation is a global problem associated with desertification, loss of biological diversity and deforestation in dry lands, which covers some 47 per cent of the Earth’s surface.

Fig. 3 Post classification change analysis for 1984 to 1994, 1994 to 2013 and 1984 to 2013 image classification.
The statistics in Table 7 and Fig. 3 showed that the percentage of Forest decreased -1.7, -1.5 and -1.4 during the 1986 to 1994, 1994 to 2013 and 1986 to 2013, respectively. On the other hand the MRA has increased 2.9, 1.6 and 2.2 during the 1986 to 1994, 1994 to 2013 and 1986 to 2013, respectively. According to Table 8 showed the conversion of classes of Forest to MRA is 14172, 22354 and 32393 hectare in 1986 to 1994, 1994 to 2013 and 1986 to 2013, respectively. Also there is a large conversion from Rangeland to MRA as 358077, 584233 and 928991 ha in period of 1986 to 1994, 1994 to 2013 and 1986 to 2013, respectively.

<table>
<thead>
<tr>
<th>LULC classes</th>
<th>1986 to 1994</th>
<th>1994 to 2013</th>
<th>1986 to 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Forest</td>
<td>-1.7</td>
<td>-1.5</td>
<td>-1.4</td>
</tr>
<tr>
<td>2 MRA</td>
<td>2.9</td>
<td>1.6</td>
<td>2.2</td>
</tr>
<tr>
<td>3 Irrigated land</td>
<td>0.2</td>
<td>0.8</td>
<td>0.6</td>
</tr>
<tr>
<td>4 Rangeland</td>
<td>-0.9</td>
<td>-0.7</td>
<td>-0.7</td>
</tr>
<tr>
<td>5 Settlement</td>
<td>6.7</td>
<td>8.8</td>
<td>11.5</td>
</tr>
<tr>
<td>6 Water</td>
<td>2.5</td>
<td>0.0</td>
<td>0.8</td>
</tr>
</tbody>
</table>

![Fig. 7 Annual LULC change rates (%) for the three study sites](image)

<table>
<thead>
<tr>
<th>LULC classes</th>
<th>1986 to 1994 (hectare)</th>
<th>1994 to 2013 (hectare)</th>
<th>1986 to 2013 (hectare)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Forest to Rangeland</td>
<td>110965</td>
<td>108154</td>
<td>135179</td>
</tr>
<tr>
<td>2 Rangeland to Forest</td>
<td>88059</td>
<td>55890</td>
<td>63816</td>
</tr>
<tr>
<td>3 Rangeland to MRA</td>
<td>358077</td>
<td>584233</td>
<td>928991</td>
</tr>
<tr>
<td>4 Forest to MRA</td>
<td>14172</td>
<td>22354</td>
<td>32393</td>
</tr>
<tr>
<td>5 MRA to Settlement</td>
<td>5145</td>
<td>17108</td>
<td>19459</td>
</tr>
<tr>
<td>6 Rangeland to Settlement</td>
<td>2460</td>
<td>5902</td>
<td>8340</td>
</tr>
<tr>
<td>7 Rangeland to Irrigated land</td>
<td>3882</td>
<td>10657</td>
<td>12776</td>
</tr>
<tr>
<td>MRA to forest</td>
<td>3877</td>
<td>13940</td>
<td>9817</td>
</tr>
</tbody>
</table>

IV. CONCLUSIONS

Deterioration and decline rate of vegetation cover is terribly occurring throughout the last thirty years. Specifically in Gadarif state large tracts of the forests and rangeland were converted to cultivation. The overall forest area and Rangeland have reduced because of expansion in modern mechanized farming as a result of increasing human population to meet the increasing demand for food. Also trees feeling by local communities for woods and other livelihoods have contributed to this decline in forest cover.

The nomads usually have no alternatives for animal fodders except lopping trees during the dry season and feeding on young regeneration throughout the rainy season. Apparently this may have contributed to this forest cover decline as well. Current information on the status of vegetation cover and changes in its area, composition and structure is limited as well as the synergistic impacts from the observed climatic variations in the study area.

During the last four decades progressive changes within the environment occurred as a consequence of forest and grassland conversion into agricultural lands.

This study recommends detailed investigations on the most affected trees species and thier disburton by such rapid land use changes and clearance.the interactive effects of the anticipated climatic changes in the study area should be an area of priority research. Also further studies on drought prediction using future climate scenarios in Gadarif state will be useful conservation and rehabilitation plans.

Finally, despite there are legislations requiers farmers to cultivate 10% of the agricultural schemes with forest trees, unfortunately these laws are not effective and majority of the farmers don’t obey it. Therefore, on the light of our findings we strongly urge governmental agencies to enforce this law and closely monitor its implementation.

REFERENCES


AUTHOR’S PROFILE

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Prof. Li Zhongqin

Chinese. Professor of Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences (CAS). His recent work includes leading a group at Tianshan Glaciological Station to establish a network for climatological, hydrological, and glaciological observations in Tianshan, Altai and Qilian Mountains in central Asia, which forms an essential basis for research and evaluation of the impact of glacier shrinkage on regional hydrologic regimes and local hazard situation.

Dr. Wang Feiting

Chinese. His research into glacier surface processes is becoming increasing important for understanding warming feedbacks on glacier surfaces. He has conducted fieldwork in Central Asia, Tibet, and Antarctica, and participated in ice core analysis campaigns at Curtin University and GNS sciences, New Zealand and in the field in Antarctica.

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