MONITORING SOIL EROSION FEATURES USING A TIME SERIES OF AIRBORNE REMOTE SENSING DATA: A CASE STUDY WILD COAST, SOUTH AFRICA

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KEYWORDS: Soil erosion, land degradation, airborne remote sensing

ABSTRACT

Soil erosion is a major geohazard that may pose both localized and off-site threats. Erosion by wind and water has caused severe land degradation in the Eastern Cape and if left uncontrolled may have detrimental consequences in critical environments along the Wild Coast. Development of a monitoring protocol to predict the susceptibility of the Wild Coast to erosion is necessary for the mitigation and prevention of further degradation. The development of such a monitoring protocol is based on the premise that erosion in the future is likely to occur under the same conditions that led to historical erosion processes.

This paper focuses on the evolution of some large wind and water erosion features within the Xolobeni coastal strip along the northern Wild Coast that have been mapped from historical, multi-temporal airborne remote sensing data using initial results of sequential Maximum Likelihood classifications. Although image analysis suggests erosion is initiated by anthropogenic factors, the wind regime in the region is responsible for the preferential growth of elongated features that trend in same direction as of the dominant winds. Erosion is generally occurring at an accelerated rate. Peripheral vegetation was found to act as a wind barrier, effectively preventing the spread of parabolic dune erosion features.

Minimisation of bare soil patches in croplands and along access tracks will curtail the creation of new wind blowouts and gully erosion features. The spread of these features can be prevented by establishing indigenous vegetation barriers on the intact soil along the fringes of the degraded area before establishing cover of plant species capable of stabilising loose sand. Such mitigation measures can be used to ensure that further degradation along the pristine Wild Coast is minimised.

INTRODUCTION

Soil erosion is a major geological hazard. According to Lal (2003) the global land area affected by water and wind erosion is 1094 M ha and 549 M ha, respectively. In South Africa, the average soil loss rate has been estimated at 12.6 t/ha.yr (Le Roux, 2011) with millions of tonnes of soil lost per annum (Collins, 2001). Land degradation has been acknowledged to impact negatively on civilisation by the Minister of Water and Environmental Affairs (DEA, 2013) and the adoption of suitable policies and practices for the mitigation of the causes of land degradation were recommended.

Rural districts of the Eastern Cape, KwaZulu-Natal and Northern Province are associated with severe degradation as a consequence of their possession of suitable physical and socio-economic factors (Meadows and Hoffman, 2002). The Eastern Cape Wild Coast is one of the World Wildlife Fund's International Global Eco-regions of Global Significance (O.R Tambo District Municipality, 2011). However, land degradation and soil erosion are critical environmental challenges faced by some municipalities within this region where the coastal zone is widely considered to be pristine. Uncontrolled soil erosion along the Wild Coast poses significant risk to environmental functioning, biodiversity and sustainability both on the degraded site as well as adjacent and downstream environments. Consequently, monitoring and controlling erosion on the Wild Coast is essential. Currently, there is no predictive local-scale erosion susceptibility model for the Wild Coast which could highlight areas at risk. It is critical for conservation planning of the region that these high risk areas be identified and protected.

The development of a monitoring protocol to predict the susceptibility of a region to erosion and the assessment of the impacts of soil erosion is necessary for the mitigation and prevention of further degradation. The development of such a monitoring protocol is based on the premise that erosion in the future is likely to occur under the same conditions that led to historical erosion processes. This implies that relationships between past and present erosion patterns and their primary causative patterns need to be assessed. Since erosion is a widespread phenomenon potentially affecting large areas, field-based monitoring programmes would be impossible to implement in practical terms, especially in remote or isolated areas along the ~250 km Wild Coast. Additionally, historical data would be inaccessible using traditional field-based approaches. Airborne and satellite derived remote sensing data on the other hand covers large areas with historical images available for the pilot site dating back to 1937, meaning that information on historical conditions can be extracted. This paper examines the first results of the erosional feature detection using a time-series of high resolution aerial photography captured between 1937 and 2009. The erosional history of the area is considered together with estimates of lateral spread rates and how they fluctuate over time.

Remote sensing and/or GIS methods have been widely adopted in several investigations on soil erosion, including studies by Agnesi et al. (2011), Taruvinga (2008) and Ustun (2008). Erosion mapping using remote sensing data such as aerial photography and/or satellite data is relatively inexpensive and enables rapid assessment of large areas. According to Vreiling (2007), the detection of erosion features from aerial photography and satellite imagery using visual interpretation is a common approach. For example, visual interpretation of SPOT data was used for the creation of a national gully location map of South Africa (Mararakanye and Le Roux, 2012). The analysis of multi-temporal data allowed for the mapping of erosion features and estimation of erosion rates in the Rierussa catchment, Spain (Martínez-Casasnovas, 2003).

STUDY AREA, DATA AND IMAGE PROCESSING

To develop an erosion monitoring and susceptibility mapping protocol, an area in the Eastern Cape Wild Coast, known as Xolobeni, was selected as the pilot study site (Figure 1). The Xolobeni area has widespread wind and water erosion features of several different generations. The study site covers an area of ~ 24 km^2 and is confined to the coastal zone approximately 14 km south of Port Edward. Erosion in the area has a strong association with Neogene to Quaternary weathered and rubified dune sands. These dune sands formed by the weathering of coastal dune sands deposited during the Neogene period coastline regression between 23 million and 2.58 million years ago McCarthy (1988). These deposits have been incised by river valleys and intense leaching and pedogenic bleaching have resulted in grey surficial sands that are particularly susceptible to erosion.

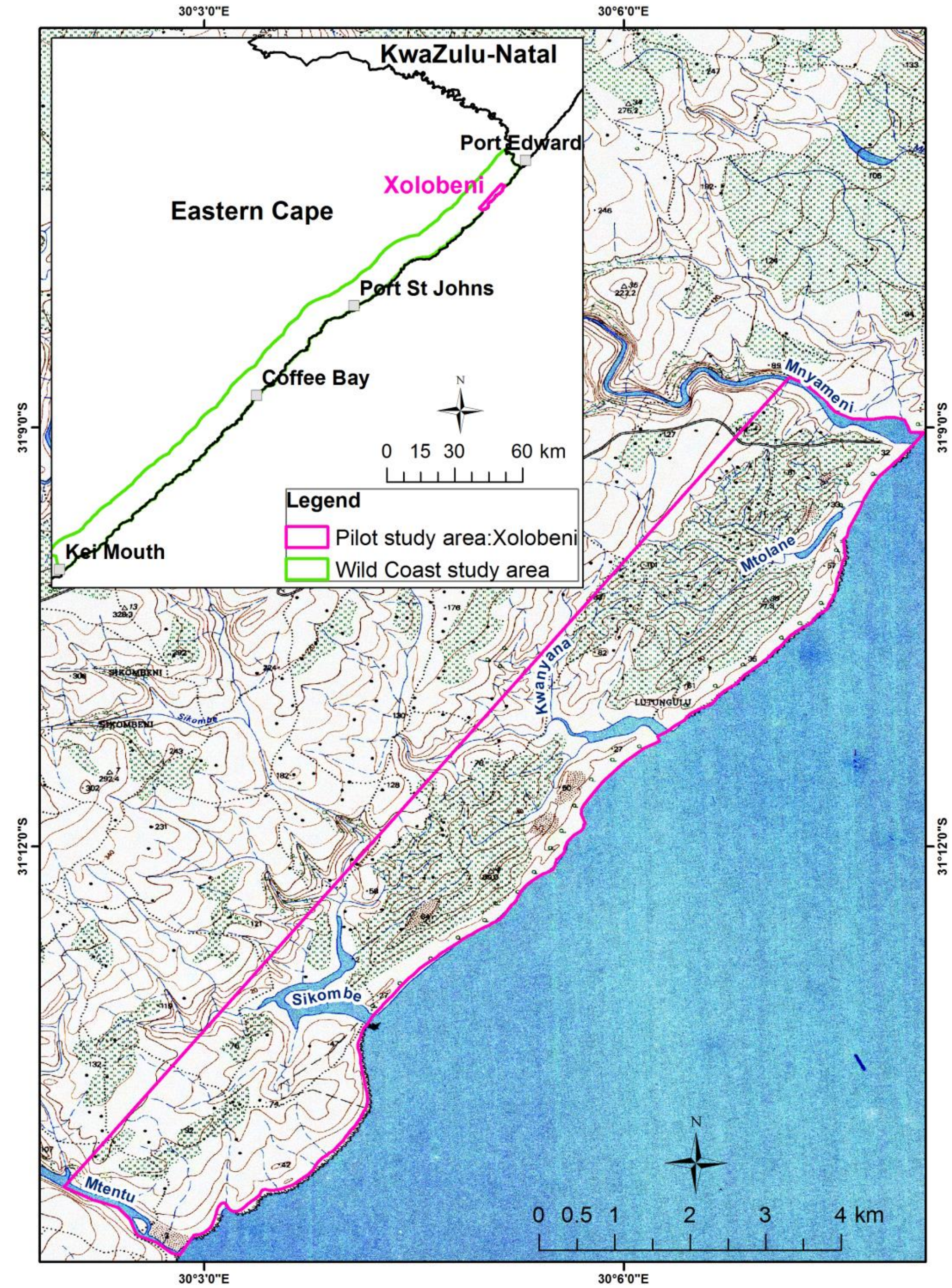

Figure 1. The pilot study area at Xolobeni in the Eastern Cape Wild Coast.

To derive spatial datasets on pre- and post- erosion conditions, the location of erosional features, as well as their evolution over time, several sources of remote sensing data were considered. The high resolution aerial photographs used in this investigation were captured between 1937 and 2009. The dates of image acquisition as well as the observation scale are summarised in Table 1.

Table 1. Aerial photography image acquisition dates, scale of observation and image descriptions

Year	Scale	Description of photography
1937	1:25000	Medium scale, black and white
1952	1:30000	Medium scale, black and white
1963	1:75000	Ultra-small scale, black and white
1969	1:40000	Small scale, black and white
1974	1:50000-1:60000	Small scale, black and white
1978	1:30000	Medium scale, black and white
1988	1:150000	Ultra-small scale, black and white
1993	1:50000	Small scale, black and white
1995	1:50000	Small scale, black and white
2002	1:50000	Small scale, black and white
2003	1:32000	Medium scale, black and white
2009	0.50m GSD	Colour

Aerial photographs covering the Xolobeni region were orthorectified, calibrated and mosaicked. The aim of the remote sensing image processing in the initial stages of the investigation was the identification and classification of eroded areas over time. For this purpose, both the Maximum Likelihood (ML) and ISODATA classification algorithms were employed. Visual assessment of the classification results revealed that the ML classification is more suited for the identification of bare ground (Figure 2). The training samples for the supervised classification process were selected through visual assessment of erosion features guided by field knowledge.

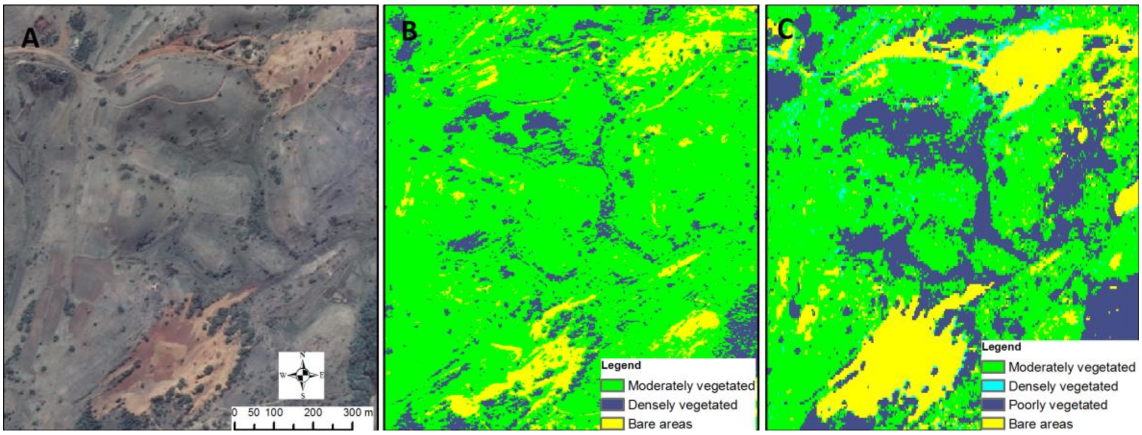

Figure 2. The 2009 colour aerial photograph (A) with the ISODATA (B) and Maximum Likelihood (C) classification results.

RESULTS, OBSERVATIONS AND DISCUSSION

An initial, visual assessment of erosion features in the Xolobeni area revealed a rapid change in the morphology of erosion features over time (Figure 3). The time series of imagery illustrates how communal farmland gradually degraded between 1937 and 1974 and by 1995 manifested as an eroded area (Figure 3). The size of the erosion feature increased significantly between 1995 and 2009 and additional erosional features can also be recognised. This assessment suggests that land degradation due to erosion is taking place at an increasingly accelerated pace in the area between the Mtolane and Kwanyana Rivers.

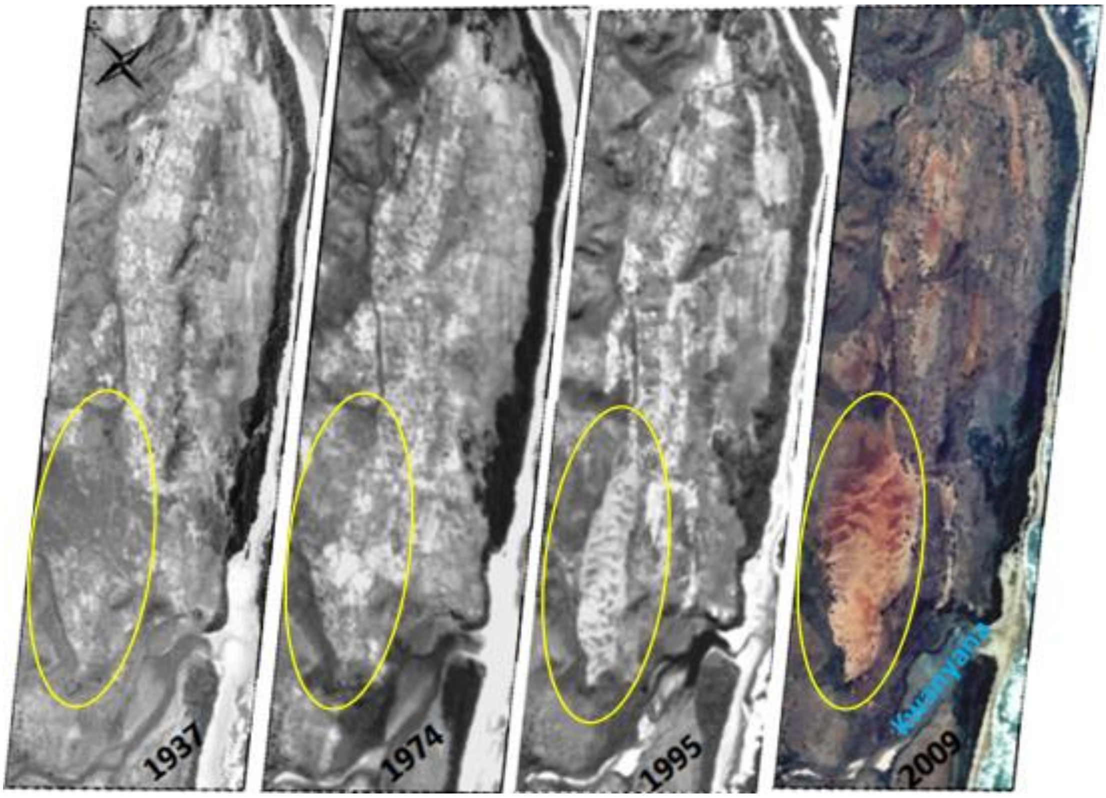

Figure 3. A compilation of aerial photographs highlighting the development of erosion features and the change in erosion morphology over time. The spread of the erosion feature immediately north of the Kwanyana river (highlighted in yellow) has initiated in farmlands and is currently an expanding large transverse dune field.

In an attempt to identify the conditions contributing to the erosion in the area, weather data was considered. Wind data revealed that the Xolobeni region is affected by a dominant north easterly wind where the driest months (June, July and August) precede the average wind speed maximum of 10 kts in September (Windfinder, 2013). The region has a bidirectional wind regime (i.e. south west and north east) (Figure 4) that has had a significant effect on the morphology of the transverse dunes characterising the large mobilising dune field north of the Kwanyana River. Figure 4 highlights that the south westerly winds can be sufficiently strong and persistent at times, forcing a complete reversal in orientation of the lee/slip faces and stoss slopes of the low transverse dunes immediately north of the Kwanyana River. Such dominance of the south westerly wind is evident in Google™ Earth imagery captured in July 2009, where there is a northerly orientation of the transverse dune slip faces that is contrary to the typical southerly orientations as reflected in the February 2011 imagery (Figure 4).

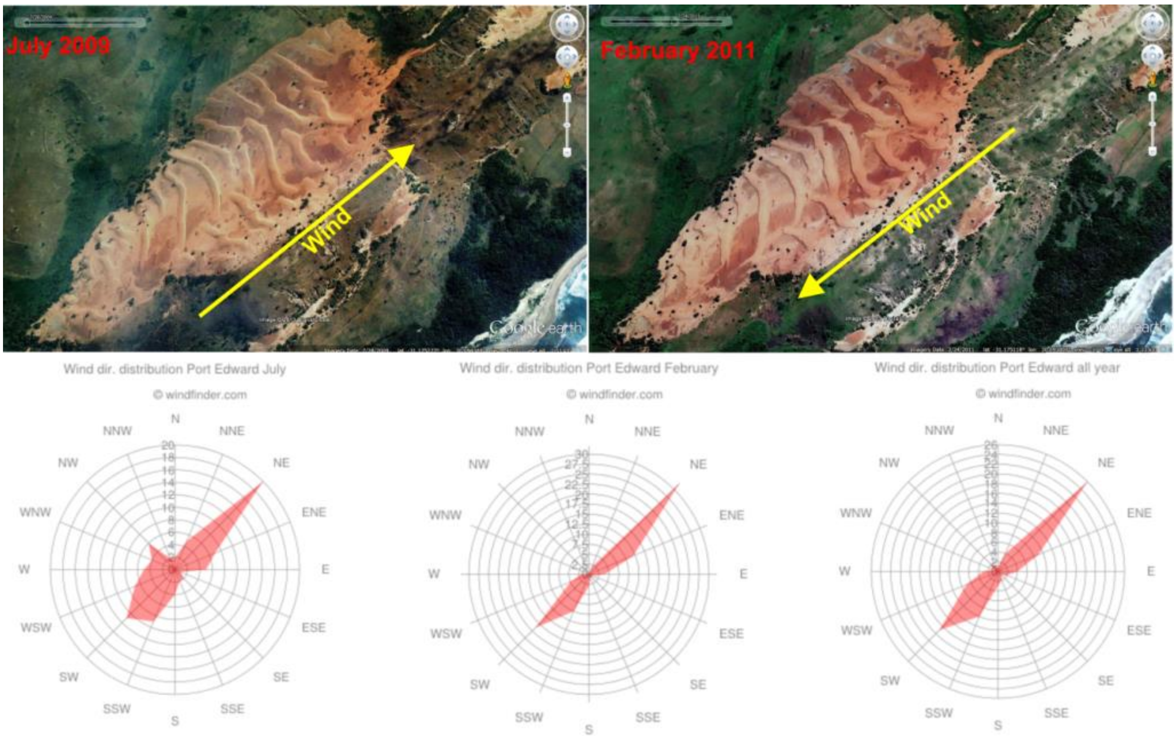

Figure 4. Although south westerly winds are strong and persistent during winter months, the dominance of north easterly winds during summer months can force a complete reversal in orientation of the lee/slip faces and stoss slopes of the transverse dunes at Xolobeni as shown in the July 2009 and February 2011 Google™ Earth images. The three windrose plots (Windfinder, 2013) for the Port Edward region confirm a bidirectional wind direction distribution for July, February and all year round.

Analysis and interpretation of the time series of aerial photographs (Figure 5) further revealed an overall increase in erosion activity including several generations of gully erosion, dune remobilisation and rapid expansion of some erosion features. The erosion feature highlighted in Figure 5 appears to have been initiated by anthropogenic activities, in bare patches on communal croplands as well as access tracks. In 1937, the feature resembled a small, elongated NE-SW trending body with an areal extent of 7 288 m^2. Lateral spread of the feature between 1937 and 1978 occurred at an annual rate of ~376 m^2. By 1978, the feature had attained an extent of 22 693 m^2. The long axis of the erosion features are generally aligned in the NE-SW direction, coinciding with the dominant wind directions in the region. This suggests that, although erosion is initiated by anthropogenic activities, the wind regime in the region drives erosional processes. The eastern extremities of the erosion feature defined by 1969 have remained relatively stable over time due to the establishment of dense peripheral vegetation, enforcing westward erosion spread. The annual spread rate almost doubled in the following seventeen years (1978 to 1995), with the areal extent of the erosion feature growing to 35 223 m^2. Further rapid growth increased the lateral extent of the erosion feature by ~ 68% during the period 1995 to 2009.

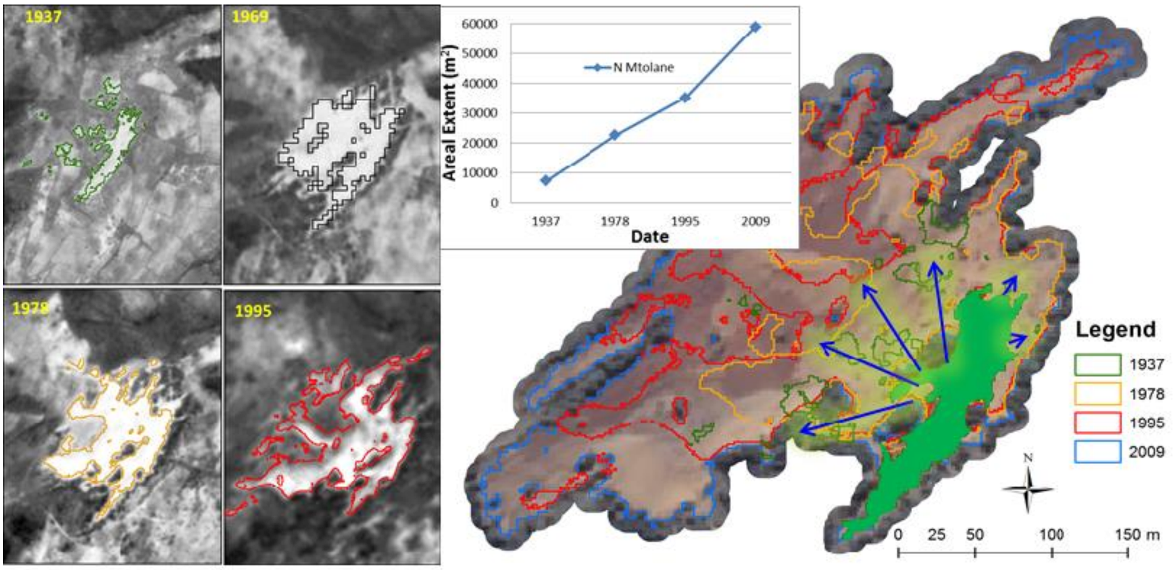

Figure 5. Historical aerial photographs of a large erosion feature. Sequential patterns of growth are indicated. The graph indicates the extent of the eroded area and its growth over time.

In contrast to the accelerated pace of erosion identified for the feature above, two features remaining relatively stable over time have been identified. The 1937 aerial photography reflects two large erosion features in the coastal landscape between the Kwanyana and Sikombe Rivers which represent wind sculpted hollows, one of which has been incised locally by deep gullies (Figure 6). Within the period 1937 to 2009 aerial photography reveals there have been no significant increases in the lateral extent of these erosional features (Figure 6). This is in striking contrast with the other younger erosional landforms of the Xolobeni coastal zone, where overall erosion spread has increased since 1937. By 1937 established peripheral vegetation is associated with these older erosion features, which have acted as wind shields for these exposed areas. An annual vegetation encroachment rate of $486m^2yr^{-1}$ was calculated for the period 1937 to 2009 for the larger feature occurring immediately south west of the Kwanyana Estuary. A density comparison of peripheral vegetation of both the pre-1937 erosion features, clearly justifies the significantly slower annual vegetation encroachment rate of $52m^2yr^{-1}$ associated with the other erosion feature situated 1.2 km north west of the Sikombe Estuary.

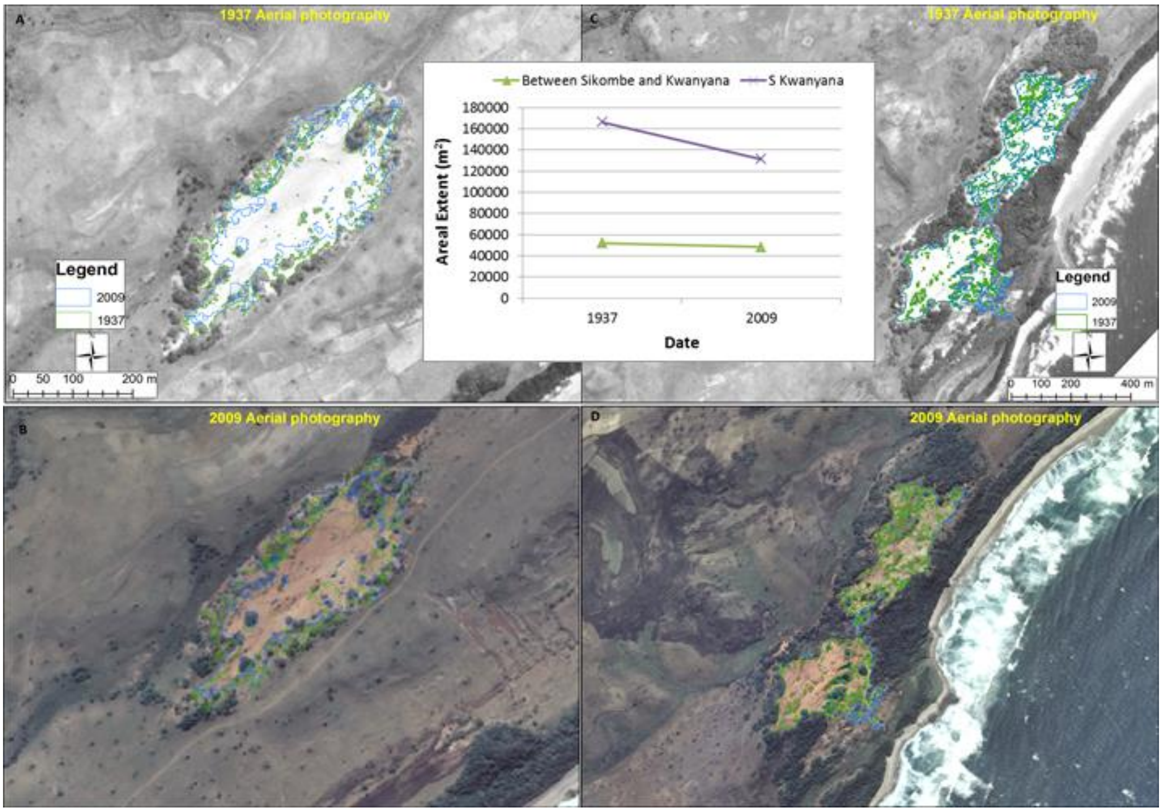

Figure 6. Historical aerial photographs of two erosion features (A,B: feature located between the Sikombe and Kwanyana Rivers; C,D: feature immediately south of the Kwanyana River). Sequential growth patterns are indicated revealing that the there is no growth in the features over time.

CONCLUDING REMARKS

The remote sensing analysis of historical aerial photographs provided a wealth of information that could be used to derive information on causative and preventative measures for erosion features. The analysis suggests that the onset of erosion is initiated by anthropogenic activities where small patches of bare ground, either in communal croplands or along access tracks, lead to accelerated land degradation over time. Elongated erosion features trend in a NE-SW direction which coincides with the dominant bimodal wind direction in the region. This suggests that, although erosion is initiated due to anthropogenic factors, the regional wind regime, channelled locally by terrain features, is responsible for the extension and lateral growth of degraded areas.

Although erosion in the area generally occurs at an increasingly accelerated pace, some stable eroded areas have been recognised. The areas where no lateral growth of erosion features occurs are associated with high density of trees and shrubs along the periphery of the eroded features. The vegetation acts as a wind barrier, effectively preventing the growth of parabolic blowout erosion features.

The information extracted from remote sensing data provided information that could be valuable to prevent future erosion and to mitigate some of the effects of already degraded land. Most notably, the minimisation of bare soil patches in farmlands and along access tracks will slow the creation of new erosion features. Furthermore, in areas where erosion features have become established, the spread of these features can be prevented by establishing vegetation barriers on the fringes of the degraded areas or planting grass and shrubs in the interdune areas to increase surface roughness and slow the wind velocity. Such measures can be used to ensure that further degradation along the pristine Wild Coast is minimised.

ACKNOWLEDGEMENTS

The authors are grateful to the Council for Geoscience and Department of Science and Technology for co-funding the research project. A special thank you to the National Geo-spatial Information (NGI) and South African National Space Agency (SANSA) for respectively providing aerial photography and satellite data used in the research. Many thanks to Chiedza Musekiwa for her invaluable inputs and Sithule Xanga for his assistance during field investigations. The authors would also like to thank Chief Lunga Baleni, Mbizana Development Trust and Xolobeni Development Trust for facilitating access to the erosion sites around Xolobeni.

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