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Use of Landsat series data to analyse the spatial and temporal variations of land degradation in a dispersive soil environment: A case of King Sabata Dalindyebo local municipality in the Eastern Cape Province, South Africa

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ABSTRACT

Land degradation as a result of inappropriate land use practices, such as overgrazing and cultivation on steep slopes, etc. is one of the major global environmental challenges. Specifically, land degradation threatens the productivity and sustainability of the natural environment, agriculture, and most importantly rural economies in most developing countries, particularly the sub-Saharan region. The main aim of this study was therefore, to assess the potential and strength of using the free or readily available Landsat series data in mapping degraded land areas at the King Sabata Dalindyebo local municipality in the Eastern Cape, South Africa (1984–2010). Data analysis was done using a robust non-parametric classification ensemble; Discriminant Analysis (DA). The results show that degraded areas vary over the years. For example, the results show that the year 1994 and 2004 incurred high degradation levels, when compared to the year 1984 and 2010. Moreover, the observed degradation significantly ($\alpha = 0.05$) varies with soil type. The chromic acrisols have the highest levels of erosion (approx. 80% in 1984), when compared to humic-umbric acrisols (less than 10% for the entire period under study). It can also be observed that considerable part of degradation occurred in the northern part of the municipal district. Overall, the findings of this research underlines the importance and efficacy of multispectral Landsat series data-set in mapping and monitoring levels of land degradation in data-scarce catchments.

1. Introduction

Land degradation as a result of inappropriate land use practices, such as overgrazing and cultivation on steep slopes, amongst others, is one of the major environmental challenges the world-over, especially in third world countries i.e. sub-Saharan Africa, South America and South Asia (Kakembo et al., 2012; Manjoro et al., 2012; Seutloali et al., 2015). Amongst different forms of land degradation; sheet-wash, rill and most importantly gully erosion have been repeatedly cited as the major environmental threats (Seutloali and Beckedahl, 2015; Seutloali et al., 2015). The continued soil loss, due to these processes, has critical implications on rural economies; as most of them rely on agriculture as a source of livings (Murdoch, 1980). For instance, literature shows that in developing countries, agriculture remains the back-bone of the rural populace; if not for the whole country (Murdoch, 1980). Besides structural, technical and political constraints to improve and adequate food production in rural areas, as highlighted in Murdoch (1980), land degradation, is one of the major challenge that cannot be ignored or left to continue unabated if rural economies are to be improved (Wassenaar et al., 2005). For example, a study by Seutloali et al. (2015) has demonstrated that the economic costs linked with the undesirable impacts of land degradation are often too high, especially for developing economies. Literature shows that, approximately millions of dollars are lost annually, due to soil erosion and associated effects in South Africa. For example, in South

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Africa, it is estimated that soil erosion cost approximately 200 million USD annually, including the offsite costs of purification of silted dam water (Le Roux et al., 2008).

Deriving up-to-date spatial and temporal information on the levels of land degradation is therefore critical if any further environmental problems are to be reduced. Mapping of degraded land areas provide valuable spatial information that may benefit operational tasks, such as rehabilitation of affected areas and any other forms of remediation. Besides, this information is critical in promoting operational and cheap soil erosion control strategies. Moreover, determining the distribution of degraded areas, as well as vulnerable soil types is valuable for coming up with possible control measures and prioritization strategies for immediate rehabilitation (Le Roux et al., 2008; Seutloali et al., 2015). In addition, this information helps in ensuring that regular monitoring and better management practices are put in place. Nevertheless, obtaining accurate and up-to-date information on the spatial and temporal distribution of degraded areas remains a challenge, especially when using convectional techniques (i.e. digitizing, field surveys etc). For instance, of late, studies using convectional techniques have been regarded as time-consuming, expensive, labour intensive and spatially constrained (Dube et al., 2014; Bangira et al., 2015; Dube and Mutanga, 2015; Seutloali et al., 2015; Sibanda et al., 2015a,b). These challenges have of late seen a shift towards the use and application of new cutting edge remote sensing methods in mapping and monitoring soil loss (Seutloali et al., 2015).

Previous studies that utilised remote sensing have shown that these data-sets have the capability of enhancing our understanding of the scale and extent of land degradation at landscape scale, a previously challenging task from conventional methods (Vrieling, 2006). For example, Servenay and Prat (2003), using SPOT satellite data successfully distinguished four stages of soil erosion in the northern part of Michoacan State, Mexico. Similarly, Lo curzio and Magliulo (2010), using Landsat ETM 7 + assessed the spatial distribution and mapped the degraded areas with a good spatial accuracy and limited cost in southern Italy. Moreover, Igbokwe et al. (2008) successfully depicted the spatial distribution of gully sites in the south-eastern Nigeria, using Landsat Enhanced Thematic Mapper, SPOT 5, Quick Bird and Shuttle Radar Topography Mission (SRTM) satellite datasets. Vrieling (2006) evaluated the potential of analysing regional erosion risk, using remotely sensed data in the West Usambara Mountains, Tanzania. They found that the spatial patterns of erosion risk is well represented, and high erosion risk areas can be properly identified using SRTM DEM and ETM + data. Due to these inherent spatial and temporal aspects, satellite data have often proved more robust and effective by providing more accurate soil erosion mapping results, when compared to ground based measurements (Vrieling, 2006).

Although the detection of degraded surface areas is an important application of field surveys, the large spatial extent of the degraded areas often inhibits its detection using these approaches. On the other hand, the currently spatial (30-m) and temporal (16 day) resolutions provided by the freely or readily available Landsat series data is hypothesized to have the potential to optimal identify, detect and map medium to large degraded areas over time, particularly in resource constrained areas, such as South Africa (Millington and Townshend, 1984; Whitlow, 1986; Vrieling, 2006; Zhou, 2008; Zhou et al., 2008; Taruvinga, 2009). Also the most important aspect with sequential images (i.e. Landsat imagery) is that they permit an analysis of the growth or decrease of degraded areas over time. Given these advantages, this study assesses the potential of using free or readily available Landsat series data in mapping land degradation levels (1984–2010) in the Eastern Cape Province, South Africa. This study will provide a tool for land degradation assessment, particularly in resource-scarce areas, such as South Africa. Moreover, given the great concern on land degradation in South Africa, the results of this study will provide up to date information on the levels of erosion which is essential for policy development for both land and water security, and above all economic development and environmental integrity.

2. Methods and materials

2.1. Study area

The study was conducted in King Sabata Dalindyebo local municipality which is under Oliver Reginald Tambo (OR Tambo) municipality District in Eastern Cape, South Africa (−31.54639°; 28.67528°) as illustrated on Fig. 1. The study area lies in the south eastern region of the Eastern Cape Province, on the Indian Ocean coastline. This municipality occupies a portion of the former marginalised homeland in Transkei. It is one of the five local municipalities, which include Nyandeni, Mhlontlo, Port St Johns and Ingquza Hill. OR Tambo is approximately 170.143 km from the east to the east and 121.725 km from the north to the south. The major cities and towns in this Municipality are Flagstaff, Libode, Lusikisiki, Mqanduli, Mthatha (previously Umtata), Ngqeleni, Port St Johns, Qumbu, and Tsolo. The topography of the area is generally rugged ranging from hilly to mountainous with an average altitude of 764 m above sea level. The hills and mountains are characterised by grasslands, as well as sporadic forests. The dominant agricultural activity in the study area is livestock rearing. The dominant soil type in King Sabata Dalindyebo local municipality area are Dystric Regosols, Gleyic Planosols, Rhodic Ferralsols, Lithic Leptosols, Humi-Umbric Acrisols, and Rhodic Lixisols (Fey, 2010). These soils are hypothesized to experience different levels of soil erosion.

2.2. Soil types found within King Sabata Dalindyebo local municipality

The dominant soil type in Oliver Tambo municipality area is Dystric Regosols followed by the Gleyic Planosols, Rhodic Ferralsols, etc. The Regosols soils are a category that encompasses all soils that are not included in any of the other reference groups (Fig. 4a) (Fey, 2010). Regosols are generally weakly developed soils characterised by un-aggregated material that have an Ochric surface horizon (Fig. 4 b). These soils are generally known for eroding landscapes especially in the arid and semi-arid areas as well as mountainous areas (Fey, 2010).

2.3. Remotely sensed data

To assess land degradation levels in the Eastern Cape, using remotely sensed data, cloudless Landsat TM images covering the study area were selected and downloaded from the Landsat archive: The United States Geological Survey Global Visualization Viewer (GloVis) (http://glovis.usgs.gov/web-link) free of charge. The images acquired in digital number format were calibrated to radiances units [$Wm^{-2}sr^{-1}\mu m^{-1}$], using Chander et al. (2009) algorithm, based on the coefficients provided along with the datasets. This conversion from image DNs to radiances was conducted for each band in Envi 4.3 software. In this study, we used the near infrared, as well as the visible wavebands to map the degraded areas. Prior to classification, all the images were atmospherically corrected, using the Fast Line-of-sight Atmospheric Analysis of Spectral Hypercube (FLAASH) model in Envi software (Kaufman et al., 1997; Felde et al., 2003). More details with regards to the application of this procedure are provided in literature (Kaufman et al., 1997; Felde et al., 2003). The images used in this study were all acquired during the dry season.

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