ELSEVIER

Journal of Arid Environments 68 (2007) 271–297

Journal of Arid Environments

www.elsevier.com/locate/jnlabr/yjare

Can human-induced land degradation be distinguished from the effects of rainfall variability? A case study in South Africa

K.J. Wessels[a,*,1], S.D. Prince[a], J. Malherbe[b], J. Small[c], P.E. Frost[d], D. VanZyl[b]

[a]*Department of Geography, University of Maryland, 2181 LeFrak Hall, College Park, MD 20742, USA*
[b]*Agricultural Research Council, Institute for Soil, Climate and Water, Pretoria, South Africa*
[c]*NASA/Goddard Space Flight Center, Biospheric Sciences Branch, Code 614.4, Greenbelt, MD 20771, USA*
[d]*CSIR-Satellite Application Centre, Pretoria, South Africa*

Received 10 November 2005; received in revised form 6 April 2006; accepted 31 May 2006
Available online 1 August 2006

Abstract

Advanced Very High Resolution Radiometer (AVHRR), Normalized Difference Vegetation Index data (NDVI, 1 km^2, 1985–2003) and modeled net primary production (NPP, 8 km^2, 1981–2000) data were used to estimate vegetation production in South Africa (SA). The linear relationships of Log$_e$Rainfall with NPP and ΣNDVI were calculated for every pixel. Vegetation production generally had a strong relationship with rainfall over most of SA. Therefore, human-induced land degradation can only be detected if its impacts on vegetation production can be distinguished from the effects of rainfall. Two methods were tested (i) Rain-Use Efficiency (RUE = NPP/Rainfall or ΣNDVI/Rainfall) and (ii) Residual Trends (RESTREND), i.e. negative trends in the differences between the observed ΣNDVI and the ΣNDVI predicted by the rainfall. Degraded areas mapped by the National Land Cover in north-eastern SA had reduced RUE; however, annual RUE had a very strong negative correlation with rainfall and varied greatly between years. Therefore, RUE was not a reliable indicator of degradation. The RESTREND method showed promising results at a national scale and in the Limpopo Province, where negative trends were often associated with degraded areas in communal lands. Both positive and negative residual trends can, however, result from natural ecological processes, e.g. the carryover effects of rainfall in previous years. Thus, the RESTREND

*Corresponding author. Present address: NASA/Goddard Space Flight Center, Hydrospheric and Biospheric Sciences Laboratory, Code 614.0, Greenbelt, MD 20771, USA. Tel.: +1 301 6146883; fax: +1 301 6145666.
E-mail address: kwessels@pop600.gsfc.nasa.gov (K.J. Wessels).
[1]Also at: Goddard Earth Sciences Technology Centre, University of Maryland Baltimore Country.

doi:10.1016/j.jaridenv.2006.05.015

method can only identify potential problem areas at a regional scale, while the cause of negative trends has to be determined by local investigations.

Keywords: Monitoring; AVHRR; NDVI; Rain-use efficiency; NPP; Communal lands; South Africa

1. Introduction

Vegetation production in arid and semi-arid regions is closely related to the long-term average precipitation (Rosenzweig, 1968; Rutherford, 1980) and inter-annual rainfall variability (Le Houérou et al., 1988), especially in Southern Africa which is strongly affected by the El Niño-Southern Oscillation (ENSO) phenomenon (Jury et al., 1997; Anyamba et al., 2002; Cao and Prince, 2005). Short-term variability in primary production makes it exceedingly difficult to distinguish long-term change as a result of human-induced land degradation from the effects of periodic droughts (Pickup et al., 1998; Dahlberg, 2000; Dube and Pickup, 2001; Prince, 2002). Human impacts are further obscured by spatial variability in topography, soil types, vegetation types and land use.

Land degradation is one of the most serious global environmental issues of our time (Dregne et al., 1991; UNCED, 1992; Reynolds and Stafford Smith, 2002b). Over 250 million people are directly affected by desertification and some one billion people in over 100 countries are at risk (Adger et al., 2000). Land degradation has a broad range of definitions that essentially describe circumstances of reduced biological productivity of the land (UNCCD, 1994; Reynolds and Stafford Smith, 2002). According to the United Nations Convention to Combat Desertification (UNCCD) definition, land degradation can be caused by both human and climate factors (UNCCD, 1994). A number of studies have shown that the perceived desertification in the Sahel (e.g. Lamprey, 1975) can largely be attributed to variations in rainfall rather than human-induced land degradation (Tucker et al., 1991a; Nicholson et al., 1998; Prince et al., 1998; Anyamba and Tucker, 2005; Nicholson, 2005). These studies demonstrated that there was neither a progressive southwards march of the Sahara desert, nor large-scale expansion of less productive land (Tucker et al., 1991a; Nicholson et al., 1998; Anyamba and Tucker, 2005). In order to combat land degradation, countries need spatial monitoring systems that are able to distinguish human impacts on vegetation production from the effects of rainfall variability (Pickup, 1996; UNCCD, 1994).

Various methods have been used to monitor changes in vegetation function based on multi-temporal Advanced Very High Resolution Radiometer (AVHRR) data (Hellden, 1991; Tucker et al., 1991b; Lambin and Strahler, 1994). The results are often dominated by erratic rainfall, associated changes in seasonality and drastic land cover or land use changes (Lupo et al., 2001), which all mask any land degradation that is generally more subtle and gradual. Two methods are explored here to distinguish human-induced land degradation from inter-annual variability in rainfall; (i) Rain-Use Efficiency (RUE = net primary production (NPP)/Rainfall or Normalized Difference Vegetation Index (NDVI)/Rainfall) and (ii) Residual Trends (RESTREND), i.e. negative trends in the differences between the observed ΣNDVI and the ΣNDVI predicted by the rainfall using regressions calculated for each pixel. Both these methods are based on the concept that land degradation causes reductions in vegetation production per unit rainfall as a result of soil