Monitoring land degradation with long-term satellite data in South Africa

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Desertification is defined by the United Nations Convention to Combat Desertification (UNCCD) as 'land degradation in arid, semi-arid and dry sub-humid areas (drylands) resulting from various factors, including climatic variations and human activities.'[1] Degradation includes diverse processes from changes in plant species composition to soil erosion that result in reduced biological or economic productivity of the land. Land degradation affects food security, national economic development and natural resource conservation strategies. Desertification refers specifically to degradation in drylands and it is widely considered to be one of the most destructive environmental processes of our time affecting an estimated 250 million people.

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South Africa's former homelands, now communal areas, show the effects of overgrazing, soil erosion and unplanned rural settlement

One hundred and eighty-four nations are signatories to the United Nations Convention to Combat Desertification (UNCCD), but there is little information on the distribution and severity of desertification beyond local scale studies; reliable and consistent country to continental scale data are entirely lacking. Most global or regional maps of land degradation constitute subjective expert opinions and cannot be used to systematically track degradation through time and space. There is an urgent need for standardized, quantitative and spatially-explicit measures of ecosystem functions to map and monitor land degradation. GEOSS has thus committed to delivering sustained observations of the earth system in order to combat desertification.

The UN Food and Agriculture Organization's (FAO) Global Land Degradation Assessment in Drylands (GLADA) programme is coordinating an effort to assess land degradation in drylands at the country and global scales. The GEOSS ten-year implementation plan has identified the completion of GLADA as a priority in the context of the agriculture societal benefit area. South Africa (SA) has been chosen by GLADA as one of six pilot countries where land assessment technologies will be developed and evaluated for future implementation in all participating countries. The SA National Department of Agriculture (DoA) is coordinating the current SA LADA process owing to its long record of research on this topic. This chapter summarises some major findings of the research and highlights the importance of long-term Earth observation data as advocated by GEOSS.

Monitoring land degradation with satellite data

Long-term, coarse resolution satellite data have been widely used to monitor vegetation dynamics and detect land degradation.[2] Vegetation production is routinely estimated with the normalized difference vegetation index (NDVI) derived from satellite data. NDVI captures the marked contrast between the strong absorption of solar radiation in the visible and strong reflectance in the near-infrared wavelengths that is characteristic of live, green vegetation. NDVI provides an estimate of the energy used by plants for photosynthesis. Remotely sensed vegetation production may very well be the single most useful indicator of land degradation at regional and decadal scales.[3]

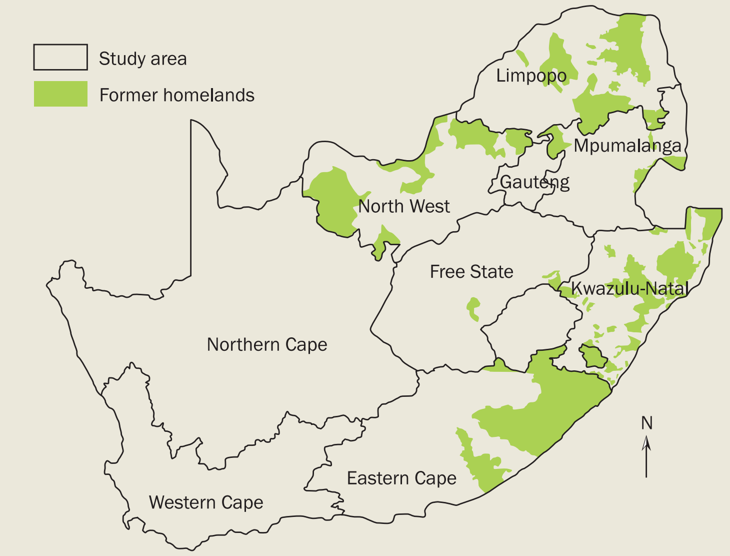
In the early 1990s NDVI data from the Advanced Very High Resolution Radiometer (AVHRR) sensor on the NOAA series of meteorological satellites were analysed and showed that the Sahara desert was not marching southwards into the Sahel, but rather expanded and contracted as a result of interannual variations in rainfall.[4] Recently, a number of studies using 20 years of AVHRR NDVI data have shown that the Sahel, which was once believed to be suffering severe desertification, has in fact become greener during the past ten years as a result of higher rainfall.[5] The occurrence of desertification in the Sahel and elsewhere has become highly controversial, but the debate is being conducted in the absence of objective, consistent data at the appropriate scales. While repetitive, global remote sensing has been applied to mapping and monitoring degradation, interpretation of the results has not always been based on sound ecological principles. A critical aspect of a useful degradation mapping and monitoring system is the ability to distinguish the impacts of human activities from natural variability in climate and spatial variations in soils and land cover types.

Land degradation in the former homelands of South Africa

In South Africa, large degraded areas have been found within the former 'homelands' — self-governing areas created before and during the Apartheid era.[6] Today these homelands, now called communal areas, are characterized by high human and livestock populations, overgrazing, soil erosion and sparse grass cover. Degradation continues to threaten the local resource base upon which rural communal livelihoods depend. The underlying cause of degradation is a combination of unemployment, poverty and an absence or failure of land use regulation. The degradation observed in the communal lands is thus principally a consequence of high population densities caused by the oppressive apartheid system rather than the outcome of traditional communal pasturalism.

These degraded rangelands have been subjectively mapped using single date Landsat images as part of the National Land Cover (NLC) map. The vast majority of the large degraded areas fall within the communal areas. We investigated the long-term vegetation production of these degraded areas with 18 years of 1km² resolution AVHRR NDVI data by comparing them to non-degraded adjacent areas with the same soils and climate. It was found that the non-degraded areas had consistently higher vegetation production as indicated by the seasonal total of NDVI obtained from satellite observations despite a six-fold variation of annual rainfall. This indicates that the degraded areas produce less vegetation per unit of rainfall and suggests that they may have changed to a different ecological state. The results nevertheless indicate that these degraded areas are functionally stable and resilient, but never reach the same vegetation productivity as the neighbouring non-degraded areas.[7] These results are both alarming and encouraging: alarming because the degraded state seems to be permanent; and encouraging because the difference in productivity was approximately 20 per cent, far from a complete loss of production as is sometimes suggested in degraded areas. Whether the difference in total rangeland production translates into economic loss remains to be determined. These results have made a significant contribution to understanding the ecological processes in degraded areas — research that would not have been possible without a long-term, regional satellite data archive.

Former homelands, provinces and study area in South Africa



Large degraded areas have been found in South Africa's former homelands

Source:

Distinguishing human-induced degradation from drought

In arid and semi-arid regions vegetation production varies between years caused primarily by inter-annual rainfall variability. Southern Africa suffers periodic droughts, some caused by the El Niño phase of the El Niño-Southern Oscillation (ENSO) cycle. Extreme variability in vegetation production between years makes it exceedingly difficult to distinguish long-term changes caused by human-induced land degradation from the effects of periodic droughts. One approach to monitoring land degradation is to use both long-term AVHRR NDVI data and rainfall surfaces to identify any negative trends in vegetation production per unit rainfall through time (1985—2003).[8]

In the Limpopo Province negative trends were largely associated with the degraded communal lands, although some well-known degraded areas did not show continued negative trends during the study period (1985—2003). A distinction should be made between degradation that occurred within or before the start of the satellite time-series; some homelands were created as early as 1913 so much of the degradation could have occurred before and may not have worsened since. The results of this analysis in northern SA are validated by the National Report on Land

Degradation,[9] which shows the perceived rates of change in rangeland condition over a ten-year period (1989—1999), as judged by local experts.

Besides land degradation, other forms of land cover and land use change (e.g. expanding subsistence agriculture or informal settlements) as well as natural processes can also cause a reduction in production per unit of rainfall. The present method should thus be used as a regional indicator to identify potential problem areas that can then be investigated in greater detail, using high-resolution remote sensing data and field data. It is unlikely that any method that depends exclusively on remote sensing from a single sensor will be able to unequivocally map the complex ecological process of degradation. Maps depicting the trends in vegetation production per unit of rainfall, as shown here, require field verification before management and policy decisions can be based on them. The Department of Agriculture is therefore actively involved in the verification process. In contrast to previous maps of land degradation in SA that were mainly based on expert opinions, the remote sensing approach is objective and repeatable, and all indications are that it will furnish a valuable regional monitoring tool.

The long-term, high temporal resolution, satellite data that are being promoted by GEOSS are indispensable, and significant efforts are in progress to improve the quality of the data. The AVHRR instruments were never intended for the uses to which they are now put and the quality of the data, while appropriate for the original application in weather forecasting, are not optimal for remote sensing of vegetation. Newer sensors such as MODIS are now in service, but these are experimental systems, not intended for long-term operational observations. Thus the role of GEOSS in encouraging long-term data collection is very important in the context of mapping and monitoring desertification.

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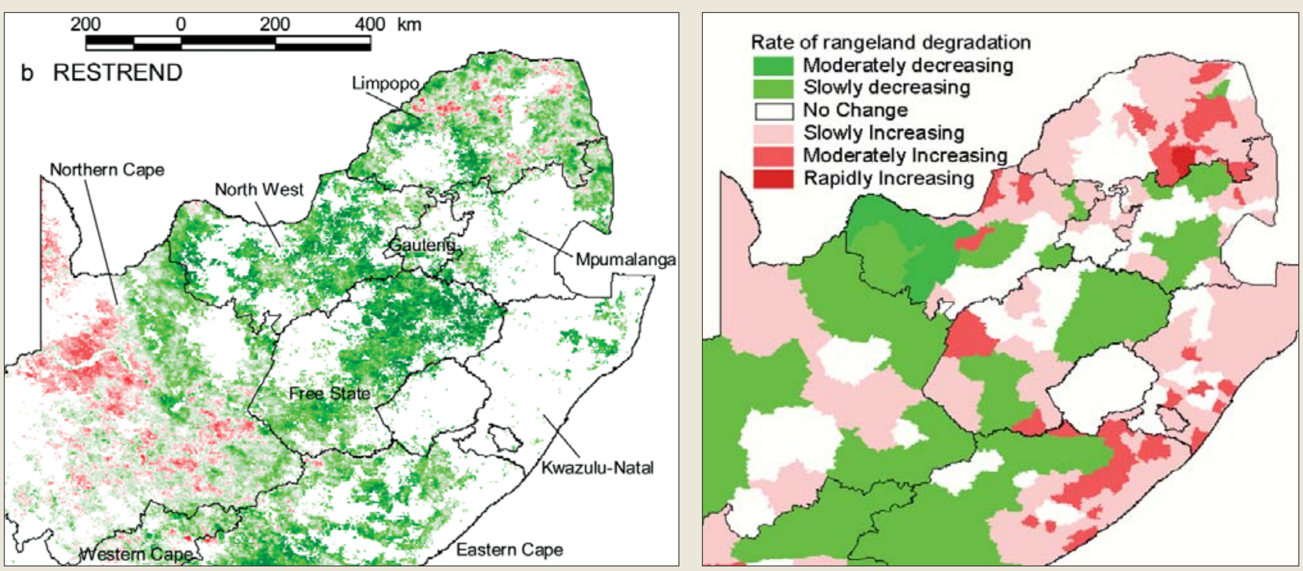
Degradation continues to threaten the local resource base upon which rural communal livelihoods depend

Trends in vegetation production per unit of rainfall



Temporal trends in vegetation production per unit of rainfall in the summer rainfall region of South Africa (red — negative, green — positive) derived with NOAA AVHRR data from 1985 to 2003. The rate of rangeland degradation as judged by experts (after Hoffman et al. 1999). The two maps agree in many parts of the region. Note the high spatial resolution of the satellite observations

Source: