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Research Paper

Spectral mixture analysis (SMA) and change vector analysis (CVA) methods for monitoring and mapping land degradation/desertification in arid and semiarid areas (Sudan), using Landsat imagery

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ABSTRACT

The severe Sahel catastrophe in 1968–1974 as well as repeated famines and food shortage that have hit many African countries during the 1970s have highlighted the need for further research concerning land degradation and environmental monitoring in arid and semi-arid areas. Land degradation, and desertification processes in arid and semi-arid environment were increased in the last four decades, especially in the developing countries like Sudan. To test to what extent remote sensing and geographical information science (GIS) methodologies and techniques could be used for monitoring changes in arid and semi-arid regions and environment, these methodologies have long been suggested as a time and cost-efficient method. In this frame, spectral Mixture Analysis (SMA), Object-based oriented classification (Segmentation), and Change Vector Analysis are recently much recommended as a most suitable method for monitoring and mapping land cover changes in arid and semi-arid environment. Therefor the aim of this study is to use these methods and techniques for environmental monitoring with emphasis on desertification and to find model that can describe and map the status and rate of desertification processes and land cover changes in semi-arid areas in White Nile State (Sudan) by using multi-temporal imagery of the Landsat satellite TM (1987), TM (2000), and ETM+ (2014) respectively. The paper also discusses and evaluates the efficiency of the adapted methodologies in monitoring the land degradation processes and changes in the arid and semi-arid regions.

1. Introduction

The increasing impact of land use and cover changes on the environment has been an issue of concern in the developing countries with consequential effects on sustainable development and long term impact on the agricultural sectors.

With the land use and land cover changes having a significant influence on the ecosystem with impact on biotic diversity, soil degradation, ability of biological systems to support human needs and the venerability of places and people to climatic, economic and sociopolitical perturbation, understanding these surface processes and predicting the impact on the environment and food production system is necessary for militating against the continuous negative impact of these changes.

Deforestation, floods, drought, desertification and land degradation have been issues of environmental concern in Sudan with increasing incidence of aridity in the region and changes in the climatic conditions of the region (Kibreab, 1996). With livestock raising, logging/deforestation and crop production dominant activities in the region, the consideration for the sustainable use of the environmental resources and long term sustainability of the environment is important and reducing the incidence of desertification and soil degradation in the region.

In the last 10 years, the issue of desertification has not only become more widely recognized, both internationally and regionally, but the social and political framework has changed dramatically in a way that makes a change in the research approach crucial (Geeson, 2002). It is very difficult to select one definition of desertification which can be treated as the generally accepted one. There are almost as many definitions as there are authors

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writing about desertification (Olsson, 1985). However most of the definitions have two principles in common:

1) Desertification is, at least partly, caused or accelerated by human activities.
2) The result of desertification is declining productivity of the land in one way or another.

The UNEP (United Nations Environment Programme) definition of desertification as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors including climatic variations and human activities" (UNEP, 1992). Land means the terrestrial bioproductive system that comprises soil, vegetation, other biota and ecological and hydrological processes that operate within the system, the definition is particularly relevant. "Land degradation" means reduction and loss of the biological and economic productivity caused by land use change, or by a physical process or a combination of the two. Several factors and processes contribute to land degradation and desertification in White Nile State. This problem decreases land productivity.

The aim of this study is to investigate the possible use of different remote sensing methods to monitoring, mapping and assessing land degradation and desertification in arid and semiarid environment in White Nile State (Sudan) using Landsat satellite imagery.

One of the most effective tools for desertification assessment is remote sensing. It has long been suggested as a time and cost efficient method for observing dry land ecosystem environments (Hassan and Luscombe, 1990), monitoring land cover degradation as well as characterizing the dynamism of sand dunes (Collado et al., 2002). The important of remote sensing in monitoring and mapping of activities in the land cover is widely recognized and well introduced. Developments in satellite technologies and remotely sensed image acquisition and analysis offer an effective opportunity for increasing the reliability of monitoring and mapping land use and land cover change over wide areas. White Nile State is located in semi central of Sudan has semi-arid climate characterized by a fragile ecosystem which makes the regions more vulnerable to land degradation and desertification processes and risk. The region is highly sensitive to climate fluctuations, where various types of impact such as changes or removal of vegetation cover, change in land use system, accumulation of sand due to rainfall fluctuation and over-grazing cases of land degradation and desertification. Therefore, monitoring and mapping of land cover change in the region is needed and highly recommended.

Spectral mixture analysis (SMA) is a sub-pixel classification technique which could be used to unmixed the soil-plant canopy measurements into the respective soil, vegetation and non-photosynthetic vegetation (Smith et al., 1990a,b). SMA depends on the spectral response of land cover components. Sub pixel classifier is an advanced image method used to detect material that are smaller than an image pixel, using multispectral imagery. It is also useful for detecting materials that cover larger areas but are mixed with other materials that complicate accurate classification. It is a powerful, low cost alternative to ground surveys, field sampling, and high-resolution imagery (ERDAS Imagine, 2013).It addresses the "mixed pixel problem" by successfully identifying a specific material when materials other than the one you are looking for are combined in a pixel. It discriminates between spectrally similar materials, such as individual plant species, specific water types, or distinctive man-made materials. It allows you to develop spectral signatures that are scene to scene transferable. Some advantages of using subpixel classifier or linear spectral unmixing over other traditional classification methods is that (1) Classification objects that are smaller than the spatial resolution of the sensor, (2) Identifies specific materials in mixed pixels, (3) create pure spectral signatures, (4) can be used for many types of applications, (5) Develops scene to scene transferable spectral signatures, even at different time of the day and year, and (6) Enables searches over wide geographic areas.

Multi-temporal imaging enables assessment of changes in the type or condition of surface features. This is one of the most important of all analyses in remote sensing, typically called *change detection*. Many of these analyses use images acquired at two points in time, known as *bitemporal change detection* (Campbell, 2011). Change detection methods are commonly used in monitoring land degradation. Change can be identified either as change in the number of environmental components or as a change in percentages of the components (Adams et al., 1995). Visual interpretation and direct measurement using map-algebra are widely used in change detection. Change Vector Analysis (CVA) is a techniques where multiple image bands can be analyzed simultaneously. As its name suggests, CVA does not only function as a change detection method, but also helps analyzing and classifying the change. In CVA, pixel values are vectors of spectral bands. Change vectors (CV) are calculated by subtracting vectors pixelwise as in image differencing. The magnitude and direction of the change vectors are used for change analysis. The change vector magnitude can indicate the degree of change. Thus, it can be used for change and no-change classification (Singh, 1989).

Sudan is a developing country where desertification is widespread. UNEP considers that three compounding desertification processes are underway (UNEP, 2007): climate-based conversion of land types from semi-desert to desert, mainly due to a reduction in annual rainfall; degradation of existing desert environment, including Wadis and oases, principally caused by deforestation, overgrazing and erosion; conversion of land types from semi-desert to desert by human activates (deforestation, overgrazing and cultivation) even if rainfall may still be sufficient to support semi-desert vegetation cover. These processes are relatively difficult to distinguish, separate and quantify on the ground (Diouf and Lambin, 2001).

Specific studies are therefore necessary to define the driving forces (variables) affecting the processes and adopt efficient site-specific strategies to combat desertification (Dawelbait and Morari, 2008). Since lack of data, funds, and governments support, gives remote sensing data priority to be reliable tool to study desertification (Khiry, 2007) in the selected study area.

According to that evolution, the overall objective of this paper is to test the application of Object-Oriented and SMA pixels based to Landsat images as a tool to study the desertification processes, and driving variables influencing land degradation and vegetation cover in the study site which located within White Nile State, Sudan during different years.

2. Material and methods

2.1. Study site

The study site I have chosen is located in the North of White Nile State, Sudan, between latitude 12 56 35 and 13 3 49 N and longitude 31 051 and 31 58 51 E, as shown in (Fig. 1). The climate is semi-desert with summer rain warm winter, average annual rainfall ranging from 100–225 mm, which falls mainly in the months of (May–September), with a peak in August (Fig. 2) Mean maximum temperature of the hottest month (May or June) is 40–42 °C, and the mean minimum temperature of the coldest month (January is 13–16 °C). There is summer grazing in Wadis and some extensive cultivation of rainfed sorghum or "Dukhn" on water receiving. The soil is mostly rather sandy soil with high infiltration rates and inherent low fertility. Sand sheet and sand dunes stabilized by vegetation.