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Desertification Monitoring Using Remote Sensing Technology

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Abstract

Desertification phenomena started spreading worldwide at high speed since the second half of the last century. United Nations reports indicate that about 35 million square kilometers of land are subject to desertification effects. This is accompanied with a loss of about 26 billion American dollars of agricultural production. This is why desertification is becoming the most natural phenomena that attracts attention of world authorities and specialists.

The dry land which is subject to desertification covers about 90 per cent of the Arab world. In these lands concentrate most of the agricultural resources of the Arab world. Hence, desertification phenomena resembles the most serious and challenging natural phenomena for the Arab world. That is due to its direct and hard effect on development. It is directly related to life needs such as water resources and plantation which are necessary to both human beings and animals.

Remote sensing technology has been used to help scientists to understand the concepts and to monitor the changes of the Earth constituents, both exterior and interior, that take place through time. That is because of the ability of remote sensors to provide a broad and repetitive view of the Earth planet. One of these changes is the process of desertification.

This paper is an attempt to present desertification as an effective phenomena, its causes, consequences and henceforth application of remote sensing in monitoring its expansion. Some of the studies that were carried out for the use of remote sensing in monitoring expansion of desertification in some Arab countries would be reviewed.

Introduction

According to a United Nations report (UNCCD, 2004) more than one billion people worldwide, most of them among the poorest in the world, are affected by drought and desertification. These people, occupying approximately one quarter of the planet, are facing major problems which include soil degradation and vegetation loss, leading to deterioration of arable land and eventually to chronic food insecurity.

It is well known that 14.9 billion hectares of the Earth's surface is land. A United Nations Environmental Program (UNEP) publication indicates that an area of 6.1 billion hectares of the Earth's surface are dry land of which 1 billion hectares are merely hyper-arid desert, while the remaining 5.1 hectares are subject to desertification process and are expected to become desert in the future (UNEP,1992).

The location of the Arab world forms a geographical unit characterized by its aridity. About 128 million hectares of the Arab world is dry and semi dry land (this means that 89% of the area of the Arab world which amounts to 144 million hectares is dry or semi dry land). Most of this land (99 million hectares, 69% of the total Arab world area) is severely dry, with annual rainfall being less than 100mm. The rest of the Arab world land can be divided into two categories: a) semi arid land that receives about 100-400mm annual rainfall. This part forms about 20% of the Arab world land; b) the remaining 11% of the Arab world land that receives more than 400mm annual rainfall and is outside the arid and semi arid zones. This can be summarized as in Table 1 below (Hassan, 2001).

Table 1. The Arab World land Categorized According to Rainfall

Type of land	Annual rainfall (mm)	Area in million of Hectares	Percentage of Total Area
Dry	< 100	99	69
Semi dry	100 - 400	29	20
Non dry	> 400	16	11
Total		144	100

The region that extends from west to east; starting from west coast of Africa across Central Africa which includes the Sahel and north Sudan and crosses the red sea to pass through the Arabian Peninsula to Central Asia is the most region that is affected by desert and desertification. More than 90% of this region passes through Arab countries both in Africa and Asia.

The northern regions of Egypt, Libya, Algeria, and Morocco are subject to severe penetration of the African great desert. The Savanna region in Sudan has been changed into dry arid land due to the effects of dunes movements, soil erosion and overgrazing. Villages have disappeared and people have moved towards nearby cultivated lands.

The western Asian region of about 39.5 million hectares which includes the Arabian Peninsula countries (Saudi Arabia, Kuwait, Qatar, Oman, Bahrain, Yemen and United Arab Emirates) and the Eastern Arab countries (Iraq, Jordon, Syria, Lebanon and Palestine) is also characterized by its dry weather. More than 72% of this area receives annual rainfall of less than 100mm. This region is also affected by severe sand dunes movements that cause environmental degradation and resource depletion that threaten present and future economic growth.

This severe deterioration of the environment north and south of the great African Sahara and across the Arabian Peninsula and Eastern Arab countries led to looking into the problem in depth.

One important key to the solution of the problem is the monitoring of desertification. In order to combat desertification we need to make continuous monitoring. The use of the remote sensing technology to monitor desertification has proved to be the most efficient approach.

This paper attempts to give some background about definition causes, consequences of desertification and how remote sensing technology can be used to monitor this phenomena . Some projects that utilized remote sensing technology to monitor desertification in some Arab countries would be outlined as models to demonstrate the efficiency of the technology in this field.

Definition of desertification

Dregne (1986) pointed out that the desertification problem and processes have not yet been clearly defined. Some definitions of desertification would be outlined here.

Aubreville (1949) defined desertification as the changing of productive land into a desert as the result of ruination of land by man-induced soil erosion. He concluded that desertification in tropical Africa was due to man's activity and not as a result of the Sahara spreading or climatic causes.

Desertification was also defined by Dregne (1976) as a process of impoverishment of arid, semiarid and sub-humid ecosystems by the combined impacts of man's activities and drought.

After the 1969 to 1973 drought in the African Sahel that affected six countries on the southern border of the Sahara and led to the deaths of between hundred thousands and two hundreds and fifty thousands people and the disruption of millions of livestock, an International Conference on Desertification was held by the United Nations in Nairobi, Kenya, in August and September of 1977. Representatives of nearly 100 nations and many international organizations; governmental and nongovernmental attended this conference to discuss the problem of combating desertification of arid lands. In spite of holding such an international conference on desertification researchers were not able to agree upon an accepted definition for the term desertification (Dregne, 1986). The definition used in the UNCOD report (UNCOD, 1977) states that desertification is the destruction of the biological potential of the land that can lead ultimately to desert like conditions.

Dregne (1986), also defined desertification as the impoverishment of terrestrial ecosystems under the impact of man. It is the process of deterioration in these ecosystems that can be measured by reduced productivity of desirable plants, undesirable alterations, accelerated soil deterioration, and increased hazards for human occupancy.

Hellde'n (1988) quoted some of the above definitions together with the one adopted by Rapp (1974) that states that desertification is the spread of desert-like conditions in arid or semi-arid areas due to man's influence or to climatic change. Hellde'n noted that "Decreasing Productivity" is a key process included implicitly or explicitly in all definitions.

In the Summit of 1992 held in Rio de Janeiro, Brazil, the term desertification was defined as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors including climatic variations and human activities".

Eden Foundation (1994) defined desertification as: a man-induced process that leads to soil nutrient depletion and reduction of biological productivity.

In the International Agreement on Combating Desertification that was held in Paris in 1994, desertification was defined as the reduction or loss of biological or economic productivity resulting from land use or from human activities and habitation patterns. Desertification is usually expressed in terms of measurable physical or biological conditions or processes which can be used as surrogates for productivity loss. These two last definitions of desertification, like the ones by Aubreville and Dregne ignored the role of climate on desertification.

The author's opinion is to define desertification as the process of degradation of land and decrease in its productivity. Reasons that lead to this phenomenon can be studied separately.

Causes of desertification

Factors leading to desertification can in general be divided into two categories: climatic variability and human activities.

1- **Climatic variability**

It is known that dry lands have limited water supplies (annual rainfall is less than 100mm). Rainfall can vary greatly during the year, while wider fluctuations occur over years and decades. This leads directly to drought, which is often associated with land degradation and hence a vital factor behind desertification.

2- **Human activities**

At this point we may pay attention to the fact that all definitions of the term desertification agreed upon the human activities as the cause of desertification. The human activities that lead to desertification can be outlined as follows:

- **Overgrazing:** This is described as the major cause of desertification worldwide.
- **Overexploiting land:** This can happen due to various reasons. It can happen due to expand in human population and hence the need for more crops, international economic forces that can lead to short-term exploitation of local resources for export.

- **Deforestation:** Destruction of vegetation in arid regions, mainly for fuel- wood.
- **Poor Irrigation Practices:** This would lead to soil salinity that can prevent plant growth.
- **Natural and man-made Disasters:** Natural disasters such as floods and droughts, and man-made disasters such as wars and national emergencies can destroy productive land by causing heavy concentration of migrants to overburden an area.

Consequences of desertification

Desertification causes reduction in the ability of land to support life. It affects wild species, domestic animals, agricultural crops and people.

The reduction in plant cover that accompanies desertification leads to soil erosion.

Desertification leads to movements of people, and hence conflicts. Dar Fur region in western Sudan is a typical example for conflicts and crisis that took place because of movements of people from north (drought part of the region) to south (where there is cultivation and pastures).

The growth domestic product of the areas affected by desertification is largely affected. At the global level it is estimated that the annual income of areas immediately affected by desertification is decreased by 42 billion American dollars. The indirect income and social costs suffered outside the affected areas, including the influx of "environmental refugees" and losses to national food production, may be much greater (UNCCD, 2004).

Monitoring desertification

Because of these serious consequences of desertification there becomes a high need to combat desertification. The first step is to monitor desertification through measuring land degradation and desertification processes. Standard methods of undertaking such measurements are substantially imperfect and economically non feasible. These conventional methods has traditionally been short of standardization because of the range of criteria and indicators (Hill, 2004).

The various data sources available through remote sensing offer the possibility of gaining environmental data over both large areas and relatively long time-periods. Although no one can confirm that remote sensing will replace traditional sources of data for inventory and monitoring there is, however, an obvious role that it would play in assessing and monitoring desertification. It has been demonstrated that satellite-based and airborne remote sensing systems offer a considerable potential in assessing and monitoring desertification in the Arab world.

Remote sensing for monitoring desertification

Remote sensing is a technique used to collect data about the earth without taking a physical sample of the earth's surface. A sensor is used to measure the energy reflected from the earth (the source of this energy can be natural like the sun and in this case the sensor is called passive or artificial like microwaves used in radar sensing where the sensor is called active, as shown in Figures 1 and 2, respectively). This information can be displayed as a digital image or as a hardcopy. Sensors can be mounted on a satellite orbiting the earth, a space craft or an aeroplane.

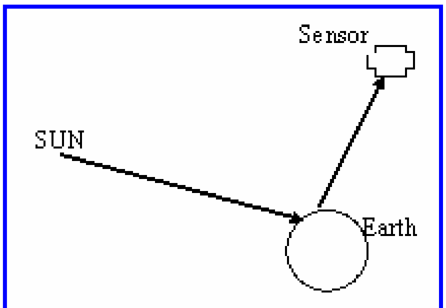

Figure 1. Passive Sensor

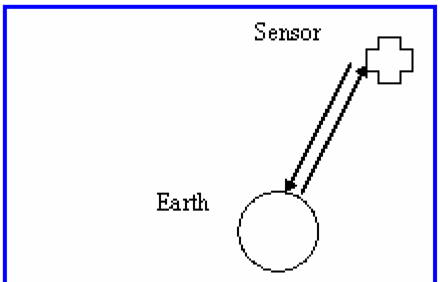

Figure 2. Active Sensor

It is well known that remote sensing has initially been used primarily for resource mapping and inventory. Many experiments, however, proved that remote sensing systems and in particular Earth observation satellites provide significant contributions to desertification assessment and monitoring. During the last three decades satellites have been providing scientists with huge information about the Earth. Landsat images of the same area, taken several years apart but during the same point in the growing season may indicate changes in the susceptibility of land to desertification. This in fact is the direct approach for measuring and monitoring desertification.

Researchers in this field, however, have developed indirect means for monitoring desertification making use of remote sensing technology. These indirect means are called indicators for desertification monitoring (Hoffman, 2002). Some of these indicators that can be determined through remote sensing techniques are summarized below.

1- Livestock size: the larger number of cattle means high grazing and hence indicates a cause of desertification.
2- Population pressure: the larger number of population indicates need for more food and water leading to severe degradation of vegetation, soil and water resources.

3- Deforestation.
4- Soil salinity.
5- Type of building material: houses constructed of wood indicates deforestation that causes desertification.
6- Cultivation of marginal land.
7- Number and distribution of water wells.
8- Migration of livestock.
9- Declining ground water level.
10- Bush encroachment and species change.
11- Normalized Difference Vegetation Index.

Harahsheh and Tateishi (2001) studied desertification processes, causes and indicators occurring in West Asia, then desertification mapping, assessment and monitoring using remote sensing and Geographic Information Systems (GIS) techniques. The study area was about 66. millions hectares, of which 32% is sand or sand dune land which has been excluded from desertification assessment and 30% is desert or desert rangeland. More than 80% of the Arab world is included within this area (Figure 3). 10-days composite of satellite data set of NOAA AVHRR 1km resolution covering the period from April 1992 through March 1993 and other data of the period 1995 and 1996 have been used in the study. Indicators used for studying desertification were: vegetation cover degradation, wind erosion, water erosion and soil salinity. Two main indicators were used for vegetation degradation study: decrease of forage productivity and decrease in the vegetation cover. The decrease of forage was linked to two variables: the intensity of livestock and normalized difference vegetation index (NDVI). The authors used the following multiple regression model to calculate the first indicator image of vegetation degradation:

$$F = 68.45 + 1.744*L – 333.46*NDVI$$

Where, F = decrease of forage in percentage, L = increase of livestock intensity, NDVI = normalized difference vegetation index as determined from remote sensing data for the period 1992 through 1993. The percentage of vegetation cover (VC%) was determined using the model developed by Porevdorj (1998) which relates the vegetation cover to NDVI as follows:

$$VC\% = - 4.337 – 3.733*NDVI + 161.968*NDVI^2$$

The vegetation cover percentage was determined for two periods 1980's and 1990's. In both periods data of NOAA AVHRR were used to compute the NDVI. The decrease in vegetation cover percent image was determined from the difference of the two periods.

The output images of decrease of forage productivity and decrease of vegetation cover percent were then combined to produce by overlapping the vegetation degradation image which was then divided into four classes: slight, moderate, severe and

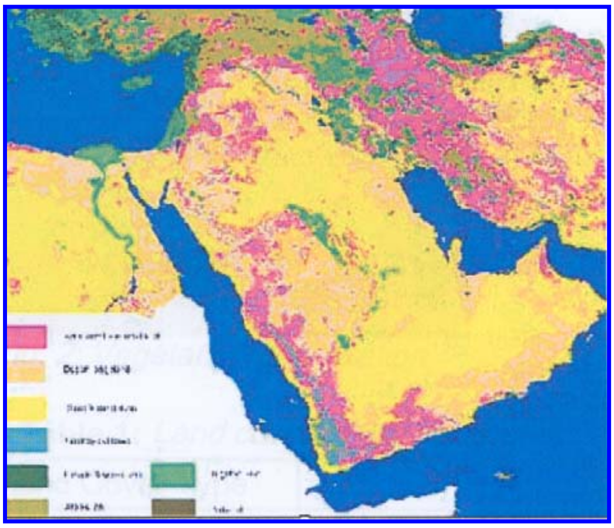

Figure 3. Land Cover map of West Asia
(Harahsheh and Tateishi, 2001)

very severe vegetation degradation according to the criteria they adopted. The study concluded that 31.3% of the west Asia is subject to severe vegetation degradation, 19.2% is subject to moderate vegetation degradation, 8.8% and 8.5% are subject to slight and very severe vegetation degradation, respectively.

Implementation examples in the arab world

In the following part of this paper some experiments that have been carried out in the field of utilizing remote sensing technology in monitoring and measuring desertification processes in few Arab countries would be outlined.

Egypt

Egypt lies in the semi arid and arid zone of Africa. Desertification can often be found in detached areas in arid and semi arid places (Pacheco, 1980). The use of remote sensing in monitoring and identification of the desertification phenomena has been investigated by Abd El-Hamid (1994). Two TM images covering the eastern boundaries of the river Nile delta (Figure 4) towards the Suez Canal (covering about 18000 hectares), taken during the summer season (July 2, 1984 and August 9, 1989) were digitally processed at the Earth Data Analysis Center (EDAC) , University of New Mexico, USA. A file for an image containing the major principal components, NDVI and the CH3/CH4 ratio (SI, soil index) was created for applying unsupervised

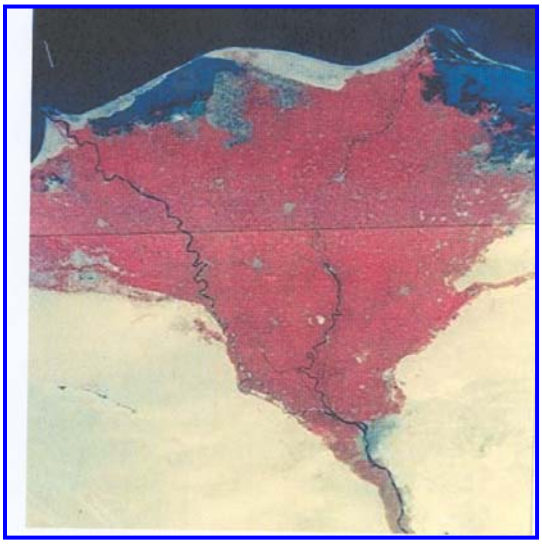

Figure 4. The light colored Areas to the west and east of the Nile Delta in north Egypt is sand-covered Land

classification which was used in the comparative study. The results obtained showed that unplanted areas were 33.9% in the year 1984 and 47.3% in 1989. This means that the rate of desertification in this part of the country was 2.68% per year.

Saudi Arabia

In studying areas expected to face desertification in Saudi Arabia, Alzoght and Mustafa (1988) concluded that 97% of Saudi Arabia is extremely arid while the remaining 3% which is located in the elevated areas of the southwest corner of the country, is subject to desertification. Desertification indicators that can be used in monitoring desertification as mentioned by Qari and Shehata (1994) are: changes in both groundwater and surface water as resources and the consequence changes in natural vegetation density and extend of agricultural areas, the soil salinization represented by the changes in the extent of sabkha areas, and the erosion deposition activities in dune covered areas. These indicators were studied by Qari and Shehata (1994) using satellite imageries, aerial photographs, maps, reports and records for the western region of Saudi Arabia. Noticeable decrease in natural vegetation density and destruction of cultivated areas were recorded. The sabkha area in the western region in the 1950's was determined from aerial photographs to be 2800 hectares (Brown et al., 1963). The sabkha areas as determined by Qari and Shehata (1994) from interpretation of landsat-TM imagery was found to be 10000 hectares. This means that the sabkha areas increased during these 40 years from 2800 hectares to 10000 hectares, or more than 250%, indicating the high spread of desertification in this region.(Figure 5).

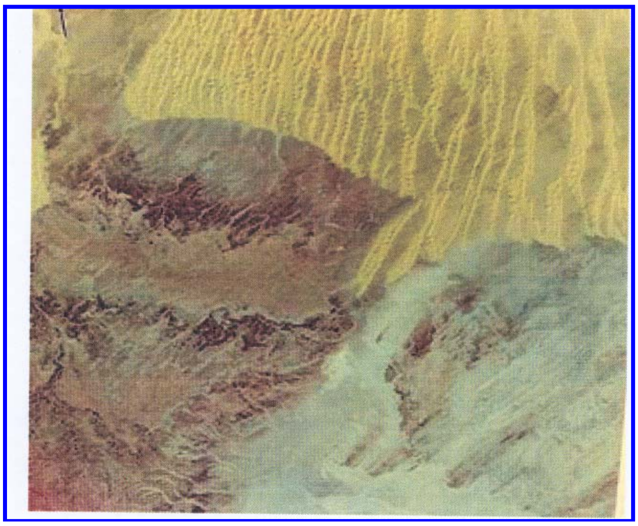

Figure 5. Most of the Arabian Peninsula is covered by barren desert and vast sand seas. The area to the north of the scene shows sand dunes in the west region

Sudan

Land cover and vegetation changes between 1972 and 1990 in Kassala Province, Eastern Sudan was studied using nine landsat Multi-Spectral Scanner (MSS) scenes acquired through the period November 1972 through to January 1990 (Larsson, 2002). After radiometric and geometric corrections were carried out a maximum likelihood classifying routine was applied. Land classes include: sand land, grassland, forest irrigated area, kerrib (overgrazed and eroded land along Atbara River), water, cultivated area, and mountain area.

It has been concluded that the sand lands remained approximately the same, with a slight increase over the 1987/1989/1990 period.

Fadul and Mohammed (1999) studied the effect of desertification on the Gezira Scheme using remote sensing techniques. They used MSS imagery of 3 spectral bands dated 1975 with scale 1:250000, TM imagery of 3 spectral bands dated 1986 with scale 1:250000, Large Format Camera (LFC) imagery dated 1983 of scale 1:250000.

Visual interpretation and digital processing of the satellite imageries indicated various forms of sand dunes, sand covered areas, areas subject to erosion and sand dunes around bushes for the area that lie between the White Nile and the western border of the Gezira Scheme (Figure 6). These areas are continuously extending during the study period. This means desertification is very much threatening the Gezira Scheme.

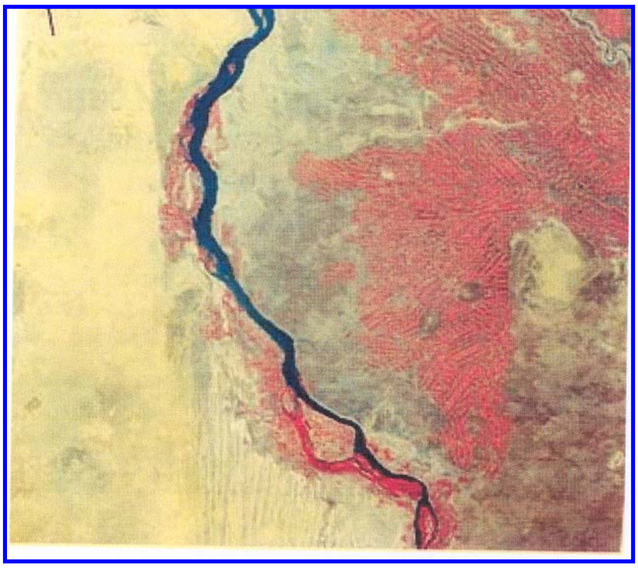

Figure 6. Sand dunes as seen to the west of The White Nile and Gezira Scheme in Sudan.

Syria

Satellite imageries have been used in monitoring desertification in the Syrian Steppe (Figure 7) since the end of 1993. A project jointly implemented by the German Federal Government and the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) extensively used Remote Sensing and GIS techniques in studying the desertification phenomena and its development in the monitored area which covers one million hectares (Ilaiwi, 1999). Satellite imageries dated to 1970's and extending at regular intervals through more than 20 years were digitally processed and the following were the fruitful products:

* **The map of the variables**: It shows areas covered by sand in the monitored area by studying satellite imageries dated 1985, 1993 and 1997.The first date resembles the start of Steppe cultivation, the second one is the date of maximum desertification

problem and the third one is selected to be two years after prohibiting cultivation in the area. From the remote sensing study it has been derived that between the years 1985 and 1993 sand covered an area of 90000 hectares (about 10% of the monitored area) It also shows the effect of banning cultivation in the Syrian Steppe which was implemented since 1995 on the retreat of sand for about 75000 hectares.

*** The grazing intensity and watersheds map**: This map has been prepared using various approaches including: digital interpretation of the Indian satellite images and digital interpretation of US satellite images (Landsat TM). This map was utilized in locating sites of the surface water harvesting in the project area (Ilaiwi, 1999).

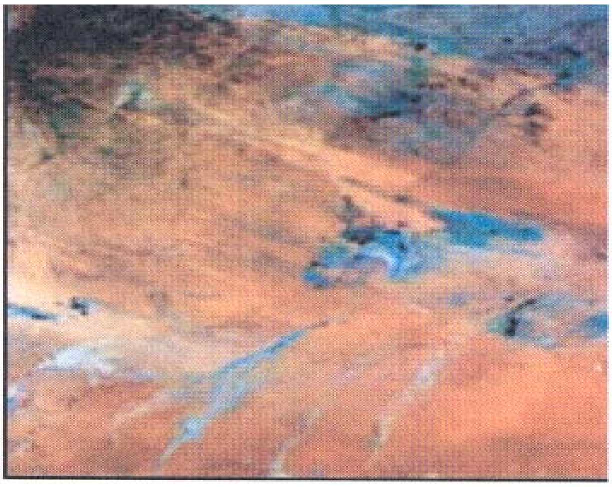

Figure 7. Landsat TM image of Syrian Steppe

Conclusions and recommendations

Repeated coverage of satellite imageries provide an efficient tool for monitoring desertification for a region like the Arab world. Implementation of remote sensing technology in desertification monitoring can be done through various means: the direct approach is by measuring the area affected by desertification, and the indirect means is by studying indicators of desertification that can be measured on satellite imageries.

In order to make full use of multi-temporal satellite imageries the following points should be taken care of:

- prepare sufficient ground control points to develop high registration accuracy.
- Imagery of high ground resolution is necessary to achieve accurate monitoring of desertification.

More research should be carried out to study indicators of desertification that can be determined through remote sensing technology.

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