Analysis of Environmental Change Dynamics in Arid and Semi Arid Climatic Zones

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Abstract: Global environmental change is one of humanity’s greatest challenges affecting both current and future generations. Many world regions face this threat but are increasing rapidly especially in arid and semiarid climatic zones. As a case study, North Kordofan State of Sudan now has existing risks and vulnerabilities associated with many reasons; some areas affected by environmental and climatic impacts, in addition to ethnic conflicts between nomads and sedentary farmers, as well as with socio-ethnic and socio-political conflicts destabilizing the critical areas on the western and southern parts of the state. The study aimed to address the change during the past decade by overlaying maps of Land Use/Land Cover (LU/LC) classes in the State acquired at different points in time, as well as to assess the vulnerability associated with the environmental change. Data were collected in two forms; socioeconomic data and multi-temporal satellite data (i.e. LANDSAT TM and ETM) to study the LU/LC changes. The result of the case studies reveals that, an intensive and dynamic rate of deforestation clearly related to admixture dynamic interactions between social and ecological systems. In sum, we urgently need rethinking about the serious threat of environmental change in these areas. Moreover, new strategies and research development are needed to cope with high levels of the change.

Keywords: Environmental changes, arid and semi-arid regions, remote sensing, LU/LC, Sudan.

1. Introduction

Environmental change is one of the most serious problems in less-developed countries characteristics. Despite decades of massive infusion of advanced technology from the developed world to proposed solutions to tackle this problem in different ways, but continue to elicit questions regarding the results appropriateness of this technology in developing countries generally and the Africa’s countries in particular. In recent years, there is no doubt that global climate change has observable development impacts, which seriously threatens the ability of individuals and communities at all levels. During this process, the clear degradation in the situation of ecosystems has produced a global concern of the urgency to mitigate environmental threats and related impacts.

Meanwhile, despite the decades of world summits, transnational advocacy, and scholarly research, we haven’t sufficiently investigated negative environmental and social outcomes as explicated by the deadlock of environmental change. This degradation takes several forms such as the continuing obstruction effects on human wellbeing of market failure, poverty, violence, war, along with water, energy, health and food security concerns. But the most significant one is the biodiversity extinction crisis practically on natural resources. Arid and Semi Arid climatic zones where nearly by 40 percent of the world population lives, very sensitive for these threats. Nowadays, many concerns have been raised about the transnational environmental impacts [1]. This threat is in many regions of Africa such as Somalia, Ethiopia and now Sudan which are increasing rapidly.

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Sudan is typical of other developing countries in the continent is being highly vulnerable to environmental change and climate variability. The interaction of multiple stresses; endemic poverty, ecosystem degradation, complex disasters and conflicts, limited access to capital, infrastructure and technology have all weakened people's ability to adapt to changes in the environment. Many of the challenges we face nowadays are the unintended consequences of efforts to enhance the sustainable management and biodiversity conservation with the welfare of humankind. Several studies supported that there is a strong link between environmental variability and LU/LC changes [2]. This relationship has taken more important dimension when we start thinking of building resilience against insecurity or problems of sustainable management of ecosystem services.

There is no doubt an accurate spatial extent of LU/LC data and its dynamics are required. Despite the importance of LU/LC as an environmental variable that support environmental planning, resources management, and public policy decision making, the paucity of information about the LU/LC and its dynamics is clear. Understanding the importance of LU/LC and forecasting the effects of its changes is particularly limited by the scarcity of precise and accurate LU/LC data [3]. Current technologies such as remote sensing and geographic information system (GIS) provide a cost effective for the understanding of landscape dynamics and human-environment interaction [4]. Furthermore, has given a rise to the advent of more accurate and referenced data, which in turn have created opportunities for improved assessments and linking between the cover and the use of land. The enhanced understanding of the Earth System and human-induced hazards are essential if we want to better predict and mitigate the expected global changes and the impacts on human civilization. Data collection and information system based on Earth observations constitute critical inputs to the exploration of sustainable management of the Earth providing evidence for decision-makers, supporting the science that underpins strategies for global environmental governance and for monitoring our progress on all geographical scales. Earth observation data has an important role in regional planning at different spatial and temporal scales. Moreover, it can help in analyzing the rate as well as the causal factors or drivers of changes [5].

Nowadays, worsening socioeconomic, environmental, humane and politics circumstances have underscored the urgency of understanding the interactions between these factors to prepare a successful adapt strategies that can be variously help to implement a development paradigm and appropriate pathways contributing to both sustainable development and conservation objectives. To enhance any development strategy, it has to be supported by a greater and better understanding of the variables that make up a particular problem. For that the present research was designed to monitor and assess the change by overlaying maps of LU/LC classes in North Kordofan State of Sudan acquired at different points in time, as well as to evaluate the vulnerability associated with the environmental change. It also outlines some of the actions being taken to help a country adapting to the changing climate, and makes recommendations for how such actions could become more effective of ecosystem services.

2. Materials and Methods

2.1 Study Area

Sheikan and Um Rawaba are two of the four provinces that make up the semi-arid area of North Kordofan state, which is one of the most vulnerable areas in the country concerning desertification and land degradation processes. It is located in central Sudan between latitudes 9° 30' and 16° 24' N and longitudes 27° to 32° E [6]. The total population of
North Kordofan in 2008 was 2.9 million distributed [6], the urban population constitutes 34% of the total population, nomads 16% and the sedentary rural population 50% with an annual growth rate of 1.45% [6]. The region has a varying climate, ranging from desert and semi-desert. Average rainfall estimated is 250-400 mm to 400-750mm [7]. The rainy season varies from about three months or less in the north to about five months in the south, with rains occurring between May and October. The mean annual isotherm is 27° C with extreme temperatures ranging between 10°C to 46° C. [8], April to June is the hottest period and December to January is the coldest. The livelihood activities found in the area are agro-pastoralism, nomadic pastoralism and rain-fed agriculture, both traditional farming for subsistence and mechanized farming for commercial operations. In addition to that, a third source of livelihood is derived from the natural forests in form of woody and non-woody production derived from various trees, with emphasis on *Gum Arabic* production from *Acacia senegal*. Figure 1 below shows the location of study area.

2.2 Data Collection

The data were collected by different methods to cover a wide range of research topics necessary to achieve the objectives.

2.2.1 Remotely Sensed Data

Earth observation data in the form of LANDSAT TM and ETM imagery are the main source of data used in this research. A subsets of the selected area, where located in path 172 and row 051, were selected to detect the potential environmental changes over time.

2.2.2 Socioeconomic Data

The socioeconomic data were collected through a field survey to enhance the data processing framework. Sample size of respondents (households) was one hundred distributed between Sheikan and Um Rawaba unites according to the principle of Population Proportional to Size (PPS). Structured questionnaires were used in face-to-face interviews of individual household members with key-informants. The other data used in this research were the meteorological information, census of population information, records and reports about rain-fed agriculture. GPS devise was used to geolocate the collected data.
2.3 Data Analysis

2.3.1. Image Data Processing and Registration

In pixel-based image analysis approaches the main idea of image classification strategy is to categorize all pixels in an image into a homogeneity LU/LC classes based on pixel-by-pixel spectral properties [9]. It is a hard classifier, each pixel is only belongs to one class or not. In the present study, the image processing and analysis have been carried out using ERDAS Imagine version 2011 and ARC/GIS softwares. These include radiometric, spatial and spectral enhancements, unsupervised classification, and change detection. Image registration technique was applied based on ground control points using the Polynomial geometric model, so that the geometry of the images (1999 and 2011) has been normalized accordingly.

2.3.1.1 Unsupervised Classification

Unsupervised classifier normally utilizes were no reference data or previous knowledge is presented as the basis for LU/LC classification. Alternatively, this classifier involves algorithms that testing the unknowing pixels in an image and aggregates them into a number of thematic classes representing natural clusters of the image values [9]. In the early stages of this work, unsupervised classification was applied to classify the image into different stratum to be used for determination of LU/LC classes. There are various clustering algorithms that can be used in the unsupervised classifier to calculate the natural groupings present in a data set [9]. The study performed the classifier based on K-means approach, the process proceed with predefined four clusters that has been located in the data. The algorithm then arbitrarily locates that number of cluster centers in the multidimensional measurement space. Each pixel in the image is then assigned to the cluster whose arbitrary mean vector is nearest. After all pixels have been classified in this manner, revised mean vectors for each of the clusters are manipulated. The revised mean are then used as the basis to reclassify the image data. The procedure continues until there is no significant change in the location of cluster mean vectors between successive iterations of the algorithm [9]. Once this point is achieved, the identity of each proposed class category was specified.

2.3.1.2 Change Detection

Temporal analysis of the classified images was applied. In order to perform a reliable multi-temporal analysis, post change detection technique (PCD) was performed to reduce the possible effects of atmosphere, sun angle, climatic variations between the years of acquired date due to the differences in the amount and distribution of rainfall, as well as to avoid the need for precise geometric correction of discrete pixels whereas there is a lack of sufficient ground control points and reference data [10]. Therefore, rather than applying spectral change analysis, the independent set of classified images were used for the analysis. Thus, the analysis provides “from-to” change classes and a change matrix for the respective classes.

2.3.2. Socioeconomic Data

Descriptive statistics analysis of data was made using PASW statistical analysis software (version 18.0) for Windows, which was organized as a series of modules and add-on applications.
3. Results

3.1 LU/LC Change in the Study Area

During the last decades Sheikan and Um Rawaba districts have been exposed to a series of recurring dry years, beside the widespread reliance of households on natural resources to meet their subsistence needs. These factors are directly contributing to degradation and depletion of renewable resources. The environmental degradation is pervasive in the study area already pose a direct threat both to human security and vegetation include; resource scarcity, biodiversity loss, ecosystem degradation in addition to the high rate of displacement and migration. The result explores that, the classifications were performed for the imageries from 1999 and 2011, which allowed for an overall assessment of change over the past decade. Our classification schemes to the LU/LC classes in the study area were resulting in four classes for each namely; forest land, agriculture land, bare land and scatter forest and shrublands. Figures 2 and 3 below shows the LU/LC classification in 1999 and 2011.

The initial clustering analysis of the data proves massive changes in LU/LC classes. Furthermore, to evaluate the results of conversions, PCD technique was applied to quantify and locate the changes. Figure 4 shows the LU/LC change dynamics in study area.

A matrix of LU/LC changes from 1999 to 2011 was created. The result reveals that, the natural vegetation has been removed, modified and replaced mainly by bare Land. As shown in table 1, Bare land was increased approximately to be 173569.6 ha (24.73%), while forest and agricultural lands were decreased to be 77405.06 ha (11.03%) and 331698.8 ha (47.26%) respectively. Relatively, scatter forest and Shrublands were increased slightly to be 119193.9 ha (16.98%) during the time period studied.
Table 1: Matrix of LU/LC Changes from 1999 to 2011 in the Study Area.

<table>
<thead>
<tr>
<th>Class Names</th>
<th>Forest</th>
<th>Agriculture</th>
<th>Bare Land</th>
<th>Scatt. forest &amp; Shrubs</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>27184.2</td>
<td>62439.8</td>
<td>17406.9</td>
<td>3827.02</td>
<td>15.79</td>
</tr>
<tr>
<td>Agriculture</td>
<td>46237.3</td>
<td>197886.8</td>
<td>73509</td>
<td>28532.4</td>
<td>49.29</td>
</tr>
<tr>
<td>Bare Land</td>
<td>3252.13</td>
<td>51317.1</td>
<td>44125.5</td>
<td>28497.1</td>
<td>18.12</td>
</tr>
<tr>
<td>Scatt. forest &amp; Shrubs</td>
<td>731.43</td>
<td>20055.09</td>
<td>38528.2</td>
<td>58337.4</td>
<td>16.8</td>
</tr>
<tr>
<td>%</td>
<td>11.03</td>
<td>47.26</td>
<td>24.73</td>
<td>16.98</td>
<td>100</td>
</tr>
</tbody>
</table>

3.2 Investigation of the Factors

From the analysis, forms of degradation were most closely related to admixture dynamic interaction between social and ecological system.

3.2.1 Climatic Impacts

3.2.1.1 Degradation

Land degradation is also a serious problem and has multiple and complex on the study area through a range of direct and indirect processes affecting a wide array of ecosystem functions and services as shown in figure 5. These impacts include undermining of food production, famine, increased social costs, decline in the quantity and quality of fresh water supplies, increased poverty and political instability, reduction in the lands resilience to natural climate variability as well as decreased soil productivity.

Figure 5: The Degradation Process in Study Area
The water resources of these localities were affected in particular the rural areas where groundwater recharge was decreased by precipitation and/or increased temperatures and evaporation. In addition to that, the time and space variability of rainfall in the northern Kordofan during the past years was quite remarkable, were decreased from 900 mm/annum to be around 300 mm/annum. The present study agreed with [11] who referred to the water scarcity is causing conflicts between nomads and sedentary farmers in many areas of the state, due to the unsuitability of the area for drilling boreholes and poor development of other water resources.

3.2.1.2 Sand Encroachment

The sand encroachment and their environmental impact in Sudan represent great concern for both scientists and governments. The soil in the study area ranges from marine sandstones interbedded with shales and mudstones in the north to unconsolidated sand and clayey sand in the Southeast of the study area. The sandy soils cover about 60% of the cultivated land, with organic matter, nitrogen and phosphorus comprising less than one percent. The main reason to aggravating of soil erosion in the study was strong winds. It is clearly evident the direct effects of this problem, where the vegetation was buried in many parts of the study area, thus causing major socioeconomic damage at local and national levels. Agricultural productivity was decreased during the period 1999 to 2011, mainly because the marked decline of rainfall and sand encroachment. Beside the soil type which locally called Qoz is solid, the clay and sandy soils, cannot fully absorb water. Moreover, the land is sloped so that water flows along the surface without reaching the roots of plants. The rain-fed sector has mainly depended on the natural base of available land and natural water sources from rainfall. Generally, agriculture in the study area is labor intensive and provides the main livelihood source. Sorghum, which is the main cultivated crop on those areas, beside Groundnut, Sesamum alatum, Cymbopogon Proximus and Roselle.

3.2.2 Human Impacts

3.2.2.1 Misuse of the land by overgrazing

Pastoralism in North Kordofan is a traditional way of life. It is a form of natural resource use and management that comprises a variety of movements ranging from pure nomads, characterized by year-round camel breeding and long-distance migration during all the year (85.7% of responders). Meanwhile 7.2 % of households preferred grazing eight months during the summer and winter seasons, the same percent for the seasonal movements over shorter distances about four months in autumn as shown in figure 6. Some pastoralists in the study area combine seasonal farming with livestock-raising; these are known as agro-pastoralists. The community in this area relies on livestock as a major asset. The livestock ownership and area cultivated determines one’s wealth. Camels, sheep, goats and Cattle the most common types of livestock in the area with total 2,466,028 distributed in Sheikan and 1,760,007 in Um Rawaba. It is a noteworthy decline in the proportion of Cattle after the drought of 1984. On the other hand, the grazing without management had a large effect on natural resources and that led to acceleration of the deforestation process.
3.2.2 Extreme Poverty with Population Growth

Kordofan and Kassala states are believed to be among the leading states in poverty levels, compared with other states. [12] suggested that, the change in the environment might affect the path of poverty. The majority of the peoples are unemployed subsistence poor farmers. The results indicated the high dependency of households on natural resources for daily life and income generation. Whereas, 80% of respondents were involved in forest products collection. This result was coincided with the change analysis outcome where the change observed on accessible areas in the vicinity of the anthropogenic activities. Moreover, there is a lack of sufficient financial and technical capacities that to manage environmental risk, ability to adapt, as well as to access credit and safety nets. The present study support [13] who noted that, in the absence of social and economic adaptation to environmental scarcity can be that contributed in migrations, ethnic conflicts and insurgencies, besides indirect effects on the international community. The study showed the interaction of severe droughts and dwindling resources as well as disputes over use of water points for livestock and pasture combined with a lack of institutionalized mechanisms for land and water rights and usage, all these factors led to widespread seasonal tensions and conflict between farmers and pastoralists on one hand and between traditional farmers and owners of large mechanized farms on the other.

4. Conclusion

The current study showed the significant overall negative impact of global environmental change on livelihood and natural resources during the period 1999 to 2011. In addition, it has been possible to identify the areas which are most vulnerable to environmental change in the study area when utilizing PCD technique with multi-temporal optical remotely sensed data. This technique demonstrates a great potential as a means to understanding landscape dynamics by map, monitor and evaluate differences in LU/LC patterns over time [14] in a way that would be relevant to policy makers and other stakeholders. More important now than any time before to think about environmental change within the broader context of sustainable and scientific management of resources away from isolated strategies. Additionally, there is a need to understand better ecosystem functioning and patterns over large areas and long periods of time, which it is not only a fundamental necessity in terms of guiding our international development management and policy framework, but also that will offer us an invaluable opportunity to reappraise the most pressing needs of a highly inequitable global society, with greatly differing social, environment and economic levels of development. In sum, new research developments are needed to cope with high levels of environmental change.
References


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