# 5.4 AN APPROACH TO MONITORING AND ASSESSMENT OF DESERTIFICATION USING INTEGRATED GEOSPATIAL TECHNOLOGIES

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## 1. INTRODUCTION

Desertification refers to land degradation in drylands. Although over 100 definitions of desertification have been developed emphasizing different processes contributing to desertification, the United Nations Convention to Combat Desertification provides the most current, authoritative definition: 'land degradation in arid, semi-arid and dry sub-humid areas resulting form various factors including climatic variations and human activities' (UNCED 1992). Drylands include those land areas of the earth receiving under 600 mm/year of precipitation and for which the ratio of average annual precipitation of potential evapotranspiration is between 0.05 and 0.65 (UNEP 1992). Desertification is often produced by a multiplicity of interacting environmental and socio-economic causes. Political instability, poverty, poor irrigation methods, deforestation, and overgrazing can all undermine the productive capability of land. The degradation process can be attended by reduced vegetation cover and soil organic matter, soil compaction, decreased infiltration, increased runoff, and increased wind and water erosion. Salinization, alkalinization, leaching, and acidification can contribute to soil degradation by reducing vegetation cover and triggering these physical mechanisms. Much of the concern over desertification of drylands stems from the resulting decline in the biological productivity of the land, ultimately reducing the land capability for crop production, livestock grazing, and thus supporting human populations.

Dryland environments extend over one-third the earth's surface, encompassing more than 1 billion residents who must make their livelihoods here (United Nations Commission on Sustainable Development, 1995). Roughly 70% of these areas have experienced some degree of degradation (UNCCD 2006), resulting in a wide range of environmental, cultural, economic and political ramifications both locally and globally. However, good information on the extent and severity of desertification is lacking, and many estimates are largely based on opinion. Desertification is to a significant extent unmeasured or poorly documented, with the result that it does not receive the attention it might in national planning efforts and as a spending priority (Dregne 2002). Furthermore, sufficient detail on local environmental conditions is lacking, undermining land management efforts at specific sites. Geospatial technologies, including global positioning systems (GPS), satellite imagery, aerial photography, and geographic information systems (GIS) hold great promise for improving the quality and quantity of information on degradation trends over large areas as well as provide for more effective management of that information. Furthermore, it is believed that dryland degradation can be slowed and reversed if areas undergoing desertification can be identified and properly managed (European Space Agency 2005). The purpose of this paper is to detail the use of geospatial technologies in enhancing monitoring and management efforts for land areas subject to desertification.

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## 2. SATELLITE IMAGERY AND AERIAL PHOTOGRAPHY

High-resolution satellite imagery, such as Landsat Thematic Mapper and SPOT, combined with medium-resolution satellite imagery, such as Landsat MSS, are widely available for environmental monitoring and hold advantages over traditional in situ data. For example, remote sensing and air photography permit observation of land areas over multiple scales, facilitating analysis by consideration of both large, regional, and smaller, more detailed spatial extents. In addition, remotely sensed observations are repeated regularly over study areas, often using different ranges of wavelengths to highlight various phenomena of interest.
Daily, multi-year observations of global extent are available free of charge for some sensors, are rapidly available after observation, and are indispensable in areas where in situ monitoring is impossible due harsh environment or political or military conflicts. Area-integrated values replace point observations, providing greater value in characterizing wide-ranging phenomena such as desertification (Kogan 2000).

Satellite imagery has proven of great value in monitoring various environmental conditions, including those related to desertification. Land use, rainfall, dustiness, vegetation density and stress, soil moisture, and soil erosion and salinization are environmental indicators readily detected by high resolution satellite imagery that may point to growing desertification of an area. These measures, integrated and managed in GIS, can provide a solid foundation for effective decision making in drylands management.

### 2.1 *Land Cover*

Land cover refers to the observed biophysical cover presented at the land surface. Example land cover classes include agricultural land, forested areas, woodlands, grasslands, bare soil, water bodies, transportation infrastructure, and various-sized settlements. Land cover mapping has been a particularly valuable and cost effective application of remote sensing. It can be performed from all optical satellite data, but high resolution data, particularly from Landsat Thematic Mapper, are particularly cost effective. Automatic classification of digital data have proven successful only for a few land cover classes, and image enhancements (high pass filtering, contrast stretching) are often used to aid visual interpretation (Lantieri 2003).

Remotely sensed land cover determinations may be valuable in monitoring land degradation in several ways. Land cover types commonly subject to desertification processes can be identified and located, and samples of each type more fully surveyed in the field. Land use change can be detected in comparisons of images taken over time, revealing locations of activities associated with desertification. These activities might include intensification of agriculture (new/larger fields, irrigation, fields encroaching on natural areas), or reduction in density of woody or rangeland cover, which are commonly attended by greater rates of erosion interpretation (Lantieri 2003). When combined with information on the physical features of the landscape (slopes, drainage patterns), hotspots of high potential degradation can be identified for more detailed study.

An example study employing analysis of land use change was performed for the Manix Basin of the Mojave Desert (1979-1997), using Landsat Multispectral Scanner imagery and Airborne Visible Infrared Imaging Spectrometer. Approximately 15-30% of the land area experienced land degradation during this time period, largely due to residential and road construction, agricultural fields irrigated under the center pivot system, and areas impacted by wind-blown dust from these areas (Okin et al. 2001). Moderate Resolution Imaging Spectroradiometer (MODIS) has been used to produce a global land cover classification at a spatial resolution of 1 kilometer by merging images from multiple passes and improved data processing techniques (http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=10288).

### 2.2 *Rainfall*

Rainfall is critical to maintenance of vegetation and thus protection of soils from erosion in dry climates. Rainfall typically is highly variable from year to year in dry lands, but long periods of unusually low precipitation facilitate degradation processes. Remote sensing-based estimates of precipitation are particularly valuable for areas where few precipitation monitoring stations exist, and are routinely performed by a number of organizations monitoring food security. For example, Monitoring & Early Warning**:** Food Assessment by Satellite Technology (http://www.earlywarning.nl/earlywarning/ew_index.htm) performs rainfall mapping based on the discrimination of cloud top levels in hourly satellite imagery, using temperature thresholds. Hourly cold cloud durations at each height classification are counted over a period of 10 days. These counts are plugged into a regression model which then predicts rainfall at local weather stations. Cloud frequency-duration information are obtained from hourly recorded visible and thermal infrared images from METEOSAT.

Evaluation of multi-month precipitation anomalies, of greater relevance to desertification analysis, is also made possible through remote-sensing technologies. For example, data from a Multi-satellite Precipitation Analysis at the NASA Goddard Space Flight Center employed both passive and active sensors, including the first precipitation radar in space, to develop precipitation anomalies for the US during October 2005-January 2006 (http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17216).

### 2.3 *Vegetation Density and Stress*

The spectral characteristics of green leaves are such that they are highly absorptive of energy in visible blue, yellow, and red wavelengths (0.4-0.5, 5.7-0.7 microns) of the electromagnetic spectrum, but highly reflective in the near infrared wavelengths (0.7-1.1 microns). Spectral responses of vegetation are further modified based on the leaf density and structure of the canopy. The relative differences in red (RED) and near infrared (NIR) spectral characteristics form the basis of several vegetation indices which are designed to assess the condition of vegetation. For example, the normalized difference vegetation index (NDVI), a commonly used vegetation index, is expressed as:

$$NDVI = \frac{NIR - RED}{NIR + RED} \qquad (1)$$

Where 0 or negative values indicate no green leaves and +1 indicates the highest possible density of green leaves. Low positive values of NDVI, where little difference exists in RED and NIR wavelengths, is typical of low density vegetation such as grassland or desert. High values, where NIR is much greater than RED, indicated high density vegetation such as forest. Daily indices are usually combined into multi-week composites and then compared to previous weeks to assess trends in the density and stress of the vegetation. Similarly, a NDVI anomaly can be achieved by comparing a monthly composite to an average monthly composite derived over 20 years. Negative anomalies of the NDVI are an indicator of drought. Low resolution (7.6km) NDVI values are made available from spectral data of the US Advance Very High Resolution Radiometer (AVHRR), which provides daily global coverage.

The NDVI has also been used for crop condition assessment, measures of leaf area index, percent cover, and green biomass (Wiegand and Richardson 1987). Furthermore, in semiarid areas, NDVI is directly related to past rainfall and seasonal primary production (Tucker and Nicholson 1999). The NDVI satellite-derived information on healthy vegetative cover has been developed for the Sahara Desert, revealing large interannual fluctuations in the spatial extent and vigor of dry land vegetation caused largely by interannual precipitation variations. Tucker used high-resolution satellite imagery to count individual trees and bushes at three sites where the Sahara transitions into the Sahel (Tucker and Nicholson 1999). Areas with lower levels of vegetation caused by fuel wood cutting or drought may be undergoing desertification because of the loss of protection to the soil afforded by the vegetation. Temporal comparisons of the images may also be used to detect areas undergoing vegetation loss and growing desertification. Airborne Visible/Infrared Imaging Spectrometer data permit more detailed evaluation of the physical structure of vegetation.

Numerous developments in remote sensing of vegetation have occurred since first development of the NDVI. Combining land surface temperatures with vegetation indices (Nemani and Running 1989) allows a better assessment of vegetation stress. As water becomes limiting to plants, evapotranspiration rates drop, so that further energy income is channeled into heating. Rapid increases in remotely sensed thermal infrared may suggest growing drought and vegetation stress, and a number of vegetation indices now take into account the effect of temperature. Further work is need to address errors in measurement brought on by variations in atmospheric water vapor content, aerosols, soil type and topography.

### 2.4 *Soil Moisture*

Technologies associated with remote sensing of soil moisture are advancing rapidly. However, present soil moisture data bases, derived across a wide variety of spectral bands and various methods, are limited in resolution and accuracy. In the US, the School of Forestry at the University of Montana combines AVHRR NDVI data with surface temperature in regression applications to calculate the Soil Moisture Index (SMI). The EARS Laboratory in the Netherlands also estimates SMI and other related soil moisture measures as the end product of assessment of the terms of the water balance, which are derived at a resolution of 5km using Meteosat data (Lantieri 2003).

Microwave wavelengths are better at detecting variations in soil moisture content due to the polar nature of the water molecule. Remote sensing using active microwave systems (radar) holds advantages over sensors measuring visible and NIR bands due to its ability to penetrate clouds and operate at night, allowing continuous monitoring of the earth surface. Backscatter-measuring scatterometers can be used in determining soil moisture anomaly indicators. These instruments have also been used by the Institute of Photogrammetry and Remote Sensing at the Vienna University of Technology to produce a global soil moisture archive, with data at a resolution of 25km (Lantieri 2003). While soil moisture estimates derived from microwave-sensing satellites have been limited by availability, resolution, and technology, good success has been achieved using microwave sensors from towers and aircraft, and in also exploiting passive microwave bands. Technological advancements in microwave sensing systems over the next decade are expected to greatly increase soil moisture mapping capabilities (Jackson 2005).

### 2.5 *Soil Erosion and Salinization*

Surface features associated with land degradation can be detected on aerial photographs, very high resolution imagery, or sometimes high resolution imagery. For example, patterns of salinization associated with widespread irrigation systems appear as white areas on such imagery, and erosional gullies occurring over large areas can be detected. Similarly, introduction of high levels of sediment induces a color shift into receiving water bodies, pointing to high local rates of soil erosion (Lantieri 2003). Most common remote sensing systems do not provide the level of detail required for such assessments, however, but can provide useful information for determining optimal location of in situ assessments.

Wind-blown dust, particularly in dust storms, is more readily apparent on remotely sensed imagery. Earth Observatory (earthobservatory.nasa.gov) presents a series of images illustrating effects of dust storms. The Sea viewing wide field of view sensor shows a massive dust storm emanating from the west coast of Africa for February 11, 2001 (http://visibleearth.nasa.gov/view_rec.php?vev1id=7347)

### 2.6 *Aerial Photography*

Detection of many of the land surface features indicative of developing desertification requires very high resolution imagery, or low-level aerial photography. While the cost of surveying small areas through aerial photography is not prohibitive, repeated coverage over large areas is often outside the budget of resource management agencies. Ground truth, in situ surface observations for remotely sensed data or aerial photography are a necessary component of ensuring quality databases.

## 3. GPS AND GIS

Geographic Information Systems serve as a means of integrating and manipulating in situ surface observations, satellite-based environmental indicators, aerial photography, and other available spatial information in support of effective dryland planning, decision making, and research. GPS technologies facilitate that integration of information by providing exact locational coordinates of land observations and repeated samples for meshing the various sources of data. Land observations gathered for study sites no longer require markers, and are easily evaluated even for remote locations. Evaluation of individual and composite GIS data layers permits assessment of desertification risk in a manner and timely fashion that was not possible before. Furthermore, the digital GIS data can be transmitted from one use to another using various digital media, including the internet. The resultant growth of digital databases and information exchanges should enhance research of underlying causes and means of addressing desertification. For example, DesertWatch of the European Space Agency manipulates combined in situ data and satellite information with various processing tools, models, and geographic information systems to produce a variety of national and regional risk maps, severity/recovery maps, and pressure indicators that meet the United Nations Convention of Desertification reporting requirements. The hope is to provide a reliable and accurate database from which to monitor desertification trends (European Space Agency, 2005). In another example, USDA geographers have determined 'tension zones' susceptible to desertification by combining soil maps, temperature and moisture from 25,000 surface monitoring stations in a GIS. Over 1.4 billion people were found to live in zones of the greatest tension (Eswaran et al. 1998).

The vast spatial extent of drylands and our inability to effectively measure land degradation in these areas has traditionally limited our ability to understand, address and prevent desertification. Using recent advances in geospatial technologies, including remote sensing, aerial photography, GPS and GIS, remotely sensed environmental indicators of desertification can be merged with in situ data to monitor and evaluate physical and socioeconomic operators over large areas. Current developments in satellite technology, computer speed and capacity, and resolution of imagery hold exciting prospects for the development of informational products that allow both effective monitoring and protection of the drylands that support a significant portion of the world's population.

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