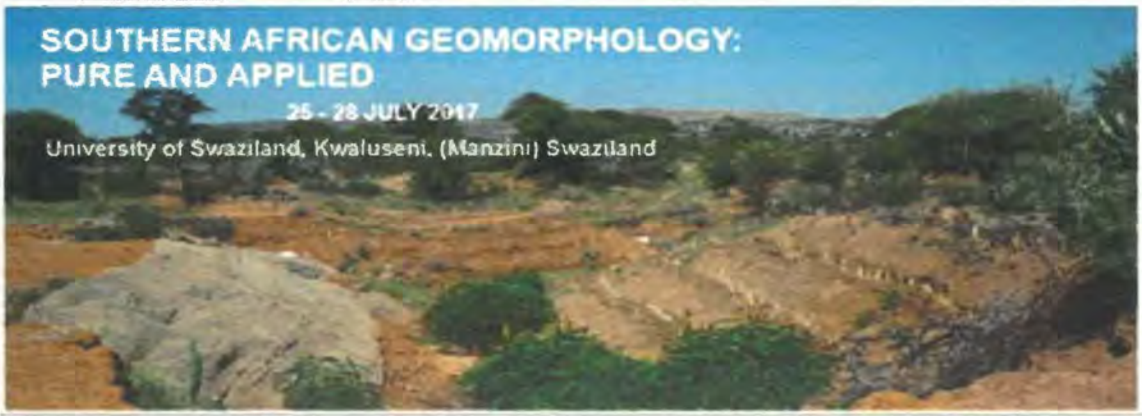

Field Guide for the SAAG Preconference Excursion 22-25 July 2017

Drakensberg and KZN north coast on route to Swaziland

Edited by Paul Sumner and Heinz Beckedahl

Draft prepared for the Southern African Association of Geomorphologists

SAAG Preconference Excursion Field Guide

Contents

SAAG Preconference Excursion: Drakensberg and KZN north coast on route to Swaziland

Paul Sumner[1] and Heinz Beckedahl[2]
[1]*University of Pretoria* [2]*University of Swaziland*

PREFACE

Established in 1988, the Southern African Association of Geomorphologists (SAAG) has been hosting conferences on the sub-continent since 1990. The past two conferences have been held in Namibia (2012) and three years later in Lesotho (2015). In 2017, the University of Swaziland hosts the SAAG meeting thus continuing on a of neighbouring countries across southern Africa. For this conference, an excursion was proposed as a tour of postgraduate study sites in KwaZulu-Natal on route to Swaziland. The study sites visited on the first three days fall within, or adjacent to the Tugela River catchment, extending from the Drakensberg to the coast. On the final day, the focus changes slightly to highlight collaboration with EDTEA (Department of Economic Development, Tourism & Environment Affairs, in terms of showcasing some of the applied aspects of land degradation and soil erosion in northern KZN, specifically around Ulundi.

From Mont-Aux-Sources (3282m) on the Lesotho-South Africa border, the Tugela (or *Thukela* in Zulu) River follows a 500km route from the Drakensberg (Figure 1) through the KZN Midlands to the Indian Ocean coast north of Durban. The total catchment area is approximately 29,000 square kilometres.

Figure 1: A view of the Drakensberg escarpment and foothills across the Sterkspruit river, a tributary of the Little Tugela River. Note the mixed land use, including commercial farming (sorghum in the centre), rural housing and woodlots. The escarpment is a nature conservation area.

The upper catchment is characterised by wilderness areas, as administered by Ezemvelo KZN Wildlife, private resort and recreation areas, and farming (including forestry, irrigated and dryland cropping, dairy and former homeland villages with associated grazing and smallholder agriculture). Several dams impede the upper Tugela River and water is transferred to the interior through the Tugela-Vaal water transfer scheme brought online in 1981.

Nearer the coast, the catchment is characterised by a mix of urban areas and agricultural practices, including sugar cane and plantations. In the lower reaches of the Tugela River and at the river mouth (Figure 2 upper image), sediments are visible in the channel and the sand supply likely impacts on the coast, particular the dune and estuary systems to the north, such as the Amatikulu and Siyaya rivers (Figure 2 lower image).

Figure 2: The Tugela River mouth (upper image) in 2015 and a rare opening of the Siyaya River through the beach sediments to the sea in June 2017 (lower image).

The geology of the catchment is relatively simple. The upper regions comprise of Drakensberg Group basalts and underlying sediments from the Clarens, Elliot and Molteno Formations, with numerous dolerite intrusion. Ecca and Dwyka Group Karoo rocks underlie the lower reaches. Partridge et al. (2010) describe the geology and geomorphic regimes; including the Great Escarpment at the source of the Tugela River, the Ladysmith Basin, the South Eastern Coastal Hinterland and the South Eastern Coastal Platform (Figure 3). The escarpment is an erosional landform characterised by high local relief and steep river profiles; for example, near its source the Tugela River falls 948m in the Royal Natal National Park (RNNP). The coastal margin is relatively narrow but widens north of the Tugela River mouth (in the vicinity of the Umlalazi River) where it is underlain by young (Cretaceous to Miocene) marine sediments.

Figure 3: The Tugela River passes through four geomorphic provinces: Great Escarpment at the source, the Ladysmith Basin, the South Eastern Coastal Hinterland and the South Eastern Coastal Platform (source: Partridge et al., 2010)

Rainfall is markedly seasonal, with a predominantly summer rainfall regime with occasional winter rain. In the upper catchment, rainfall can exceed 1300mm (e.g. at Royal Natal National Park; Nel, 2009) decreasing to ~850mm at the coast where annual average temperature is 23 °C (Olivier and Garland, 2003). At the source of the Tugela River, mean annual air temperature is estimated at approximately 6° (see e.g. Nel and Sumner, 2008) with occasional winter snowfalls.

Four studies are presented for the upper region of the Tugela River catchment and four for the coastal region. Catherine Smart outlines the historical records for rainfall from the central and northern Drakensberg region and Carel Greyling documents deep-seated palaeo-mass movements. Two projects focus on erosion and land use; Mzukisi Kuse and Sindiso Lubisi analyze historical erosion patterns near Loskop and outside RNNP using historical aerial photographs and satellite images. At the Tugela Mouth, Henning Blignaut used a similar approach to document the changes at the mouth and adjacent sand bank. North of the Tugela mouth, Renate van Heerden models discharge for the Amatikulu and Nyoni Rivers in the context of historical land use change and climate variability. A similar approach is adopted by Mivan Howard for the smaller Siyaya River catchment where sand mining has commenced. Finally, Joos Esterhuizen documents sand dune and estuary dynamics at the Amatikulu and Umlalazi coastal areas.

The final day on route to Swaziland moves back inland to Melmoth and Ulundi to discuss the impact of erosion of colluvium on impoverished communities (Figure 4) in a very practical sense (the characteristics of the underlying colluvial material have been extensively described by e.g. Botha, 1992), and to introduce the concepts associated with Land Degradation Neutrality under the UNCCD. The route then takes passes through Mkhondo (Piet Retief), into Swaziland through the Mahamba border post, and then traverses the Hlatikulu Gorge on route to the University campus at Matsapha.

Figure 4: The steep gully sidewall is rapidly encroaching on a dwelling in the greater Ulundi area, threatening the safety of the inhabitants.

REFERENCES

Botha, G.A. 1992. The geology and palaeopedology of late quaternary colluvial sediments in northern Natal, South Africa. PhD thesis, University of Natal.

Olivier, M. and Garland, G.G. (2003). Short-term monitoring of foredune formation on the east coast of South Africa. *Earth Surface Processes and Landforms* 28: 1143–1155.

Nel, W. 2009. Rainfall trends in the KwaZulu-Natal Drakensberg region of South Africa during the twentieth century. *International Journal of Climatology* 29: 1634–1641

Nel, W. and Sumner, P. 2008. Rainfall and temperature attributes on the Lesotho–Drakensberg escarpment edge, southern Africa. *Geografiska Annaler* 90 A: 97–108.

Partridge, T.C. , Dollar, E.S.J , Moolman, J and Dollar L.H. 2010. The geomorphic provinces of South Africa, Lesotho and Swaziland: A physiographic subdivision for earth and environmental scientists. *Transactions of the Royal Society of South Africa* 65: 1-47.

Distribution and characteristics of deep-seated palaeo-mass movements in the northern and central Drakensberg, South Africa.

Abraham Carel Greyling
Department of Geography, Geoinformatics and Meteorology, University of Pretoria

Abstract: Evidence for large deep-seated palaeo-mass movements is found within the Drakensberg. However, the distribution and origin of these movements is not fully documented or understood. By studying the distribution and geomorphic characteristics of palaeo-mass movements in the northern and central Drakensberg, this study sets out to understand the formation of these mass movements. The method was divided into three phases; detection, verification and mapping. Thirty three possible mass movements were located through the use of a criteria-based searching method of satellite imagery, topographic maps and geological maps. The criteria consist of geomorphic features associated with known international and national palaeo-mass movement sites. Confirmation then consisted of infield verification of the features identified by criteria and thirteen sites were verified. In the third phase, confirmed sites were mapped, a morphological analysis was conducted and a relative age was estimated. Three important facts were confirmed. Due to the distribution of mass movements within the sandstone formations and close relation to dolerite sills, the geological characteristics, such as weaknesses in the sandstone formations, are considered major predisposing factors. The geomorphic characteristics of the mass movements have a large variety in appearance, size, age and types, indicating that one single trigger event is an unlikely cause to the movements in this area. This study proposes that the main cause for large deep-seated mass movements in the Drakensberg was subsequent to the Neogene uplift, which caused deeply incised valleys that led to the ideal conditions for the occurrence of these movements. This section of the field guide will provide detail on two of the large deep-seated palaeo-mass movements found in the northern Drakensberg.

1 INTRODUCTION

Large deep-seated palaeo-mass movements in the Drakensberg have been documented by Boelhouwers (1992) in the Bushman's River valley, by Bijker (2001) in the Injisuthi river valley, by Singh et al. (2008) in the Meander Stream valley and by Singh (2009) in the Mahai valley. Unfortunately, mass movement research in southern Africa is limited (Hardwick, 2012) and little is known about the distribution throughout the rest of the Drakensberg.

Mass movements influence the topographical, geological and hydrological settings on the slope and can reduce the stability of the slope (Guzetti et al., 1999). Reactivation of large landslides causes massive changes in the slope morphology and, together with scarp retreat, can cause substantial damage to infrastructure and socio-economical activities (Borgatti et al., 2006). Furthermore, new and smaller movements, as well as gully erosion, are prone to occur on these older sites (Singh et al., 2008)

In the Drakensberg the immediate threat of mass movements is less pronounced, but palaeo-mass movement deposits often provide a relatively horizontal area in relation to the surrounding steep areas. It is not uncommon for infrastructure and settlements to have been developed in these areas or used as farm land. Therefore, mapping the distribution of these movements has a practical application due to possible safety concerns produced by the large deep-seated mass movements. Morphological maps will contribute to landslide susceptibility maps, hazard zoning as well as landslide inventory maps produced in the Drakensberg region.

To fully understand the occurrence of deep-seated mass movements throughout the Drakensberg, a crucial step would be to identify palaeo-mass movements in the region and document their geomorphic characteristics. This may provide critical information on how and why they occurred. However, compared to their newer (or more recent) counterparts, locating and identifying a palaeo-mass movement is not done easily (Mather et al. 2003; Šilhán and Pánek, 2010). Nevertheless, identification is possible and important to understand valley evolution and subsequent landscape development.

Here, the methodology used to identify palaeo mass movements is outlined and two large deep-seated mass movements found in the study area are described. Further information as well as a detailed description of each identified, classified and mapped mass movement can be found in Greyling (2017).

2 STUDY AREA AND METHODS

The study area is located in the northern and central Drakensberg (Figure 1). The area covers a national park, private land and a game reserve. Royal Natal National Park forms the northern boundary. Ndedema and Monk's Cowl are in the central regions of the study area and Injisuthi is an area within the northern part of the Giants Castle Game Reserve. Injisuthi forms the southern boundary of the study area. Included in the study area, between the park and reserve, is an historically tribal land, called Mweni. The study area stretches across the lower valleys of the Drakensberg towards the great escarpment forming the boundary between South Africa and Lesotho.

Figure 1: Study area and an indication of the location of possible large deep-seated palaeo-mass movements.

The method is structured in three phases. First, a detection phase, where analysis of aerial images, topographic and geological maps were completed to identify structures and typical topographic features found on mass movement affected slopes (Lebourg et al., 2014). A criteria was created from common geomorphic features found on, or as a resulting consequence, of various internationally and locally published studies, such as Mather et al. (2003) and Pánek et al. (2008), and used as indicators for past mass movement events.

Second, a verification phase, which includes in-field mapping and verification of features identified in the first phase. Finally, an analysis phase consists of post-field work mapping, morphometric analysis, classification and dating of mass movements. Age estimation of the study sites could be a relative estimation only, and each confirmed site was dated by the proposed activity state introduced by Mather et al. (2003). A specific classification method was derived for this study, and was adopted from Singh (2009), Hardwick (2012) and Hungr et al. (2014), although various adjustments were needed to include different aspects of palaeo-mass movements

An detailed explanation of the classification and each criterion can be found in Greyling (2017). In summary, the criteria are divided into main topics or groups where specific features such as rotated geology or misplaced boulders are found.

The groups are as follows:

- the topographic shape of the slope
- valley constraint or river pinching caused by the landslide event
- deranged drainage patterns and upstream meandering of the valley river
- hummocky terrain and topographic undulations
- incised flanks
- recent erosion events such as active landslides
- forms of sediment displacement.

3 FINDINGS

Within the first phase, thirty three possible movements were identified (Figure 1). After which, thirteen were confirmed. The following section will discuss two of the mass movement sites in the Royal Natal National Park: the site known as Mahai Valley and the Thendele mass movement site.

3.1 MAHAI VALLEY MASS MOVEMENT

The Mahai mass movement was first identified and mapped by Singh (2009). Field observations suggest that the movement is larger than originally defined by Singh (2009). The movement's length, from the main scarp (2030m.a.s.l.) towards the toe (1400m.a.s.l.) is 2.681km. The movement spans across an area of 281ha and can be considered as a "very large" mass movement according to the classification set out in Greyling (2017). The width of the toe spans 0.983km and in the transportation zone of the movement, where it is considered to be pinched, it spanns 0.730km (Figure 2).

The main scarp spans 0.977km, although this could vary due to the uncertainty involving the origin of the movement. The movement occurred in the sandstone layers and possibly the lower basalt region. A dolerite sill, situated along the back scarp of the movement, is visible and could have played a pivotal role in the formation of the movement.

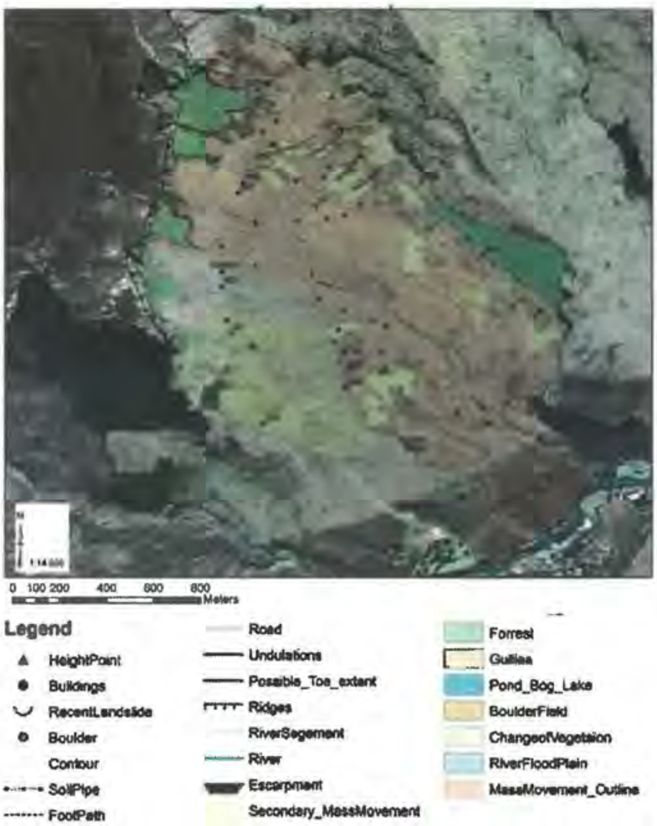

Figure 2: The layout of the Mahai Valley complex mass movement imposed over a satellite image.

Observations from the toe indicate that features on the southern flank, near the toe, represent an unmoved geological structure. This consists of an area that remained stationary during the event, consequently pinching the downward flow of debris and regolith of the movement around the Mahai campsite and onto the valley floor. Further evidence is found in the valley symmetry between the unmoved structure and the opposite valley bedrock; an ongoing geological structure across the river follows a continuous structure on the study site. The main body and the zone of accumulation supply the following evidence: topographic undulations, deeply incised streams, changes in the vegetation, and large boulders within the regolith. Evidence of displaced bedrock and the continuation of displaced material down slope are visible. Areas with bogs and ponds are visible within the accumulation zone (Figure 3).

On the southern side of the movement, a raised step-like topography indicates its flank or edge. On both flanks of the movement, the opposing geology seems to correlate and is on the same level, showing cross-valley symmetry. This step-like geology is not part of the mass movement, but below and also across the main scarp secondary movements occurred as indicated in Figure 2. Rock falls are in abundance along the main scarp, while down slope towards the toe, hummocky terrain is visible. The main body of the slide shows no signs of structured bedrock and boulders are scattered throughout the body and the direction of the displaced material changed during the occurrence. There is some indication that the initial movement occurred closer to the upper north side of the slope, located near Castle Rock, with secondary movements along the escarpment. Located at the main scarp of the movement is a drop in height that develops down slope into a rise. This forms the minor scarp of the movement where the rest of the movement flows out towards the valley floor. Height difference in this area is vast, with a 500m difference in the main scarp and the minor scarp has approximately 200m height difference. The minor scarp accounts for river deflection and the derangement pattern at the base of the main scarp. Changes in vegetation develop from a forested to a wetland area, from where the river incised through the geology and formed a steep valley.

Figure 3: Bog developing due to restriction of water flow down slope at the Mahai Valley site. In the background large imbedded boulders are visible

Due to the size and various features, this mass movement can be defined as a "very large" complex landslide. Although it could have occurred as a rotational movement, there is no clear substantial rotation surface of rupture visible or easily identifiable. The toe of the movement forced the river to create a new path around it, suggesting that the nature of the movement was in a flow-like manner, supported by Singh (2009).

The age of the movement is debatable; some valley pinching and river deflection is evident, indicating that the movement must have occurred after the current valley floor had been formed. However, the condition of the main scarp is dissected and vegetated, with an unclear lateral margin, except at the incised valley on the right side of the movement. There are deeply incised streams over the main body which have irregular direction of flow. According to these observations and relative eroded nature of the features visible on the main body, the movement is classified as "old" (see Greyling, 2017).

3.2 THENDELE MASS MOVEMENT

The mass movement site was probably formed by two separate events, as indicated in Figure 4; the larger first, followed by a second, smaller movement. The smaller movement is considered more recent, due to the fact that the movement features are more clearly visible and the large event would have covered and concealed the smaller event. Both movements are considered to be rotational landslides, however, the rise in height at the toe is not as prominent but still visible. The length of the main movement (measured in the direction of movement) is approximately 0.89km. Width at the toe, middle and escarpment are 0.556km, 0.455km and 0.269km respectively. The toe on the valley floor is situated at 1580m.a.s.l, while the crown is at 1923m.a.s.l. and the top at 1756m.a.s.l. This mass movement covers an area of 54.113ha and can be classified as a "large" movement (Greyling, 2017). The second more recent event has a length of 0.425km, width at toe level is 0.494km, in the middle it has a width of 0.376km and the main scarp with a width of 0.191km. the movement occurred within the Clarens Formation and the underlying sandstone formations.

Figure 4: The layout of the Thendele rotational landslide imposed over a satellite image.

The southern edge of the movement is well defined and an incised stream indicates the boundary. Incised streams are common features on palaeo-mass movements as proposed by Mather et al. (2003). River segment deflection is visible on the southern and northern side of the movement. Towards the main scarp is a clear lack of bedrock as well as a discontinuation of bedrock from the southern flank, across the incised river segment, to the body of the movement itself. Observations in-field, suggest that the slide moved onto a floodplain where it pinched the river and forced the river to flow around it. There is an approximate 2m drop in difference between the current river bed and the previous floodplain where the movement has spilled onto and another meter difference between the colluvial and fluvial material. Large boulders can be found at toe level within the regolith. Erosion of the toe can be seen in Figure 5, exposing angular boulders which is a clear indication of colluvial deposition.

Figure 5: Erosion of the toe near the left flank exposes angular boulders within the soil which indicate a colluvial deposit.

Clear river deflection, together with wetland formation and associated changes of vegetation, are visible on the edges of the movement. Large rotated boulders are found throughout the whole slope. Non-conforming valley symmetry is evident, which is a clear indication of the mass movement.

The slope can be described as step-like. Four steps are clearly visible, with spot heights on each step creating minor scarps. Each step increases in height from the main scarp to the spot heights, indicating a rotational surface of rupture. At each level there is river derangement around the scarp, thus in each layer different vegetation and river deflection occur on the slope. On the northern edge of the movement bedrock is visible, with deeply incised flanks.

Due to the geomorphic signs in the study area, this mass movement can be considered as "mature to old" (see Greyling 2017). Incised river segments are present on the main scarp but is vegetated and the lateral margins are clearly identified with incised streams and tributaries.

The internal morphology of the mass movement is characterised by undulating topography and disrupted drainage patterns.

4 CONCLSION

The broader study confirmed and mapped thirteen large-deep seated movements in the central and northern Drakensberg region, giving an indication to the larger role deep-seated mass-movements played in the formation of the current Drakensberg landscape (Greyling, 2017). Two of the mass movement sites are presented above.

By identifying shared and unique characteristics of the movements, through the use of the criteria, it was proposed that the Neogene uplift created perfect conditions for the initiation of these movements and therefore can be credited as a main cause (Greyling 2017). However, lithological control cannot be ignored as an important preparatory factor in the distribution of the movements throughout the study area.

5 REFERENCES

Bijker, H.J. 2001. A hydrological-slope stability model for shallow landslide prediction in the Injisuthi Valley, KwaZulu-Natal Drakensberg. MSc dissertation: University of Pretoria.

Boelhouwers, J.C. 1992. Field guide to the geomorphology of the Giant's Castle Game Reserve, Natal Drakensberg. MSc University of Natal, Pietermaritzburg.

Borgatti, L., Corsini, A., Barbieri, M., Sartini, G., Truffelli, G., Caputo, G. & Puglisi, C. 2006. Large reactivated landslides in weak rock masses: a case study from the Northern Apennines (Italy). *Landslides* 3: 115-124.

Greyling, A.C. 2017. The distribution and characteristics of deep-seated palaeo-mass movements in the northern and central Drakensberg, South Africa. MSc dissertation: University of Pretoria.

Guzetti, F., Carrara, A., Cardinali, M. & Reichenbach, P. 1999. Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, Central Italy. *Geomorphology* 31: 181-216.

Hardwick, D. 2012. A mass movement classification for the southern Drakensberg, South Africa. PhD Thesis, Johannesburg: University of Witwatersrand.

Hungr, O., Leroueil, S. & Picarelli, L. 2014. The Varnes classification of landslide types, an update. *Landslides* 11: 167-194.

Lebourg, T., Zerathe, S., Fabre, R., Giuliano, J. & Vidal, M. 2014. A late Holocene deep-seated landslide in the northern French Pyrenees. *Geomorphology* 208: 1-10.

Mather, A.E., Griffiths, J.S. & Stokes, M. 2003. Anatomy of a 'fossil' landslide from the pleistocene of SE Spain. *Geomorphology* 50: 135-149.

Pánek, T., Hradecký, J., Smolková, V. & Šilán, K. 2008. Gigantic low-gradient landslides in the northen periphery of the Crimean Mountains (Ukraine). *Geomorphology* 95: 449-473.

Šilhán, K. & Pánek, T. 2010. Fossil and recent debris flows in medium-high mountains (Moravskoslezské Beskydy Mts, Czech Republic). *Geomorphology* 124: 238-249.

Singh, R.G. 2009. Landslide classification, characterization and susceptibilty modeling in KwaZulu-Natal. MSc Thesis, Johannesburg: University of Witwatersrand.

Singh, R.G., Botha, G.A., Richards, N.P. & McCarthy, T.S. 2008. Holocence Landslides in KwaZulu-Natal, South Africa, *South African Journal of Geology* 111:39-52.

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Trends in soil erosion and land use in the upper Tugela River catchment

Mzukisi Kuse

Department of Geography, Geoinformatics and Meteorology, University of Pretoria

Abstract: Each year, approximately 75 billion tons of soil are eroded from the world's terrestrial ecosystems and the majority of agricultural land in the world is losing soil at rates of between 13 tons/ha/year and 40 tons/ha/year. South Africa is prone to soil erosion, because of poor farming methods, together with soils which are erodible. In order to understand more about the nature of soil erosion in South Africa, the geology and lithology needs to be well understood too. This study adds to the understanding of the relationship between soil erosion and land use. In South Africa soil erosion research has been undertaken but every region requires its own research on a different scale and using different techniques. The outcomes from this study support the notion that soil erosion processes are very complex and that delineation of soil erosion features possess a certain level of subjectivity. Human influences and land use dynamics also influence the rates of soil erosion and this study shows how different land uses, but similar environmental factors, can lead to different rates and intensities of soil erosion.

1 INTRODUCTION

People have lived in the northern Drakensberg for the past 5 000 years and in the southern Drakensberg for the past 10 000 years, according to archaeological research (Ezemvelo KZN Wildlife, 2016). The length of the uKhahlamba Drakensberg Park is 180 km and ranges from the Royal Natal National Park in the north to Bushmen's Nek in the South (Chellan and Bob, 2008). There are five streams which source from Mont-Aux-Sources; the Tugela and its tributary the Bilanji which flow into the Indian Ocean; the Khubedu, a tributary of the Orange River and its own tributary the Khubela; and the Elands, a tributary of the Wilge and hence also of the Vaal and the Senqu/Orange rivers (Mthembu, 2011).

The local municipality of Bergville is made up of privately owned commercial farmland and two tribal authorities: Amazizi and Amangwane, as well as smallholder settlements which are privately owned. The tribal areas are situated on the western portion of Bergville located on the edge of the interior basin and the foothills of the Drakensberg and ranges up to the Drakensberg and Lesotho borders. (Mthembu, 2011).

This study investigates erosion phenmomena in the upper Tugela River region. Field observations were conducted in six study sites in the Bergville district, followed by a desktop research which entailed the use of ArcGIS, Google Earth, statistics and an analysis of aerial images which date from 1964 to 2014.

2 STUDY AREA AND METHODS

The upper Tugela River catchment is located in eastern South Africa. At the foothills of the Drakensberg in KwaZulu-Natal lies the municipality Bergville (Mthembu, 2011). It is within the district of Bergville that we find Zwelisha, Clifford Chambers, KwaMiya, Mont Aux Sources Resort, Busingatha and Upper Thendele; these villages and settlements form part of the study site and sampling points (Figure 1).

Figure 1: Location of the study sites in the KwaZulu-Natal province.

There is approximately twice as much total runoff in KwaZulu-Natal per unit of rainfall than for the average of South Africa as a whole, and the province is a contributor of a quarter of the streamflow of South Africa (Nel and Sumner 2006). Bergville usually receives approximately 643mm of rain per annum, with the majority of the rainfall occurring during mid-summer (Figure 2). The average midday temperatures for Bergville vary from 19.3°C in June to 27.9°C in January. When the temperature drops to 2.1°C on average during the night, this area becomes the coldest in July (SAexplorer, 2014).

The study area is predominantly covered by Northern KwaZulu-Natal Moist Grassland and Northern Drakensberg Highland Grassland, with Drakensburg foothill moist grassland covering certain areas of the study site (Okhahlamba SDP, 2013). There are also pockets of forests which are indigenous all throughout the municipality, but commercial forestry is also found in the area. The Grassland Biome covers the study area predominantly and there are scattered bushland present (Okhahlamba SDP, 2013).

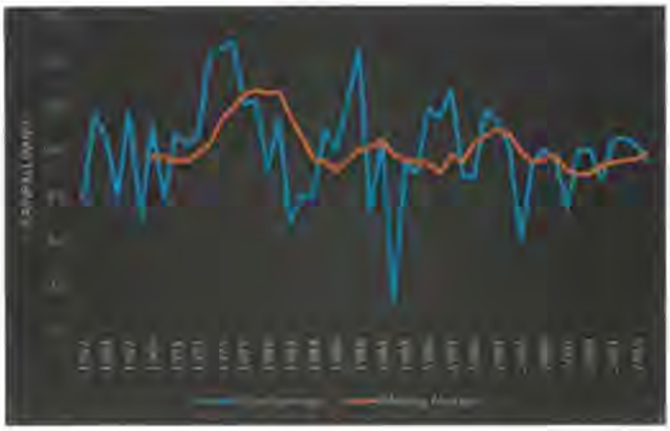

Figure 2: Rainfall trends in the Drakensburg during the twentieth century.

Irrigation is an important part of the land use, from a water resources perspective. The approximate area which is irrigated is 276 km^2 from a report about the Tugela Water Management Area. Commercial timber also plays a significant role in the land use of the Tugela river catchment and has an impact on the water resources. Other land uses include subsistence dryland agriculture (mostly maize), and cultivation of sugar on the flat alluvial land or rolling hills which surround the estuary (DWAF, 2004).

The study sites form part of the foothills of the Great Escarpment, which developed as a consequence of scarp retreat (Moore and Blenkinskop, 2006); Karoo Supergroup sediments and later lavas make up the escarpment in the KwaZulu Natal region. The soils found around the Drakensburg region have a low potential for agriculture, but good to high agricultural potential exists in the majority of the area beyond the municipality of the Drakensburg (Okhahlamba Spatial Development Plan, 2013).

Aerial photographs were received in digital format from the Department of Rural Affairs and Land Reform, which covered the study site area for the years 1964 and 1986. The digital aerial photographs for 2014 were received from the Bergville municipality and used in conjunction with Google Earth images. The study sites were then located in the images and other land features associated with them. The images from 1964 and 1986 had to be georeferenced, so that they could be projected in ArcGIS and used for analytical purposes. The 2014 images already had a projection.

Shapefiles were produced in order to create a distinction between the different erosion types from 1964, 1986 and 2014. Different erosion types were digitized from the three sets of years. The erosion types were given different markers and colours in order to distinguish between the different sets of years. The digitized erosion types were overlain over each other, so that they could graphically express the extent of the erosion and land use change over the three different sets of years.

Population was estimated following the criteria given by Schulze (1969). Clusters of modern buildings which evidently constituted schools, churches, or trading stores were excluded from the counts, but the huts surrounding them were included. Grain huts could straightforwardly be differentiated from huts which for settlement purposes on the aerial photographs by their shape and size, and thus they were also not included for the population estimation.

To estimate the population growth, the land use change maps which were constructed for the 1964, 1986 and 2014 years were used. The settlement class was used as an indication of a growing population. The settlement class did not exactly give the population numbers, but it expressed that the number of residences was increasing. The topographical map was also used to analyse how the study sites grew from huts to fully fledged settlements. Information from StatsSA (2011) was obtained, but only had population numbers stretching from 2011.

3 FINDINGS

The results for the study were divided into six study sites, but for the purpose of this field guide, two study sites will be considered here. These study sites cover the village study site (Busingatha) and the other study site represents the commercial study sites (Upper Thendele).

Upper Thendele did not have any gully erosion evident in 1964, only sheet erosion and a few rills were present. The rills in Upper Thendele were found in the vegetated area of the study site (Figure 3). These rills only covered approximately 7% percent of the vegetated area. The Upper Thendele site is a secluded area with mostly vegetation cover and a minimum number of people.

Upper Thendele was covered by sheet and rill erosion only and had less apparent erosion. Sheet erosion covered approximately 4% of the cultivated land area and rills approximately 8% of the cover. The Upper Thendele study site is a controlled area and access is restricted (Figure 4). The erosion which occurs here is mostly as a result of natural factors rather than anthropogenic influences.

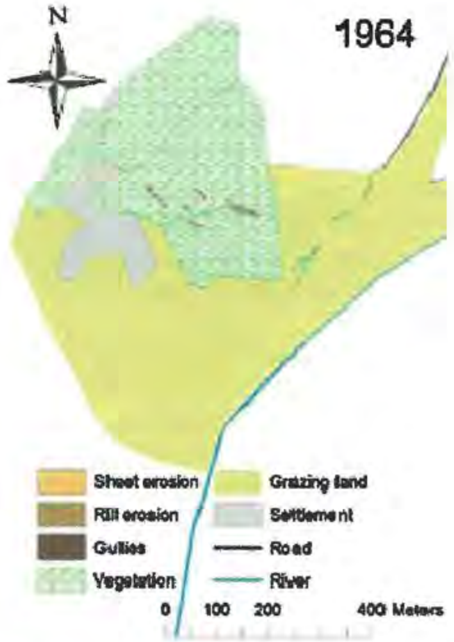

Figure 3: Trends and changes in land use over time in Upper Thendele in 1964

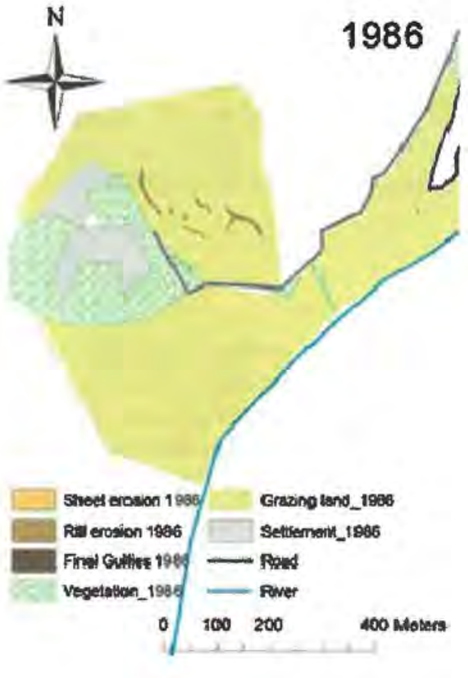

Figure 4: Trends and changes in land use over time in Upper Thendele in 1986

In Upper Thendele, the extent of erosion was still low in 2014, when compared to the other study sites. The erosion covered the grazing land and cultivated land. Sheet erosion covered approximately 9% and rills 14% of the grazing land. These numbers are as a result of the low population numbers in Upper Thendele (Figure 5). The rills have developed over time and express that the has been an increase in erosion at the study site.

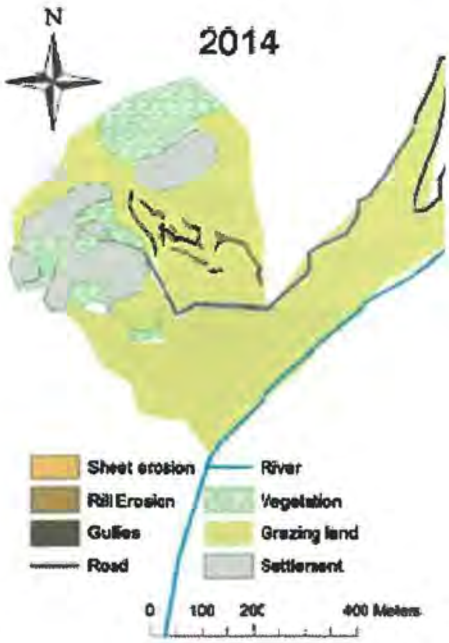

Figure 5: Trends and changes in land use over time in Upper Thendele in 2014

In 1964, gullies were not extensive and widespread in Busingatha, rills and sheet erosion was more apparent. Gullies covered approximately 7% of the cultivated land area in Busingatha and also covered a small portion of the grazing land, vegetation and the settlement (Figure 6). The overall gully coverage in Busingatha was very minimal in 1964. Sheet erosion also covered most of the grazing land in Busingatha and this is the area where the animals trample and remove vegetation which anchors the soil.

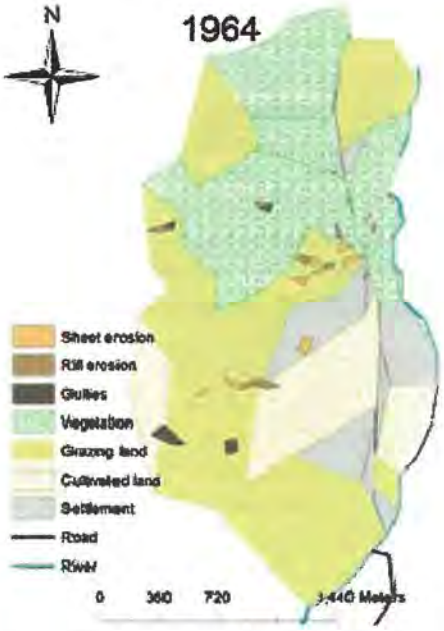

Figure 6: Trends and changes in land use over time in Busingatha in 1964

Busingatha experienced an increase in erosion therafter. A noticeable change was the increase in gully erosion over the area. Gullies had covered approximately 7% of the cultivated land, 3% of grazing land, 9% of the vegetation area and 1% of the settlement area (Figure 7). The cultivated area is where people change the land use the most, because people need to convert natural land to farm land for growing food. The gullies in the settlement area came as a result of the rising population numbers. There is also an inverse relationship between the settlement area and the vegetation area in Busingatha; the vegetation area decreased as the settlement grew in numbers.

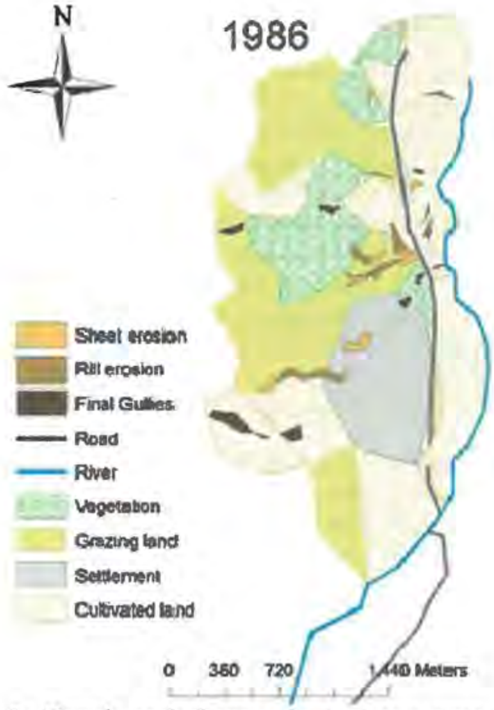

Figure 7: Trends and changes in land use over time in Busingatha in 1986

In 2014, sheet, rill and gully erosion were present in Busingatha. The erosion covered the cultivated lands, grazing land and settlement land use zones (Figure 8). Sheet erosion was mostly expressed over the cultivated land and grazing land zones. The sheet erosion had developed into rills over time and the erosion had become more severe in the area. Sheet erosion covered approximately 3% of the cultivated area and nearly 4% of the grazing land. Rill erosion had intensified over time and covered more of of the settlement area, percent of cultivated land and of the grazing land.

Figure 9 shows that the erosion coverage increased from 1964 to 2014; with the village study sites experiencing very high sheet, rill and gully rates compared to commercial study sites. In 1964 and 1986, erosion coverage was relatively low with most study sites with gully cover being less than 10%, with Busingatha being the exception. The population estimation method adapted from Schulze (1969) and Hattingh (1973) was used to analyze the severe erosion in Busingata in 2014.

Figure 8: Trends and changes in land use over time in Busingatha in 2014

The population estimation method expressed the extensive population growth which occurred in the study sites and Busingata experienced the greatest population growth. This population growth is linked with erosion and an extensive gully system was present in the ground-truthing field trip. In 2014 the gully area intensified significantly across all the study sites. Erosion in Upper Thendele did not intensify greatly over the years. The Mont Aux Source resort area experienced zero gully levels in 1964, but gully patterns developed over the years following the establishment and growth of the hotel.

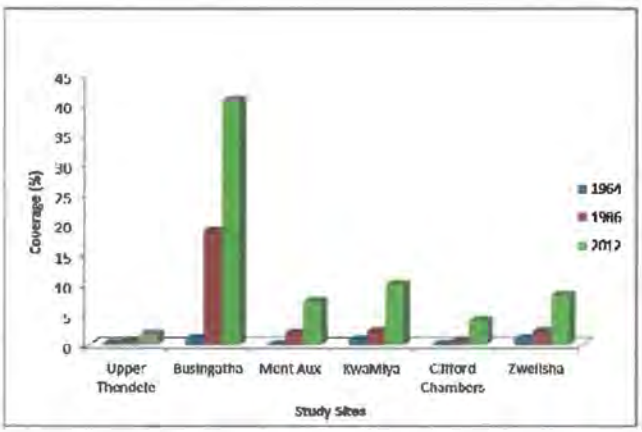

Figure 9: Erosion cover totals over all the study sites, in three time periods; 1964, 1986 and 2014.

4 CONCLUSION

Investigating the trends in land use in the upper Tugela catchment was accomplished by using methods and techniques ranging from analysing aerial photographs and academic publications which were developed in the early 1960s. The method to identify the changes in land use was taken from Kakembo and Rowntree (2003), but was adapted to fit the context of this study. The study has shown that there were changes over the 50 year sample period with regards to the vegetation, grazing land, settlement and cultivated land classes. The vegetation and tree cover (vegetation class) decreased in extent because of the influence of the increasing population on the land and the consequential exacerbation of soil erosion.

Main findings from the study:

- Overgrazing plays a role in determining the extent of erosion. However, it is the relationship between increasing population numbers and the particular nature of livestock keeping among village dwellers which influences overgrazing levels, and subsequently erosion.
- This study shows that population numbers influence erosion processes. Population changes can cause sheet erosion to develop into interconnected and complicated gullies, and possibly into riverbank erosion if not mitigated in time.

Main recommendations from the study:

- Mitigating soil erosion impacts is an issue which has to be addressed not only on the local scale, but even national government needs to make it a point that the general landscape of the country is well managed with regards to soil erosion.
- Obtaining high quality imagery, robust mapping and statistical analyst programs, and specialists from different fields to work with soil erosion data should also be top priority in further studies.
- Studies that include mapping of soil processes should indeed not just be limited to geomorphologists, but should encompass a more transdisciplinary approach.

This study provided just a glimpse of soil erosion and land use change processes, because it only concentrated on one particular region, and therefore could not provide a comparative analysis. Further studies of this kind should seek to build upon what has been established in this study, ranging from the methodological framework to choosing of a study site. Government policies and land use strategies are also very important factors to be considered when assessing erosion and land use systems, because they do affect physical and anthropological factors, and subsequent environmental pressures.

5 REFERENCES

Chellan, N. and Bob, U. 2008. Sustainable Ecotourism in the uKhahlamba Drakensberg Park: A Stakeholder Analysis. *Alternation*, 15: 290 – 315.

Department of water affairs and forestry. 2004. Internal Strategic Perspective: Thukela Water Management Area. https://www.dwaf.gov.za/Documents/Other/WMA/7/ThukelaISPNov04full.pdf

Ezemvelo KZN wildlife. 2016. Royal Natal National Park. http://www.kznwildlife.com/

Hattingh, R.S. 1973. Population counts and estimates in a Bantu Rural area. *South African Geographical Journal*, 55: 40-47.

Kakembo, V. and Rowntree, K.M. 2003. The relationship between land use and soil erosion in the communal lands near Peddie town, Eastern Cape, South Africa. *Land Degradation & Development*, 14: 39–49.

Moore, A. and Blenkinsop, T. 2006. Scarp retreat versus pinned drainage divide in the formation of the Drakensberg escarpment, southern Africa. *South African Journal of Geology*, 109(4): 599-610.

Mthembu, B.M.J. 2011. Rural tourism as a mechanism for poverty alleviation in Kwazulu Natal: the case of Bergville. Unpublished PhD Thesis: Department of Recreation and Tourism, at the University of Zululand.

Nel W, Sumner PD. 2006. Trends in rainfall total and variability (1970–2000) along the KwaZulu-Natal Drakensberg foothills. *South African Geographical Journal*, 88: 130–137.

Okhahlamba Local Municipality. 2013. Okhahlamba spatial development framework. http://www.okhahlamba.org.za/docs/webcont/2013/Okhahlam a%20SDF%2022%20February%202013.pdf

SAexplorer. 2014. Climate of the Drakensburg. http://www.saexplorer.co.za/south-africa/climate/underberg_climate.asp

Schulze, R.E.1969. A comparison between official population data and aerial photograph population survey in the Tugela location. *South African Geographical Journal* 51: 123-132.

Statistics South Africa. 2011. Annual Report 2010/2011. http://beta2.statssa.gov.za/publications/AnnualReport/AnnualReport2011.pdf

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Rainfall variability and drought in the KwaZulu-Natal Drakensberg, 1955-2015

Catherine Smart

Department of Geography, Geoinformatics and Meteorology, University of Pretoria

Abstract: This on-going study assesses the long-term rainfall records in the KwaZulu-Natal Drakensberg, thus contributing towards an improved understanding and management of the area. Records from five stations covering the central and northern Drakensberg indicate that over the 1955 – 2015 period there is a statistically significant decrease in rainfall. The long-term trends in interannual variability show an increase in the variability of annual rainfall at the five stations. Mean annual rainfall in the Drakensberg is highly seasonal and analysis of the monthly rainfall indicates an increase in the variability of the distribution of monthly rainfall and strengthening of rainfall seasonality in the Drakensberg through a significant decrease in autumn rainfall. The El Nino Southern Oscillation influences summer rainfall variability in the Drakensberg and a strong correlation exists between summer rainfall and the Southern Oscillation Index for preceding periods. This correlation suggests that the changes in the intensity and frequency of the El Nino Southern Oscillation should affect rainfall in the Drakensberg. Assessment of meteorological drought using the Standard Precipitation Index, showed a significant decreasing trend indicating an increase in the number of dry years over time. Hydrological drought was assessed using the Streamflow Drought Index. Both indices found an increase in the number of dry years experienced over time and highlighted 1982, 1992, 1994, 2003, 2007 and 2015 as years with the lowest rainfall and drought conditions.

1 INTRODUCTION

South Africa is characterised by highly a variable climate. Rainfall variability in particular contributes to complexity in long-term trends and change in climate (MacKellar et al., 2014). Rainfall totals and seasonality are crucial for understanding the environment in order for farmers to be able to plan their cropping seasons. Recently, there has been a decrease in rainfall and an increase in rainfall variability noted. For example, the Bell Park Dam in the Cathkin region, that was built to aid the 1982 drought, dried up for the first time in 2015.

The South African Weather Service (2017) document a 403 mm average rainfall total for SA in 2015 far below the annual average of 608 mm. Mackellar et al. (2014) also show statistically significant decreases in rainfall and the number of rain days for the central and northeastern parts of South Africa in the autumn months and significant increases in the number of rain days around the southern Drakensberg in spring and summer.

This study follows from the work of Nel (2009) who assessed rainfall variability in the KwaZulu-Natal Drakensberg and demonstrated a shift in seasonality for 11 stations for the period 1955-2000. Mean annual rainfall showed no significant trend but an increase in summer rainfall, with a decrease in autumn and winter rainfall, resulted in a shorter wet season and increased seasonality (Nel, 2009). This present study attempts to extend this work to 2015 and to identify the occurrence of droughts related to the lack of rainfall. From this, trends in rainfall and drought patterns or cycles can be identified.

This study can also provide information pertinent to farmers in the area with regards to their planting season, as a delay in the onset of seasonal rains can alter their farming practices.

2 STUDY AREA AND METHODS

The site selected for investigation of rainfall variability and drought is the central and northern of the Drakensberg. Rainfall data for the stations in the Drakensberg was obtained from the SAWS but records were not available up to 2015 for all of the 11 stations used in Nel's (2009) study. However, records were made available for five selected SAWS stations located in the area. Figure 1 illustrates the geographical location of the stations. Table 1 highlights the specific historical records, co ordinates, altitudes and types of station.

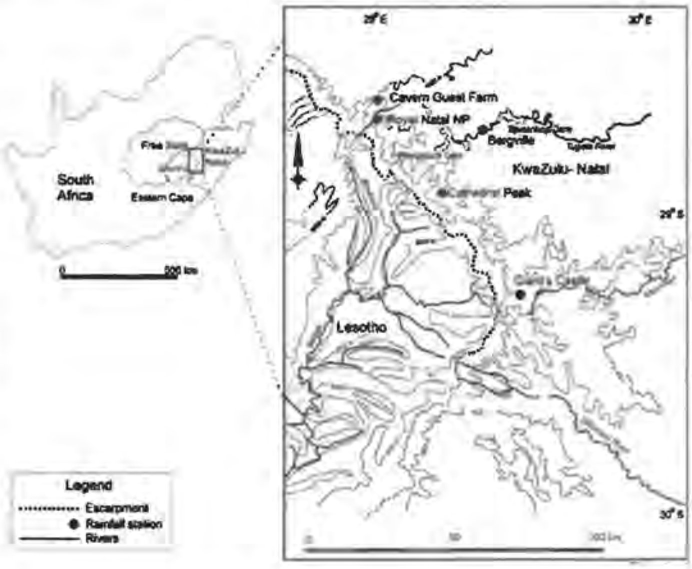

Figure 1: Location Map of rainfall stations in the Drakensberg (adapted from Nel, 2009).

Table 1: Rainfall station attributes and records.

Rainfall Station	Historical record	Latitude (S)	Longitude (E)	Altitude (m.a.s.l)	Manual/ Automated
Cavern	1947 – 2015	28° 38′	28° 58′	1980	Manual
Royal Natal	1948 – 2015	28° 41′	28° 57′	1392	Automated (1988)
Bergville	1934 – 2015	28° 44′	29° 21′	1128	Manual
Cathedral Peak	1941 - 2015	28° 57′	29° 12′	1448	Manual
Giant's Castle	1948 – 2015	29° 16′	29° 31′	1754	Automated (2006)

To test for trends in annual rainfall, the data at each station in the Drakensberg region for the period 1955 – 2015 was used to calculate an arithmetical mean for the region and this mean for each year was plotted. To analyse the long-term trends in interannual rainfall variability at each station for the period 1955 – 2015, the absolute deviation of annual rainfall from the mean annual rainfall (absolute deviation) was analysed. A linear regression was applied to all data to discern any temporal trends with the related degree of significance. Rainfall in the Drakensberg is seasonal and the seasonality can be described through the monthly rainfall totals as a percentage of the total amount of rainfall (Nel and Sumner, 2006). To define intra-annual variability and to quantify its temporal and spatial trends a modified version (De Luis et al., 2000; Ceballos et al., 2004) of the Precipitation Concentration Index (PCI) was applied.

To calculate the SOI, the method used by the Australian Bureau of Meteorology is the Troup SOI, which is the standardized anomaly of the Mean Sea Level Pressure difference between Tahiti and Darwin (Troup, 1965). The SOI data were retrieved from the Australian Bureau of Meteorology's website. Discharge data was obtained from the Department of Water and Sanitation's (DWS) website. The stations and the data are run and collected by the DWS. The surface water level data along the Mlambonja River at Kleinerivier was chosen to encapsulate the central and northern Drakensberg. Meteorological droughts are analysed using the Standard Precipitation Index (SPI) by Mckee et al. (1993) and hydrological drought is analysed using discharge data with the Streamflow Drought Index (SDI) from Nalbantis and Tsakiris (2009).

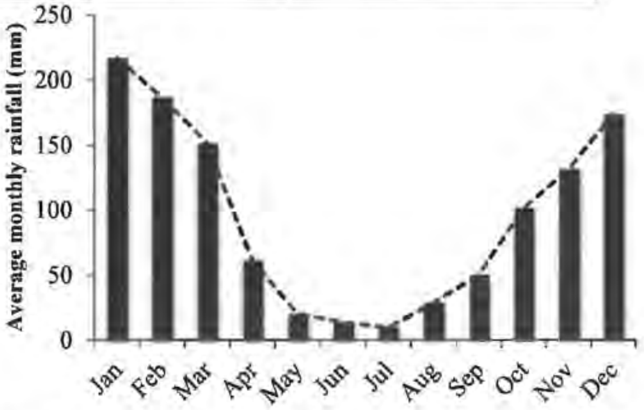

Figure 2: All station monthly rainfall average for 5 stations in the Drakensberg.

Rainfall over the general Drakensberg also increases with increasing altitude (Figure 3). This relationship is not significant to 95th confidence interval.

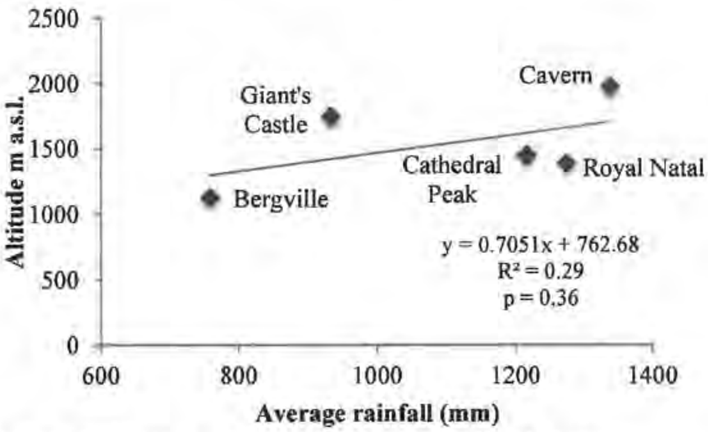

Figure 3: Average rainfall for each station in relation to altitude for the period 1955-2015.

3 FINDINGS

The rainfall regime is classified on the hydrological year, November – March (summer), April (autumn), May - August (winter) and September and October (spring) (Nel, 2009). Across the six stations it is clear that rainfall is most predominant in the summer and the lowest rainfall totals occur in the winter period (Figure 2). It was found that 75.16% of the rainfall occurs in summer, 13.25% in spring, 6.26% in winter and 5.32% in autumn.

3.1 RAINFALL TRENDS

A linear trend in mean annual rainfall in the Drakensberg from 1955-2015 is evident (Figure 4). The trend shows a decrease in mean annual rainfall over time, but this decrease is statistically significant. Years observed with below average rainfall include 1980/82, 1990/92, 2003, 2007 and 2015. Years of high average rainfall are always followed by a decrease in rainfall in the following years. These small-scale fluctuations in rainfall have a cyclcity of approximately every 3 years.

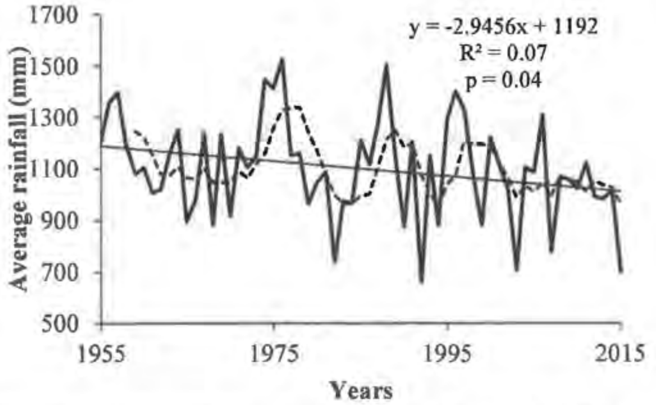

Figure 4: Time series of mean annual rainfall for 5 combined stations and five year moving average for the period 1955-2015.

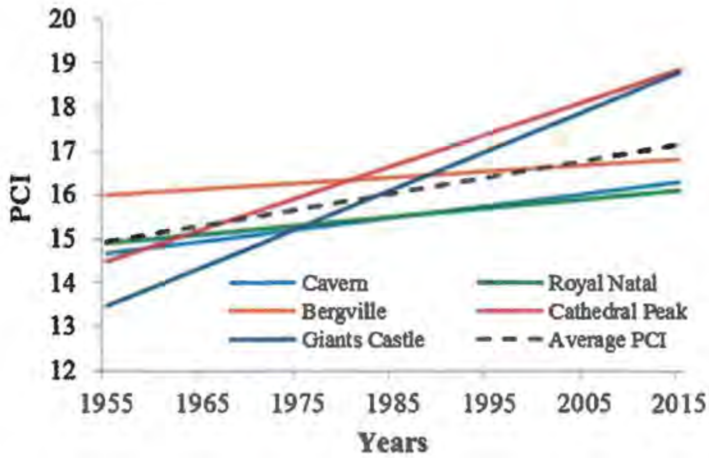

Figure 6: Linear trends of PCI for the period 1955-2015.

The long-term trends in interannual variability showed an increase in the variability of annual rainfall on average for the 5 stations measured over the 61-year period (Figure 5). Three of the five stations have increasing trends, however, only Giant's Castle has a statistically significant ($P = 0.01$) increase in interannual rainfall variability.

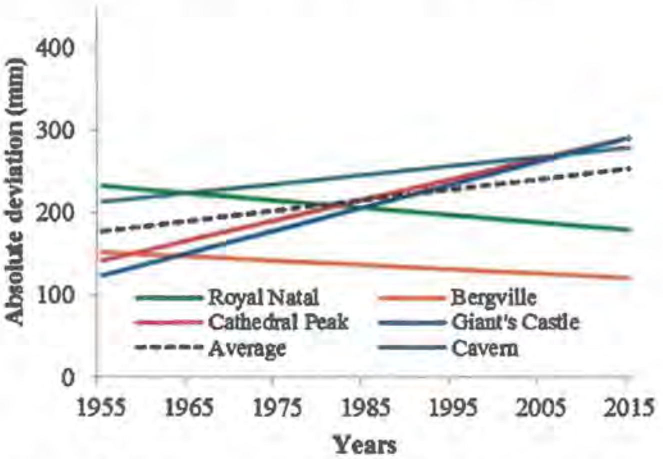

Figure 5: Linear trends of the absolute deviation of rainfall measured for the period 1955-2015.

3.2 SEASONALITY

An increase in Precipitation Concentration Index (PCI) indicates an increase in the seasonality of monthly rainfall in the Drakensberg. All stations show an increase in PCI values from 1955 – 2015, indicating an increase in the variability of the distribution of monthly rainfall (Figure 6). The increase in PCI over time at Giant's Castle and Cathedral Peak stations are statistically significant where $P < 0.001$ and $P = 0.01$ respectively, thus indicating that seasonality at these two stations is strengthening significantly. From the linear regression, the PCI at cathedral Peak increased from 14.4 to 18.9 and from 13.5 to 18.9 at Giant's Castle.

A decrease in the mean summer, winter, spring and autumn rainfall can be observed (Figure 7). Only autumn has a statistical significant trend of decreasing rainfall over time where $P = 0.05$.

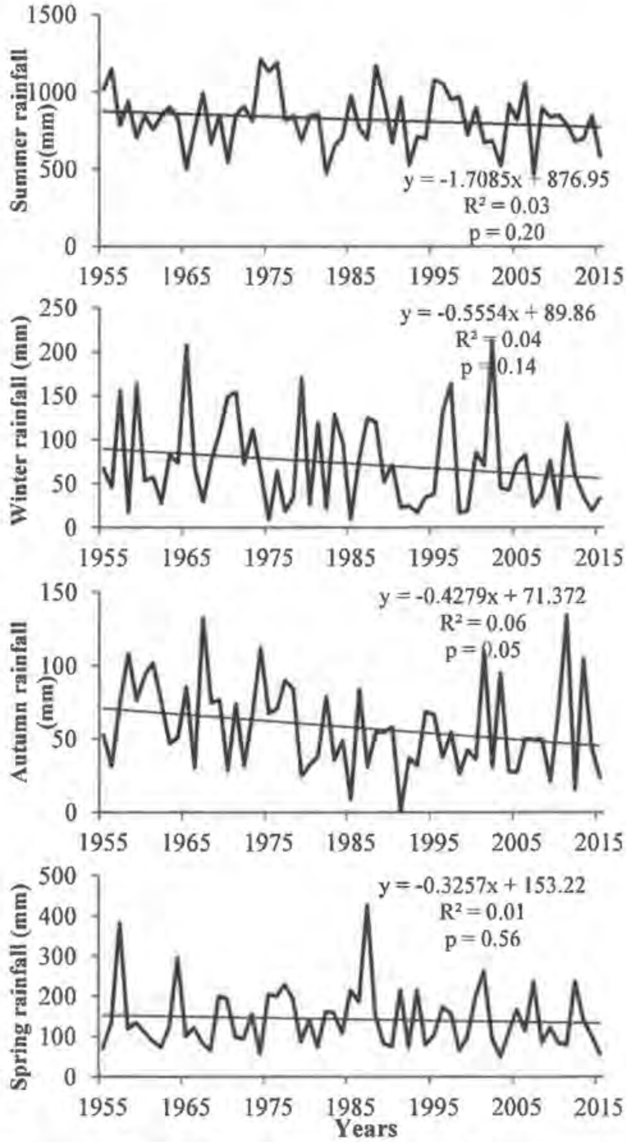

Figure 7: Time series and linear trends of summer, winter, spring and autumn rainfall for the period 1955-2015.

Analysis at of the seasonal trends at the individual stations showed an overall average decrease in rainfall over time for summer, winter, autumn and spring (Figure 8). All stations have decreasing trends across the seasons, except Bergville that has opposing trends in summer and autumn. Giant's Castle has a significant trend of decreasing winter (P = 0.05), summer (P < 0.001) and autumn (P < 0.001) rainfall. In autumn Cathedral Peak and the average of the stations both have a significant decrease in rainfall where P = 0.05. This indicates there is noticeable decline in rainfall over time in this area.

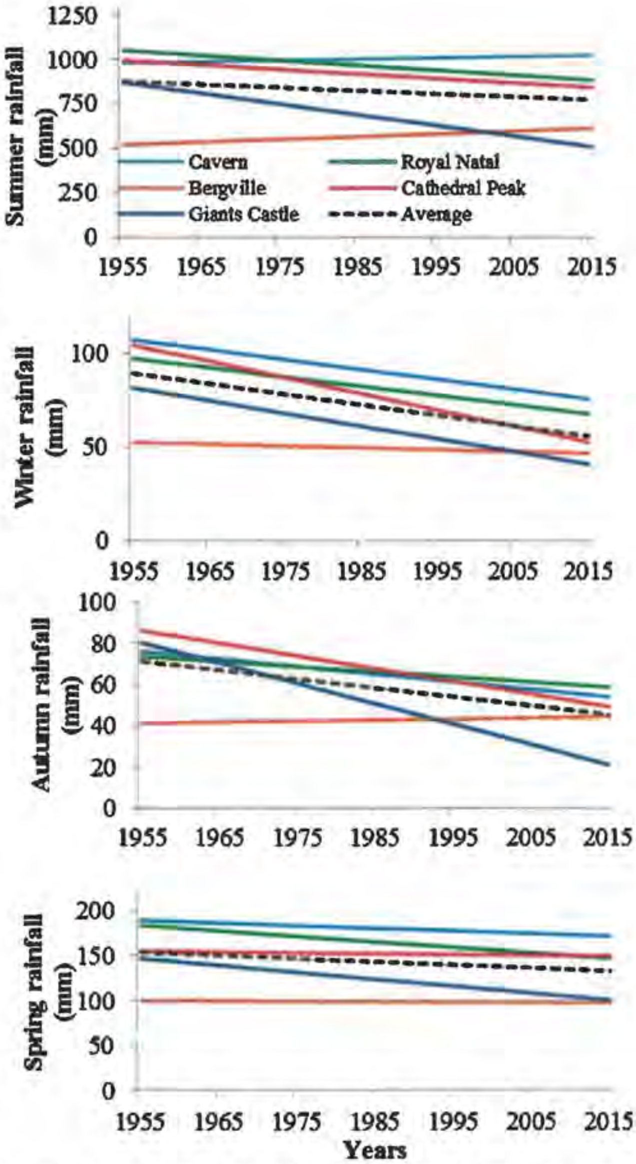

Figure 8: Linear trends of seasonal rainfall across 5 stations in the Drakensberg from 1955-2015.

3.3 SOUTHERN OSCILLATION AND SUMMER RAINFALL

A statistically significant correlation (r = 0.47, P = <0.001) exists between summer rainfall in the Drakensberg region and the SOI (Table 2). The summer rainfall correlates highly significantly. All lagged correlations that were tested are highly significant for P<0.001. The correlation coefficients between summer rainfall and the preceding months are all above 0.4 with the highest lagged correlation (r = 0.45) from the four months preceding the start of the summer rainfall season (July to October). This suggests that summer rainfall is strongly related to El Nino Southern Oscillation events.

Table 2: Correlation coefficient r with the relevant level of significance P between standardized regional summer rainfall and the mean SOI values for certain periods.

Rainfall Period	**Period of SOI values (non-lagged)**	**r**	**p**
Nov - March	Nov + Dec + Jan	0.39	0.002
	Nov + Dec + Jan+ Feb + Mar	0.47	<0.001
	Period of SOI values (lagged)		
	May + Jun + Jul + Aug + Sep	0.42	<0.001
	Jun + Jul + Aug + Sep	0.45	<0.001
	Jun + Jul + Aug + Sep + Oct	0.44	<0.001
	Jul + Aug + Sep	0.45	<0.001
	Jul + Aug + Sep + Oct	0.45	<0.001

3.4 METEOROLOGICAL DROUGHT

The average Standard Precipitation Index (SPI) for the Drakensberg stations has an overall decreasing trend indicating drying conditions over time across the Drakensberg region (Figure 9). This trend is not statistically significant. The graph follows the same trend as the mean annual rainfall graph. The most dominant dry period occurred between 1990; 1992 and 1994 where SPI values indicate moderate to extreme dryness (Figure 9). The year 1992 was the driest year on average (-2.57) followed by 2015 (-2.29) and 2003 (-2.23).

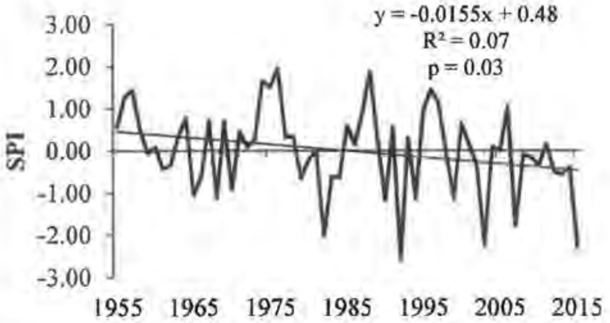

Figure 9: Average SPI for 5 stations in the central and northern Drakensberg over the period 1955 – 2015.

Extremely dry years are identified in Table 3 as 1982, 1992, 2003 and 2015. There is an average of 11 years occurring between these dry periods. Over the 61-year period, more dry periods occurred than wet periods in the last approximately 30 years, indicating an increase in dry years over time.

Table 3: Percent occurrence of each SPI drought category for the Drakensberg stations over the period 1955-2015.

SPI Value	Description	% Occurrence	Years
> 2.00	Extremely wet	0.0	None
1.5 to 1.99	Very wet	6.6	1974. 1975, 1976, 1988
1 to 1.49	Moderately wet	8.2	1956, 1957, 1996, 1997, 2006
- 0.99 to 0.99	Near normal	68.9	42 in total
- 1.00 to -1.49	Moderately dry	8.2	1965, 1968, 1990, 1994, 1999
-1.50 to – 1.99	Severely dry	1.6	2007
< - 2.00	Extremely dry	6.6	1982, 1992, 2003, 2015

3.5 DISCHARGE

The Mlambonja River has an overall increasing discharge trend over time (Figure 10). The years with the lowest recorded discharge are 1983 (10.41 m^3/s), 1992 (6.27 m^3/s) and 2015 (9.4 m^3/s) and these years, correlate to low rainfall experienced during the same period. In the last 16 years, however, an overall decrease in discharge is portrayed.

The Mlambonja discharge follows the trend of the Drakensberg rainfall and has a significant correlation of $P < 0.001$ (Figure 11). From about 2006 onwards there are more instances where the discharge exceeds rainfall.

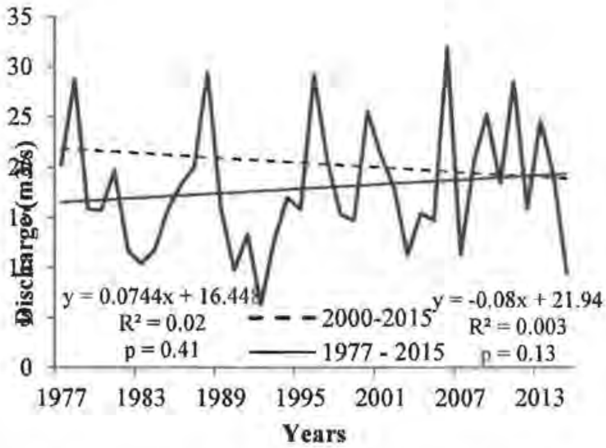

Figure 10: Discharge of the Mlambonja River over the period 1977 – 2015.

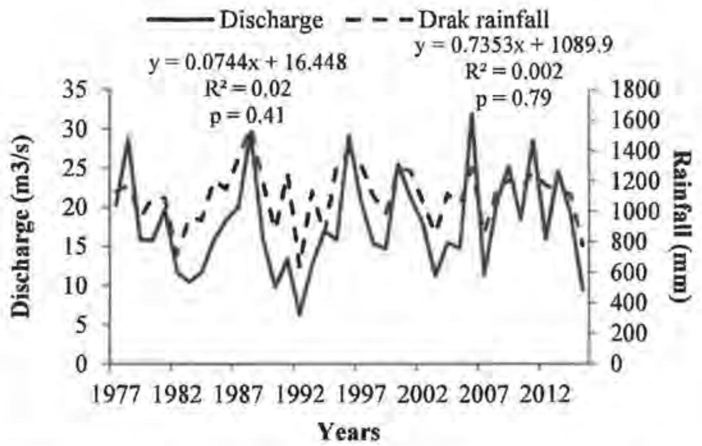

Figure 11: Overall discharge from the Mlambonja River in relation to yearly rainfall totals in the catchment and Drakensberg for the period 1977-2015.

3.6 HYDROLOGCAL DROUGHT

The streamflow drought index at Mlambonja River indicates a trend of increasing wetter years over time (Figure 12). Severely dry years years include: 1983 (-1.88), 1992 (-1.66) and 1995 (-1.62). Moderately dry years include 1990, 1993, 2007 and 2012. Fluctuations of SDI values increases from 2000 onwards.

Over the 38-year time period, 18 years had an SDI value of 0.00 or less. Mild droughts constitute 44% of the dry years, 22% were considered moderate droughts and a high percentage (17%) of the dry years were classified as severe droughts (Table 4).

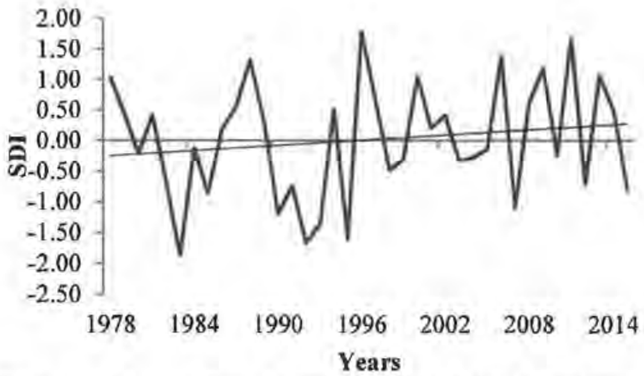

Figure 12: Streamflow Drought Index for the Mlambonja River from 1978 – 2015.

Table 4: Percent occurrence of each Streamflow Drought Index category for the Mlambonja River Discharge data from 1978 – 2015.

Description	**SDI Value**	**% Occurrence**	**Years**
No drought	< 0.0	0	None
Mild	0.99 to 0.0	44	1980, 1981, 1985, 1991, 1998, 1999, 2003, 2004, 2005, 2010, 2015
Moderate	-1.0 to - 1.49	22	1990, 1993, 2007, 2012
Severe	-1.5 to - 1.99	17	1983, 1992, 1995
Extreme	≤ -2.0	0	None

4 SUMMARY

The KwaZulu-Natal Drakensberg is a summer rainfall dominated region. Mean annual rainfall is decreasing over time. This is reflected in the discharge that follows rainfall and in the Drakensberg and is decreasing overtime from 2000 – 2015. Absolute deviation of rainfall from the mean indicate an overall average of increasing deviation of rainfall from them mean. All stations show an increase in PCI values from 1955 – 2015, indicating an increase in the variability of the distribution of monthly rainfall. A decrease in the mean summer, winter, spring and autumn rainfall for all five stations from 1955 – 2015 can be observed (Figure 7). Only autumn has a statistical significant trend of decreasing rainfall over time where P = 0.05. This follows the findings of Nel (2009).

Meteorological drought incidences are increasing with a higher percentage of years experiencing dryness over time. Hydrological droughts occur in the KwaZulu-Natal Drakensberg and have become more prominent over time. Prominent dry years that reoccur over varying analysis include 1982, 1992, 2003 and 2015 with an average cyclicity of 11 years.

5 REFERENCES

Ceballos, A., Martinez-Fernandez, J. and Luengo-Ugidos, M.A. 2004. Analysis of rainfall trends and dry periods on a pluviometric gradient representative of Mediterranean climate in the Duero Basin, Spain. *Journal of Arid Environments*, 58: 214-232.

Department of Water and Sanitation. 2017. Monthly Precipitation data. [Online]. Available: https://www.dwa.gov.za/default.aspx [19/05/2017].

McKee, T.B., Doesken, N.J and Kleist, J. 1995. Drought monitoring with multiple time scales. Proceedings of the Ninth Conference on Applied Climatology. *American Meteorological Society*, Boston, p. 233–236.

Nalbantis, I. and Tsakiris, G., 2009. Assessment of hydrological drought revisited. *Water Resources Management*, 23(5): 881-897.

Nel, W. 2009. Rainfall trends in the KwaZulu-Natal Drakensberg region of South Africa during the twentieth century. *International Journal of Climatology*, 29(11): 1634–1641.

Nel, W and Sumner, P.D. 2006. Trends in rainfall total and variability (1970-2000) along the Kwazulu-Natal Drakensberg foothills. *South African Geographical Journal*, 88(2): 130 – 137.

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Soil erosion: a case study of Maqabaqabeni in the Loskop area

Sindiso J. Lubisi

Department of Geography, Geoinformatics and Meteorology, University of Pretoria

Abstract: Maqabaqabeni is a rural village area located in the KwaZulu-Natal province, approximately 200km inland from Durban. It was established in the 1980s after a Shoe factory was opened, within the main homelands of the area. The area is currently dominated by intense sheet erosion forms and gully erosion reaching depths of more than 2 m. Prior to this, Maqabaqabeni was a commercial farmland with little human activity and interaction taking place. Erosion rates were minimal as compared to the post 1980s when farms gave space for human settlement. Erosion had intensified almost immediately after the settlement establishment and construction of the main road to Estcourt. While it cannot be neglected that the area received its highest annual rainfall totals in the 1990s, the settlement has had the most influence in the rapidly intensifying erosion with little or no management methods being employed.

1 INTRODUCTION

Soil erosion can be defined as the process of removal and displacement of soil material by mobile agents such as wind, water or ice (Montgomery, 2007). Unsustainable human interaction with the soil is one of the notable impacts in initiating and where already existing, accelerating and intensifying the erosion processes. In return, soil erosion changes the landforms where it occurs and can have influence on the living conditions and nature of settlement of people (Feiznia & Nosrati, 2007).

In South Africa alone, more than 70% of the topsoil has been affected by erosion (Le Roux et al., 2007). The study area, Maqabaqabeni, in Loskop is no exception. Maqabaqabeni is situated around the Drakensberg foothills which is part of the Karoo Supergroup (Grab, 2009). Erosion at the area is yet to be mapped and this study aims to fill parts and hopefully, most of the gap.

Most studies on mapping soil erosion have been conducted with mathematical and analytical approaches that require analyses of soil erodibility and sediment deposits in order to draw conclusions based on soil quantitative results (Tahir et al., 2010). Various similar studies have been previously conducted for different regions and areas around the world. Until the early 1990s, erosion forms have been mapped in large-scales (Mboya et al., 1999). This has raised issues for remote areas where the same might not be apparent as assumed from large-scale studies (Summer & Walling, 2002). Mapping soil erosion is one of the most challenging topics which requires field work and remote-based work (Yu et al., 1996). This study will adopt these two techniques with a more quantitative approach. Soil factor models derived from previous studies will be used where applicable while others will be modified in order to aid in the successful creation of a GIS database of the erosion phenomena at Maqabaqabeni.

2 STUDY AREA AND METHODS

The Maqabaqabeni area is located in KwaZulu-Natal approximately 200km inland from Durban. It is a rural-community area that was established in the 1980s after a Shoe factory was opened. The area lies in the Drakensberg foothills and drains into the Little Tugela River (Figure 1).

Figure 1: Location of Maqabaqabeni and study area

Historical images of the study area from 1942, 1962, 1982, 2013, and 2016 were compared. A 20 year gap is considered between the first three timelines as well as 30 years interval from 1982 to 2013. The choice was influenced by the lack of apparent broad land use changes within the 30 years from 1982. This method was assumed to provide the basis from which differences between natural and human impacts have influenced the erosion in this area (e.g. Pető et al., 2008).

Erosion phenomena is classified and mapped according to the original Southern African Regional Commission for the Conservation and Utilisation of the Soil (SARCCUS) classification method system. The SARCCUS classification tool ranks and defines four erosion forms including sheetwash, rills, gullies and wind (SARCCUS, 1981).

Available recorded annual rainfall data for Bergville with nearly the same altitude of 1130m, also with the closest weather station of approximately 42km, was assumed to be the same as that of the study area. Historical data will give significant figures of how much rainfall was received at Maqabaqabeni as well as contributing to conclusions regarding the amount of run-off and infiltration, relating to previous factors, occurs in the area (see Nel, 2009).

3. FINDINGS

It was noted from the historical images that:

a) Aerial photographs have low resolution. This may have resulted from less advanced imagery technology used at the time.
b) Some images have reflections from the ground. The time of imagery flight affecting the presence and position of shadows may have been taken into less consideration when images were taken.
c) Owing to the weather conditions at the time images were taken, clouds appear in some portions of certain images which proves the low levels of perfection of imagery.
d) Some images appear to be off the North. To minimize the effect of this, the top of each image, regardless of the true direction, shall be assumed to be north of that image.

3.1 ANALYSIS OF HISTORICAL IMAGE: 1942

In the 1940s, the Maqabaqabeni area only saw a domination of commercial farming and less of other human impacts as represented by Figure 2 below. The alignment of the farms appear to be formally and systematically formulated considering the slopes where they are placed. The availability of crops in the area slows down the speed of run-off and prevents excessive erosion where the water would collect in the lower altitudes in the middle of the image.

Figure 2: Maqabaqabeni historical image of 1942

It is evident from the middle of the image that there was a less defined tributary which flows towards the south west into the Little Tugela River. According to the SARCCUS classification system, sheet erosion appears to be the most dominating erosion form ranging from S1 (none apparent) on the sides of the tributary, to S3 (moderate) in the middle of the tributary. Some rills can be identified along the tributary. Moderate rills with considerable depths assumed to be ranging from 0.1 m to 0.3 m can be recognized north east in the middle of the tributary.

3.2 ANALYSIS OF HISTORICAL IMAGE: 1962

There seem to be few changes to the erosion forms within the 20 year period between 1942 and 1962 as illustrated in Figure 3 below.

Figure 3: Maqabaqabeni historical image of 1962

Moreover, the land use during this time appears to be similar to those observed in the past 20 years. The lack of changes in land use may be the result of this fairly stagnant erosion forms during this period. However, it can be observed from this image that the main road to Estcourt appears to be more well defined which may have resulted from maintenance of the latter over the years. The SARCCUS classifications for this year are therefore maintained as those observed in 1942.

3.3 ANALYSIS OF HISTORICAL IMAGE: 1982

In 1982, there is a fairly visible change in the landforms compared to 1962. New formations of erosion forms can be identified with pre-existing ones showing signs of progressive maturity. As illustrated in Figure 4 below, there is a new formation of an erosion form (marked "a") on the western side of the image just below the intersection between the road just at the base of the homesteads and the road cutting on the main road to Estcourt.

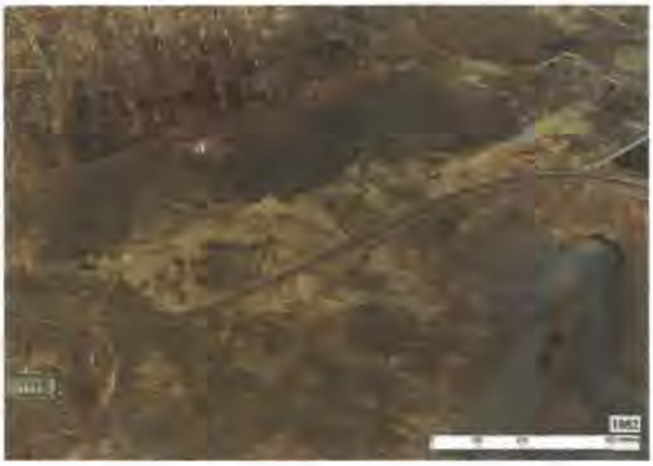

Figure 4: Maqabaqabeni historical image of 1982

According to the SARCCUS classification system, sheet erosion during this time can be classified to range from S3 to S5. Moderate sheet erosion is more or less clearly evident with very poor plant cover. Some parts of the area appear to have been severely eroded with most parts of the A-horizon exposed.

Although there is slight evidence of gullies, when viewed from closer a large range of gullies in their infancy stages is apparent. Gully formation is thus predicted to be near its first stage rating of G2, with depths ranging between 0,5m – 1m.

The image shows a series of very small tributaries formed from run-off waters connecting to a main tributary which runs into the Little Tugela River. The southern side of the main road to Estcourt appears to be less affected by erosion. However, since the southern part has an isolated hill sloping down towards this road, it can be assumed that it also has some slight to moderate sheet erosion caused by run-off.

The northern part has now been built up with houses. These developments might have been influenced by the establishment of a Shoe factory situated in the soutwestern side of the image. Moreover, there is still fairly less direct human land use in the erosion site during this time with houses only at the far North of the study area.

Within the 20 year interval, Maqabaqabeni saw nine lows of annual rainfalls with totals per annum of below 600 mm (Figure 5). Annual total rainfalls of 558 mm in 1965, 517 mm in 1966, 334 mm in 1968, 568 mm in 1969, 562 mm in 1970, 498 mm in 1972, 589 mm in 1977, 587 mm in 1979 and 563 mm in 1982, as represented in Figure 5 below (Smart, in prep). This depicts a period of dry weathers with occasional heavy rainfalls and partial floods.

The 1982 image was taken in the month of November which was preceded by only a single high average of 70 mm in October and very low averages ranging from 0 mm to 11.5 mm between May and September. This may have caused the brownish colours of the ground around the area with some visible patches of green which can mean that there is very poor vegetation and where available, it is dry.

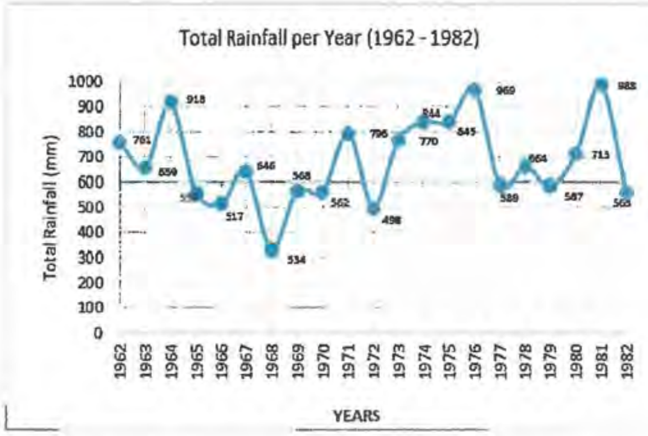

Figure 5: Maqabaqabeni historical rainfall data (1962-1982)

3.4 ANALYSIS OF HISTORICAL IMAGE: 2013

In the past 30 years, the Maqabaqabeni saw minor land use changes with the latter being the constructions of a few houses compared to those seen between 1962 and 1982 (Figure 6). Because of this and the more stable variances in the rainfall data as represented by Figure 7 below, a 30 year interval has been taken into account.

Figure 6: Maqabaqabeni Historical Image of 2013

Following the development of the main road to Estcourt in the 1980s, as well as the development of houses in the northern part of the image, saw houses built within very close proximity to the erosion site.

From the 2013 satellite image, it can be observed that the erosion forms have matured compared to those in 1982. Large well-defined rills associated with gully erosion ranging from moderate to very severe with SARCCUS classifications of R3 to R5, can be seen from the image. The apparent gully erosion forms in this image can be classified as ranging up to G3 in some parts of the tributary with intricate patterns of gullies (1-3m) exposing the entire soil profile in some places.

It can also be noticed that the erosion formation identified (as 'a') in 1982, marked 'b' on the 2013 image, has now matured from sheet to a well-defined gully erosion form. Furthermore, small "Islands" of topsoil can also be observed.

The area only saw three rainfall annual totals of less than 600 mm (559, 533 and 460 mm in 1983, 1992 and 2007, respectively). Similar rainfall variations were received during this 30 year period, with a peak of 1219 mm of total rainfall in 1996.

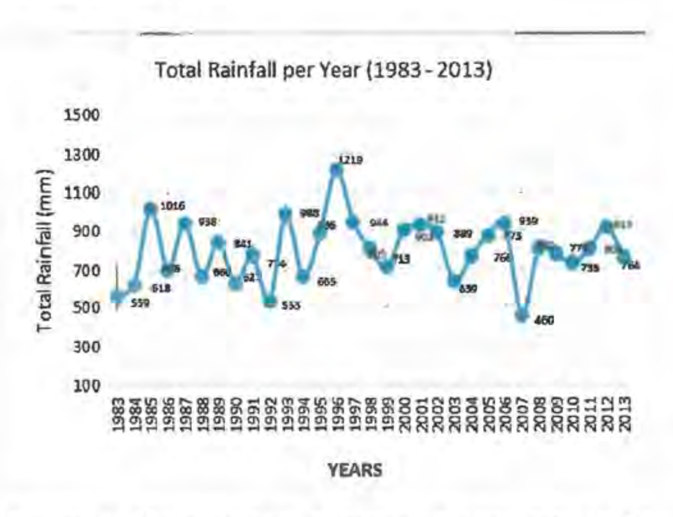

Figure 7: Maqabaqabeni historical rainfall data (1983-2013)

4 CONCLUSION

There is a distinct difference in the extent of the erosion observed between 1962 and 1982. Further extents can be identified in the 2013 image. While the natural topography of this area may have had significant influence on increasing the erosion impact, it is clear that human interaction with the environment had a greater impact.

The establishment of the Shoe factory in the 1980s coincided with the development of houses around the area. Notable erosion changes are evident from this period of 1980s up to the recent 2010s. Vegetation and the farms in the north have been displaced by houses in the 1980s. The construction of the main road to Estcourt in the same decade has also imposed significant disturbances to drainage and changes to the natural environment. Several gullies are noted extending from the road along artificial drainage lines.

The latter depicts that the presence of humans and their interaction with this environment have had significant impacts on the erosion in this area. Some other potential human activities which may have influenced erosion include; poor grazing methods owing to the earlier times as a source of food and income, as well as the lack of awareness in erosion management methods amongst the community.

It can be noticed that some structures have been destroyed and people forced to move due to the lack of erosion management methods or where present, their ineffectiveness. Figure 8 and 9 below show Google Earth images of 2008 and 2016, respectively. From the two images, the house which was present in the 2008 image has been replaced by rill erosion which can be seen in figure 9 of 2016.

Figure 8: Maqabaqabeni in 2008

Figure 9: Maqabaqabeni in 2016

Field work is yet to be conducted for this study. The field work is for collecting more quantitative erosion data such as the depths and widths of the current erosion forms, the overall extent of erosion forms, and the number of destroyed infrastructures due to this erosion. Other information to be collected include observing the types of erosion management methods and their effectiveness around the area.

5 REFERENCES

Bean, T. A., 2015. Erosion phenomena on Round Island, Mauritius. Unpublished MSc mini-dessertation: University of Pretoria, 106pp.

Dregne, H.E., 1987. Soil erosion: cause and effect. *Land Use Policy*, 4: 412-418.

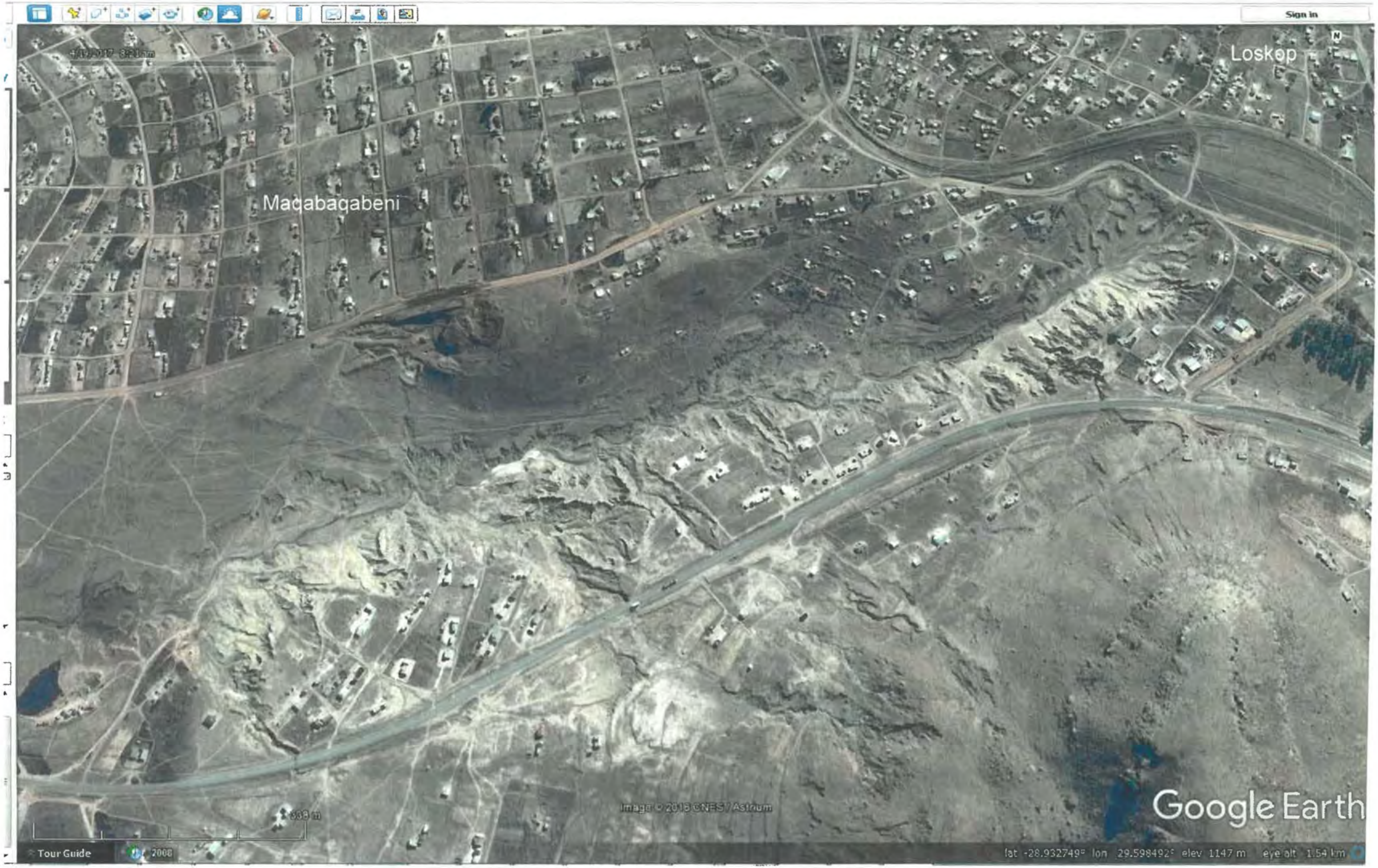
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Image © 2018 CNES / Astrium
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lat -28.932749° lon 29.598492° elev 1147 m eye alt 1.54 km

Dondofema, F., Murwira, A. and Mhizha, A., 2008. Identifying Gullies and determining their relationships with environmental factors using GIS in the Zhulube meso-catchment. *Water and Sustainable Development for Improved Livelihoods, Johannesburg, South Africa*, 1-8

Feiznia, S. & Nosrati, K., 2007. *The effect of parent material and land-use on soil erosion: a case study of the Taleghan drainage basin, Iran.* Perugia, IAHS Publisher, 300-305.

Grab, S., 2009. Drakensberg Escarpment: mountains of geomorphic diversity. In *Geomorphological Landscapes of the World* (pp. 133-142). Springer Netherlands.

Le Roux, J., Newby, T. & Sumner, P., 2007. Monitoring soil erosion in South Africa at a regional scale: review and recommendations. *South African Journal of Science*, 103: 329-335.

Mboya, T.O., Mtakwa, P. and Rönick, P., 1999. Use of Landsat Thematic Mapper and Aerial Photographs in Soil Erosion Assessment. *East African Agricultural and Forestry Journal*, 65: 157-166.

Montgomery, D.R., 2007. Soil erosion and agricultural sustainability. *Proceedings of the National Academy of Sciences*, 104: 13268-13272.

Nel, W., 2009. Rainfall trends in the KwaZulu-Natal Drakensberg region of South Africa during the twentieth century. *International Journal of Climatology*, 29: 1634-1641.

Okalp, K., 2005. *Soil erosion risk mapping using geographic information systems: a case study on Kocadere creek watershed, Izmir* . Doctoral dissertation, MSc thesis, Graduate School of Natural and Applied Sciences, Middle East Technical University (METU), Ankara.

Pető, Á., Bucsi, T. and Centeri, C., 2008. Comparison of soil properties on slopes under different land use forms. In *Proceedings of the 15th International Congress of ISCO, Soil and Water Conservation," Climate Change and Environmental Sensitivity" on CD* (pp. 1-4).

SARCCUS, 1981. A System For The Classification of Soil Erosion in the SARCCUS Region. *Department of Agriculture and Fisheries*, Pretoria, 20pp.

Summer, W. and Walling, D.E., 2002. Modelling erosion, sediment transport and sediment yield. In *Techical documents in Hydrology* (No. 60). Unesco.

Tahir, M.E.H., Kääb, A. and Xu, C.Y., 2010. Identification and mapping of soil erosion areas in the Blue Nile, Eastern Sudan using multispectral ASTER and MODIS satellite data and the SRTM elevation model. *Hydrology and Earth System Sciences*, 14: 1167.

Yu, J., Shi, C. & Yu, G., 1996. Rough Area Soil Erosion Mapping via GIS Modeling. *International Archives of Photogrammetry andRremote Sensing*, XXXI(Part B7): 816-824.

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The Amatikulu and Nyoni rivers: fluvial discharge dynamics, climate variability and land use change

Renate van Heerden
Department of Geography, Geoinformatics and Meteorology, University of Pretoria

Abstract: Land use changes and climate variability are known to affect environmental processes and fluvio-marine environments tend to be extremely sensitive to these impacts. Hydrological models have been introduced by numerous studies to explore responses in catchment processes. Spatially distributed rainfall-runoff models furthermore provide a more holistic view of the hydrological behaviour under different environmental conditions. However, the use of hydrological models in South African studies that investigate the impacts of climate and land use change on discharge is scarce and only a limited number of studies have investigated the impacts on catchment processes. Of more importance is to distinguish between the respective roles of climate and land use on specific catchments. This study implements STREAM (Spatial Tools for River basin Environmental Analysis and Management), a GIS-based water-balance model, to investigate the Amatikulu and Nyoni catchments in KwaZulu-Natal (South Africa). River and coastal morphological changes have been observed in the recent past. It is proposed that land use change and climate variability have been the largest influences for this phenomena. Climate and land use data for the period 1964-2015 are used for the model simulations. It is found that land use change had no significant impact on the discharge for this period, whilst climate had a profound effect. Climatic scenarios corresponding to projected climate change found that a 5°C increase in temperature would have the largest influence on discharge.

1 INTRODUCTION

The east coast of South Africa has attracted the interest of several researchers interested in the dynamic nature of coastal environments. Such environments are especially susceptible to change because of their ability to adapt to changes relatively quickly as it is the interface between land, air and sea (Klein *et al.*, 2001). This means that any slight alteration in land, sea or air would alter the presiding dynamics. Coastal water bodies, such as estuaries and mangroves, show substantial morphological changes and have sparked the interest in investigating the governing reasons for these alterations. (Cooper, 2001; Bouma *et al.*, 2007). Cooper (1993, 2001) investigated the estuaries formed at the river mouths of the South African east coast river catchments. It was found that the relationship between the morphological modifications of the coastal water bodies and the ruling processes are still poorly understood (Cooper, 2001), although it is clear that river-dominated estuaries are only likely to change when it needs to adapt to a different set of climatic and anthropological conditions. It is thus important to investigate the fluvial responses to climate variability and land use changes to add to the explanation for these morphological changes.

The relationship between climate change, erosion and vegetation cover is complex and becomes even more complicated with the introduction of land cover changes, because of interactions and feedbacks between the atmosphere, oceans and land surface (Jaing *et al.*, 2007; Dasseto *et al.*, 2010). Climate impacts on geomorphological processes are in some cases considered more dominant than land use change (see Jansson, 1988; Coulthard & Macklin, 2001; Vandenberghe, 2003; Dasseto *et al.*, 2010; Park *et al.*, 2011). In an attempt to investigate these influences hydrological models have been developed. However, the application of hydrological modelling seems to be concentrated in European countries and in the northern hemisphere. It has been mentioned by van Rompaey *et al.* (2005) that it is unknown how well these models would perform outside of northern and central Europe.

Local modelling studies have been carried out by a handful of researchers, including Thomas *et al.* (2010) and Schulze (2000). The need to apply different hydrological models in South Africa therefore exists. The intricate nature of processes operating in South Africa encourages further research into hydrological responses to land use and climate changes. Schulze (2000) mentions several issues, including fluctuations in hydrology that are exacerbated by fluctuations in climate.

Extensive morphological changes have been observed along the east coast of South Africa. To explain the phenomena, it is suggested that the catchment has reacted to climate variability and land use changes. A spatially distributed hydrological model is applied here to investigate the sensitivity of the Amatikulu and Nyoni catchments to climate variability and land use changes. Spatial Tools for River Basins and Environment and Analysis of Management Options (STREAM) is a river-basin management instrument (Aerts *et al.*, 1999). The instrument is a

GIS-based rainfall-runoff model which is focused on climate change effects, land use changes and the interaction between river discharges and coastal dynamics (Aerts *et al.*, 1999). STREAM enables the simulation of river discharges and water availability and facilitates scenario analysis (Aerts *et al.*, 1999). The input required for the application of the model consists of several spatially distributed layers, i.e. a Digital Elevation Model (DEM), total monthly precipitation and average monthly temperature, crop factors and the maximum soil-water holding capacity (Aerts *et al.*, 1999).

2 STUDY AREA AND METHODS

The Amatikulu-Nyoni catchment is located in northern KwaZulu-Natal (KZN) and extends to the Indian Ocean. This part of the northeast coast was formerly known as the Zululand coast. Starting in the foothills of the Drakensberg, the Amatikulu river finds its course through an area defined by hills and meanders its way to the outlet. Long barrier dunes, estuaries, marshes and lagoons defines this section of the east coast. The Amatikulu-Nyoni estuaries are located on the actively prograding area on east coast of South Africa (Cooper, 1993; Green et al,. 2013). River-dominated estuaries further characterize this particular part of the South African coast (Cooper, 1993; Bond *et al.*, 2001; Cooper, 2001; Green *et al.*, 2013).

Several studies indicate a northerly longshore drift of coastal sediments (Schoonees, 2000; Smith *et al.*, 2010; Bond *et al.*, 2013; Green *et al.*, 2013). Although most of the sediments are largely supplied by the Tugela river, it has been observed that the fluvial sediment yield of the Amatikulu river has in part contributed to the increased sediment along the east coast of South Africa (Schoonees, 2000; Smith *et al.*, 2010; Bond *et al.*, 2013; Green *et al.*, 2013). As a result of the longshore sediment transport, the Nyoni channel seldom breaks through the barrier dunes (Green *et al.*, 2013). This results in a channel parallel to the coast that joined the Amatikulu estuary after the floods in May 1971, 10 km further north. A massive barrier extending northwards defines the Amatikulu estuary and formed in response to the wave action from the south east (Begg, 1978). Sediments largely supplied by the Tugela forms this 4,5 km long sandbar (Begg, 1978). Since the Amatikulu is a shallow, river-dominated estuary, it maintains an outlet due to the fluvial discharge and diminutive tidal exchange (Cooper, 1993; Green *et al.*, 2013). It is further characterized by a braided channel pattern. The dynamic and unstable nature of the Nyoni and Amatikulu estuary features and channel migration have been extensively studied and results from these studies show the migration of the Amatikulu-Nyoni mouth (Begg, 1978; Cooper, 1993; Green *et al.*, 2013).

The Amatikulu catchment is 900 km² with a mean annual run off of 201.07×10^6 m³ and an annual run off of 132-188 m³/s (Begg, 1978; Green *et al.*, 2013). River length is recorded to be roughly between 84 km and 108 km. The small low-flowing Nyoni river is about 25 km long, contribute an average $21{,}6 \times 106$ m³ run-off annually. It covers an area of 114 km² (Begg, 1978). Since it is largely maintained by fluvial discharge, the Amatikulu inlet would go through open and closed phases (Green *et al.*, 2013). In the 1978 report, Begg (1978) stated that the mouth was closed very seldom, although concerns of this situation were lifted, as it was just able to maintain the inlet. As a result, the estuary plays a cardinal part in the characteristics of the river. It covers an area of 1.22 km² with a floodplain of 550 m. Saltwater influences are noted up to 7.5 km upstream of the estuary. Extreme siltation in the estuary is noted in 1978, as well as infilling of the estuary by wind-blown sand (Begg, 1978).

Figure 1: Matigulu-Nyoni river catchment in KZN.

In order to simulate river discharge, the STREAM model was set up for the Matigulu-Nyoni catchment. The model requires digitized maps for land use, soil water holding capacity and elevation. Apart from these maps, tables containing monthly precipitation and temperature values are also necessary. All the information is imported into the model as a matrix of values which is then used to calculate the discharge volumes.

3 FINDINGS

After model calibration, the simulated discharge volumes were found to approximate reality. Once the model calibration was accepted, different scenarios were simulated and links between land use (Table 1) and climate was further investigated. The results of these investigations are listed below.

Table 1: Type of land use change from 1990-2013

Land-use Change	% Change
Farmland/ Cultivated to Grassland/ Bush	4.42
Farmland/ Cultivated to Urban/ Built-up	0.58
Forest/ Plantations to Farmland/ Cultivated	1.63
Forest/ Plantations to Grassland/ Bush	3.09
Forest/ Plantations to Urban/ Built-up	0.89
Grassland/ Bush to Farmland/ Cultivated	7.27
Grassland/ Bush to Urban/ Built-up	0.86
No change	71.66
Urban/ Built-up to Farmland/ Cultivated	4.16
Urban/ Built-up to Grassland/ Bush	2.09

- Land use change:

It is clearly seen within the catchment that significant development has taken place in the form of built-up areas and sugarcane plantations (Table 1). However, it is not clearly reflected in the results in the table, where built-up area has shown a decrease of 3.97%. To explain the inconsistencies in the above data, one has to consider the method of data acquisition. Land use maps were generated through classifying satellite imagery RGB values. During the time in which the data was obtained, the land use classification methods were updated and refined, and therefore the resolution of the data is different between the different study periods. This anomaly has occurred possibly as a result of a refined resolution of land use classification methods between the 2013 classification and 1990 classification, where the latter was done only recently after 2013.

Table 2: Total land use change

Land use category	% Area change	
	1964-1990	1990-2013
Natural	-2.94	0.51
Waterbodies	1.55	-0.51
Cultivated	-27.07	8.22
Bare ground/ Degraded	-0.07	-0.03
Built-up	n.a.	-3.97
Plantations	8.26	-4.21

Although cultivated land shows a significant increase (8.22%), land used for plantations show a decrease of 4.21%. This might be because land that was previously used for plantations is now in part used for cultivated land. Upon investigation it became clear that the largest form of change was that of grassland to cultivated land, explaining about 7% increase in cultivated land, where urban or built-up land contributed 4% to cultivated land.

Once again this can be explained by the method of data acquisition, and that with refined resolution more detailed differentiation can be made between built up areas (farm houses, roads and sheds etc.) and cultivated land. However, a large part of the increasing cultivation area is due to plantation and forests, contributing 1.63% to cultivated land. Another large part of the declining plantation area is attributed to grassland or bush (3.09%), which could be an indication of land abandonment. Another map was produced to indicate where there were areas that have undergone land use change and areas where there were no change (Figure 2).

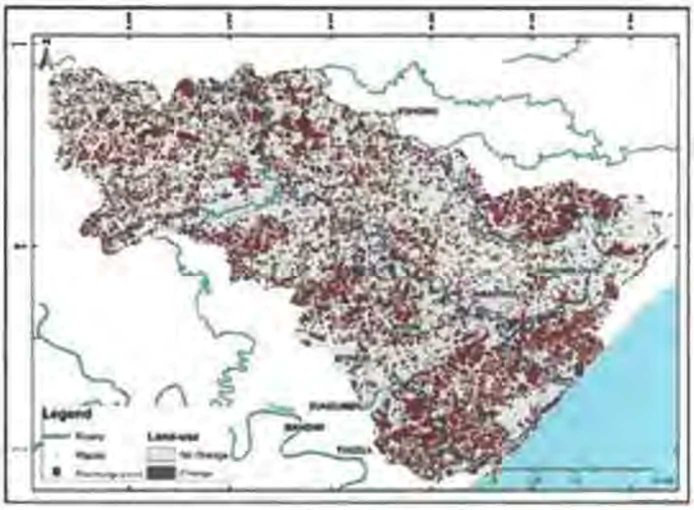

Figure 2: Distribution of land use change

A total of about 72% of the catchment has not undergone any changes. Of the other 28%, most changes occurred along the southern coastal areas and the upper north-western catchment.

- Climate:

The influence that climate has on the catchment was evaluated through several means. The past observed climate data was summarized in graphs to establish trends in precipitation and temperature. In figure 3 the total monthly precipitation is shown for the period 1930-2015. The moving average trend line shows the general precipitation pattern as close to decadal wet-dry periods. This means that roughly every decade since 1933 there would be periods of elevated precipitation that is followed by a period of lower precipitation.

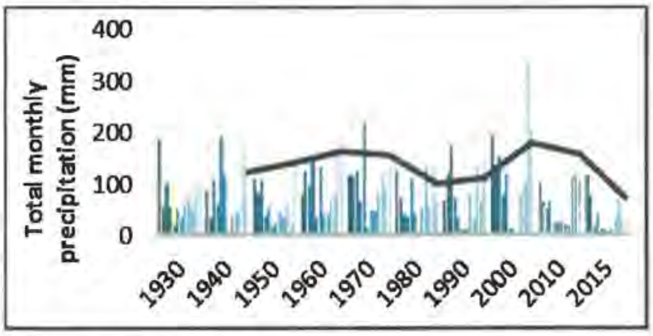

Figure 3: Total monthly precipitation for the catchment

The observed average annual temperature records are depicted in the graph below (Figure 4). The average annual temperature follows roughly a similar pattern to that of the total monthly precipitation pattern seen in the above graph. For each warm period, a colder period would follow. It is interesting to note that the warm period somewhat coincides with the wetter period except for the period 1984-1996. A slight warming trend based on January temperatures is further identified in this graph.

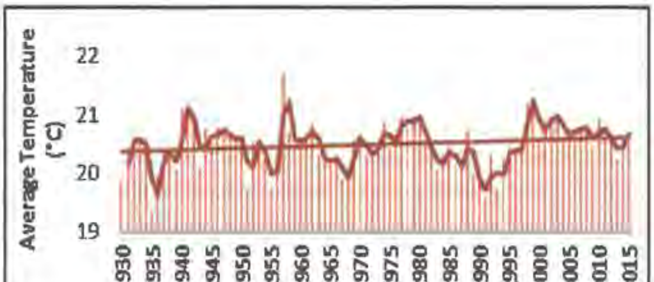

Figure 4: Average annual temperatures for the catchment

This result is interesting since the reasonable assumption is that with increased temperatures (as seen in the IPCC's projections for climate change), the country will experience decreased precipitation. However, the study does continue to look at scenarios where precipitation will decrease in the years to follow.

• Discharge:

Since the aim of the study was to look at how climate and land use respectively influence the discharge of the river, several scenarios where investigated using the STREAM model. To start off the investigation, actual observed climate values and digitized maps for land use were used. There is no visible difference between the discharge volume distributions when using the 1964 Land Use Map (LUM) compared to the distribution when using the 2013, LUM. Low discharge volumes of about 14 million m^3 were calculated for the period 2005-2015 and high discharge volumes of about 40 million m^3, regardless of the LUM. The graph below illustrates the simulated discharge for the different land use map years to put this argument into perspective (Figure 5).

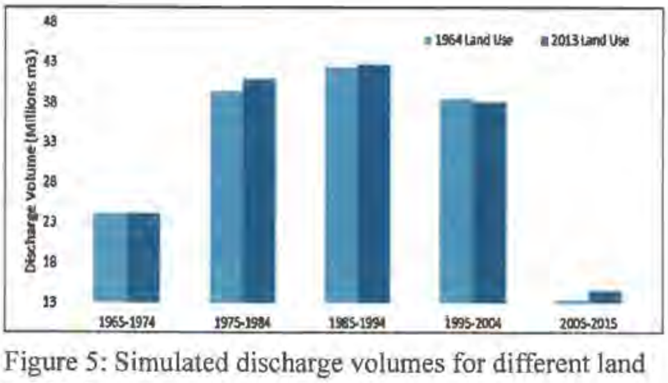

Figure 5: Simulated discharge volumes for different land use maps

When land use scenarios were investigated, the whole catchment was changed to a single crop factor value. What is interesting to note is that it was only when completely altering the land use within the catchment to crop factor values of 0.3, 0.5, 1.0 and 1.1 that there were significant differences in the discharge volumes in the catchment. When simulating actual land use change scenarios that have occurred within the catchment in the recent past, relatively insignificant changes were observed in the discharge volumes. This might just be because the model is not sensitive to slight alterations in land use. If it is considered how the model calculates the effect of land use, this is understandable, where build-up land is given a crop factor value which will be similar for grassland or shrub land. The question arises as to whether this method of including land use into the simulation is a good reflection of reality. However the reasoning of using crop factor values to calculate the effect of land use is sound, seeing that the crop factor is calculated by the well accepted RUSLE and USLE soil erosion calculations. Following these studies, using crop factor values to determine runoff is accepted.

The scenario that most closely follows the same discharge volume distribution to the distributed crop factor scenario (reality) is where whole catchment consists of a 0.8 crop factor. Total coverage of 0.8 crop factor values would include grassland, urban or built-up areas as well as bush and shrubbery, and represents the least impact scenario. When the catchment is completely covered by 1.1 and 1.0 crop factor values, the discharge volumes are expected to be critically low. These crop factor values include land uses such as forests, plantations, wetlands and cultivated areas. High discharge volumes can be expected when the catchment is covered by 0.5 and 0.3 crop factor values. Thus high discharge volumes are expected for changes in land use to barren land or water bodies.

Further investigations focused on the climatic data from 1964 since this period coincides with the period for which there is discharge and land use data. The aim of these investigations was to establish the relationships between climate and discharge. A simple correlation test was performed to test the relationship between discharge volumes and climate parameters individually. Naturally, a strong correlation was found between precipitation and discharge volumes supporting the age-old argument that the hydrological cycle is a closed system. A poor negative correlation was found between temperature and discharge volumes. This means that there is no reason to believe that the temperatures would influence the volume of discharge, and if any, it has a inverse influence. Therefore, if in some cases, the temperature would be the cause for the discharge volume observed, it would be that as the temperatures increase, the discharge volumes would decrease. Once again, this is self-explanatory, seeing that higher temperatures cause higher evaporation and less water on the land surface. This seems to contradict the above argument where higher temperatures causes higher precipitation, and therefore there should be higher discharge volumes. This argument is formed from figure 5, where it was found that an increasing trend in precipitation occurred simultaneously with an increasing temperature trend, but it is evidently more complicated. Another argument is where a poor negative correlation was found between precipitation and temperatures. An explanation for this discontinuity in observations can be that the graph established a trend line based on summer precipitation and summer temperatures (January measurements), whereas the Pearson correlation test was performed on the complete distribution which includes every seasons precipitation and temperature values.

When investigating the effect of climate on discharge, it is almost imperative that precipitation would have the largest contribution to the discharge volumes. This is in a large part true, but as seen from the above observations, precipitation is largely influenced by temperature. Therefore there is a close link between the increase of temperatures and an increase in precipitation which then increases the discharge volumes of the rivers. However, when the results of the IPCC scenario based simulations were investigated, a completely opposite result was found. With the increased temperature scenarios, less discharge was simulated for the catchment, which meant that higher evaporation rates resulted in an overall dryer period.

4 CONCLUSION

From the model results it was found that for this particular catchment that land use changes had no significant impact on the discharge volumes. There are several possibilities for this finding, of which the method of land use incorporation into the model is one. Since the crop factor values are used which combines several land use types it may have had an influence on the result. However, if it is considered that crop factor is the value given to the effect that a land use type has on runoff, i.e. what fraction of water will be flowing over that particular use of land and what fraction of water will infiltrate. The use of crop factors to study catchment runoff is also well known and has enabled catchment scale studies where it was necessary to evaluate the use of land on the water runoff into the river.

Apart from the above-mentioned possibility, it could be said that land use in fact does not have any significant influence on the discharge volumes of the Amatikulu-Nyoni catchment. This means that climate has the larger impact on the discharge volumes. Therefore, if climate continues to change, or if temperatures continues to increase, the likely consequence will be seen within the discharge volumes of the Amatikulu-Nyoni river catchment. This will also then impact the amount of freshwater coming from the river, which in turn have marked effects on the estuary freshwater-saltwater balance. Once this balance is disturbed, several ecological processes will have to adapt.

It is necessary to use different methods to determine exactly whether land use did not have such a significant influence on the discharge volumes in order to determine the adaption or mitigation options available for this area. If it is found that land use have a remarkable influence in this catchment it means that another investigation into the degree of influence is necessary as well as which land use type has the largest impact.

Since it is clear that climate has a definite influence on discharge volumes, research can be focused on what combined effect of future precipitation and temperature will have on the catchment.

5 REFERENCES

Aerts, J.C.J.H., Kriek, M., Schepel, M., 1999, STREAM (Spatial Tools for River Basins and Environment and Analysis of Management options): 'Set Up and Requirements'. *Physical and Chemical Earth (B)*, 24, 6, 591-595, Elsevier Ltd.

Begg, G, 1978, Natal Town and Regional Planning Report: *The Estuaries of Natal*, 41.

Bond, J., Green, A.N., Cooper. J.A.G., Humphries, M.S., 2013, Seasonal and episodic variability in the morphodynamics of an ephermal inlet, Zinkwasi Estuary, South Africa, *Journal of Coastal Research*, 65, 446-451, Coastal Education & Research Foundation, Inc.

Bouma, T.J., van Duren, L.A., Temmerman, S., Claverie, T., Blanco-Garcia, A., Ysebaert, T., Herman, P.M.J., 2007, Spatial flow and sedimentation patterns within patches of epibenthic structures: Combining field, flume and modelling experients. *Continental Shelf Research*, 27: 1020-1045.

Cooper. J.A.G., 1993, Sedimentation in a river dominated estuary, *Sedimentology*, 40: 979-1017.

Cooper. J.A.G., 2001, Geomorphological variability among microtidal estuaries from the wave-dominated South African coast, *Geomorphology*, 40: 99-122.

Coulthard, T.J., Macklin, M.G., 2001, How sensitive are river systems to climate land use changes? A model based evaluation. *Journal of Quaternary Science*, 16: 347-351,

Dasseto, A., Hesse, P.P., Maher, K., Fryris, K., Turner, S., 2010, Climatic and vegetation control on sediment dynamics during the last glacial cycle. *Geology*, 38: 395-398

Green, A., Cooper, J.A.G., LeVieux, A., 2013, Unusual barrier/ inlet behaviour associated with active coastal progradation and river-dominated estuaries. *Journal of Coastal Research*, 69, 35-45.

Jansson, M.B., 1988, A global survey of sediment yield, *Geografisika Annaler; Series A; Physical Geography*, 70: 81-98.

Jiang, T., Chen, Y.D., Xu, C., Chen, X., Chen, X., Singh, V.P., 2007, Comparison of hydrological impacts of climate change simulated by six hydrological models in the Dongjiang Basin, South China. *Journal of Hydrology*, 336: 316-333.

Klein, R.J.T., Nicholls, R.J., Ragoonnaden, S., Capobianco, M., Aston, J., Buckley, E.N., 2001, Technological Options for Adaptation to Climate change in Coastal zones. *Journal of Coastal Research*, 17: 531-543.

Schoonees, J.S., 2000, Annual variation in the net longshore sediment transport rate. *Coastal Engineering*, 40, 141-160, Elsevier Ltd.

Sculze, R.E., 2000, Modelling Hydrological Responses to land use and climate change: A Southern African Perspective. *Ambio*, 29: 12-22.

Smith, A.M., Mather, A.A., Bundy, S.C., Cooper, J.A.G., Guastella, L.A., Ramsay, P.J., Theron, A., 2010, Contrasting styles of swell-driven coastal erosion: examples from KwaZulu Natal South Africa. *Geological Magazine.*, 6\147, 6: 940-953.

Thomas, A., Chingombe, W., Ayuk, J., Scheepers, T., 2010, A comprehensive investigation of the Kuils-Eerste River catchments water pollution and development of a catchment sustainability plan. *Water Research Commission*, n.a., n.a.

van Rompaey, A., Bazzofi, P., Jones, R.J.A., Montanarella, L., 2005, Modelling sediment yields in Italian catchments. *Geomorphology*, 65: 157-169.

Vandenberghe, J., 2003, Climate forcing of fluvial system development: an evolution of ideas, *Quaternary Science Reviews*, 22, 2053-2060, Elsevier Ltd.

Verstraeten, G., Lang, A., Houben, P., 2009, Human impact on sediment dynamics - quantification and timing, *Catena*, 77: 77-80.

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Geomorphic changes at the Tugela River mouth: a time series analysis

Henning Blignaut

Department of Geography, Geoinformatics and Meteorology, University of Pretoria

Abstract: The Tugela River mouth is situated approximately 100km north of Durban on the wave-dominated east coast of South. This highly dynamic river-dominated estuary constantly undergoes geomorphic changes as a result of various factors which include the effects of flood events, overall rainfall variability (which leads to discharge variation), fluvial and marine sediment transport and deposition, as well as wave action. In this study, the historical changes that the river mouth has undergone are examined by using satellite images and aerial photos dating from 1953. Episodic events such as floods and times of low/high rainfall in the Tugela catchment had a large impact on the amount of sediment flowing out of the mouth, in turn influencing the amount of erosion or accretion of sediment at the mouth. The mouth peninsula, as well as the beaches to the south and particularly to the north, have been under constant influence by the erosion and deposition of sediment enhanced through the oceanic process of longshore drift. After significant floods (notably in 1984 and 1987), sand barriers of the mouth were eroded, after which shoreline progradation took place after a few years as a result of sediment deposition. In recent years, however, erosion has removed much of the beach to the north of the mouth as sediment is transported along the coast via longshore drift.

1 INTRODUCTION

The Tugela River has the largest drainage basin of all rivers in KwaZulu-Natal and has its origin in the Drakensberg. Large amounts of sediment (5,1 to 6,3 × 106 m^3 /year) have been found to flow into the ocean at the mouth, also having other environmental impacts, such as increased yield in the fishing industry at the Tugela shelf (Lichter and Klein, 2011; Turpie and Lamberth, 2010; Olivier and Garland, 2003). These sediments also supply sand to most of the beaches of northern KwaZulu-Natal (Day, 1981). This, in particular, is seen at the Amatikulu/Nyoni river mouth (20 km north of the Tugela River mouth along the coast) and provides evidence of the very dynamic eastern coastline.

Olivier and Garland (2003) found floods and sediment supplied by the river to be crucial factors in accretion and formation of dunes on the beach to the north of the mouth. Anthropogenic impacts on the discharge of the river are also crucial to consider; many dams have been constructed along the Tugela and its tributaries within the study period, leading to a decrease in discharge.

The effects of sediment deposition (from coastal and terrestrial origins) and floods are expected to be the main factors to influence the Tugela mouth's morphology. In this study, the geomorphic changes to the Tugela river mouth over the past 60 years are examined by analysing remotely sensed images (aerial photographs and satellite images) and by the study of rainfall, flood and discharge data.

2 STUDY AREA AND METHODS

The Tugela River mouth is located on the east coast of South Africa, approximately 100km north of Durban (29°13.5' S; 31°30' E). The mouth forms the starting point of the 'Zululand coast' that stretches north up to the Mozambique border and consists of long barrier beaches and sand dunes up to 180m high (Begg, 1978; Orme, 1980) (Figure 1).

Figure 1: Satellite image of the Tugela river mouth in 2015.

Average annual rainfall measured at Mandini (1987 - 2014), 20km north-west of the mouth, is 852 mm. Seasonal and annual temperature ranges are small on the subtropical eastern seaboard, causing the annual temperature range for the water in estuaries to range from 19 to 28°C (Perissinotto et al. 2002). The Tugela River mouth has an annual average air temperature of 23°C (Olivier and Garland, 2003).

A large portion of the east coast of South Africa where the Tugela river mouth is situated, is classified as 'moist savanna and bushveld with subtropical forest patches (Cowling et al., 2004). Situated around the estuary is the Hlogwane dune forest, which is a remnant of the indigenous coastal forest. Distinctive tree species observed include *Mimusops caffra, Euclea natalensis* and *Psydrax obovata* and a prominent dune plant observed at the mouth is *Scaevola scunbergii* (Olivier and Garland, 2003).

The main land use in the area surrounding the Tugela River mouth area include many sugarcane plantations. A small coastal town, Tugela Mouth, is situated just north of the estuary and is surrounded by rural settlements. In terms of geology, sediments from the Natal group, intruded by dolerite dykes and sills and capped by basalt, dominate the geology of the catchment (Garland and Broderick, 1992). Variation in catchment geology which also includes Beaufort and Ecca sediments, large tracts of highly erodible duplex soils and land uses including cattle game ranching with high stocking rates, contribute to higher levels of erosion in the catchment and therefore posing the opportunity for sediment to be easily transported by the Tugela River (Olivier and Garland, 2003).

A 60-year time series of remotely sensed data consisting of aerial photographs and satellite images was used to plot features at the Tugela mouth region. Scanned aerial photographs were acquired from the South African Geospatial Institute for the years 1953, 1964, 1972, 1983, 1989 and 2000. Satellite images were acquired from USGS (United States Geological Survey) for 1989, 1991, 1999 and 2002. The rest of the images (2006 – 2015) were obtained from Google Earth. The scanned aerial photographs and satellite images were imported into the Geographic Information System (GIS). ArcMap 10.3, ESRI's newest version of ArcGIS, was used. All the satellite images and aerial photographs were georeferenced in ArcMap 10.3 in order to ensure the correct representation of images, after which specific features were digitized. Digitized features include the river outline, sand bar positions at the mouth's peninsula and positions of the beaches to the north and south of the mouth.

Discharge data was downloaded from the Department of Hydrology website. Monthly discharges (million m^3/month) of the Tugela River at Mandini, 20km north of the mouth, was obtained and included data from 1959 to 2015 . Rainfall data was obtained from the South African Weather Service in Pretoria for five different stations: Amatikulu, Stanger, Eshowe, Mandini and Ladysmith. Because of the fact that rainfall stations of Amatikulu, Stanger, Eshowe and Mandini were commissioned and decommissioned at certain periods, all four were needed (although they are closely situated to one another) to fill in the gaps. Ladysmith, being situated in the upper reaches of the Tugela's catchment, was added to the analysis to give a better representation of the overall rainfall of the catchment. Significant floods and events in KZN include those in 1984, 1987 and March 2008 (see also Blignault, 2015).

3 FINDINGS

Discharge data (with some missing years) are available for Mandini (Figure 2). This is combined with rainfall data (see Blignaut, 2015). Notably high discharges and floods occurred in 1965/67, 1973/4, 1977/78, 1984, 1987, 1999/2000. A storm surge in 2007 caused severe erosion along the KZN coast. The time series of change at the mouth from 1953 to 2015 is presented below in Figures 3-5.

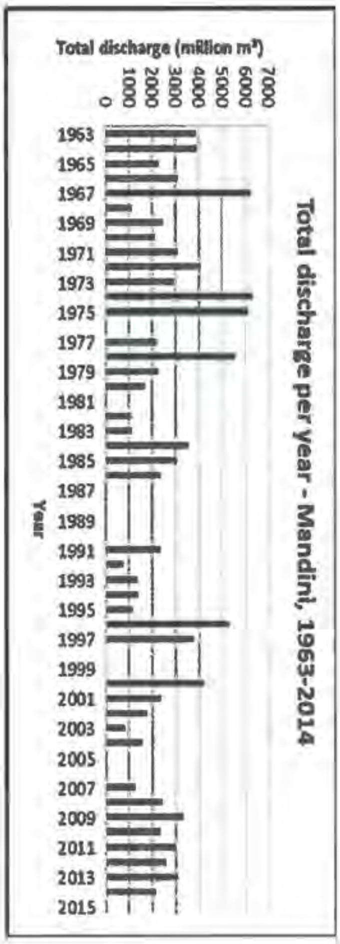


Figure 2: Annual river discharge at Mandini station (1987 – 2014).

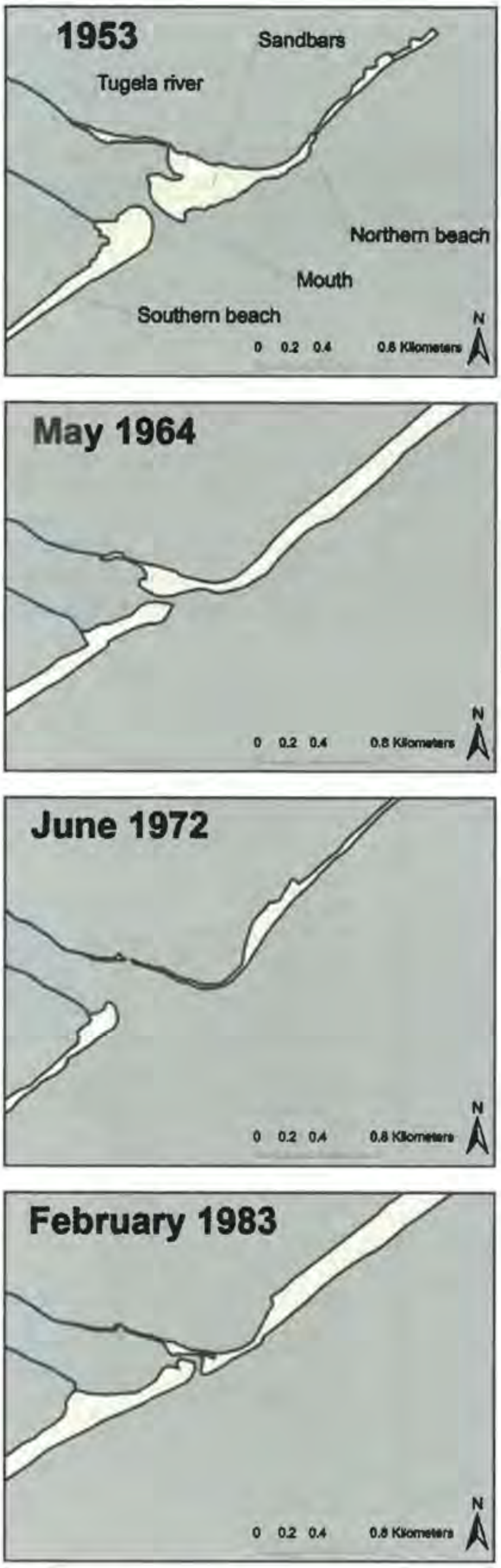


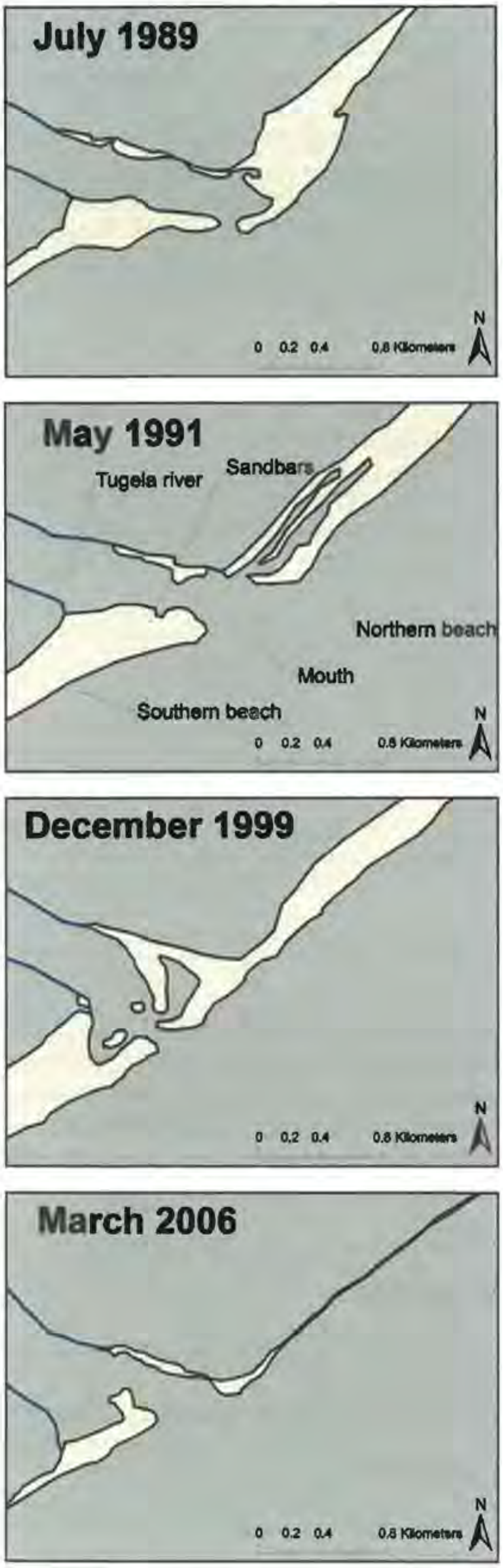
Figure 3: A time series of the mouth, sandbar and beaches at the Tugela estuary from 1953 to 1983, where:

1953 – The sandbars on the mouth cover a large area and there is a small, central opening present. The season the aerial photograph was taken is unknown. No significant floods have been recorded to have taken place prior to or in 1953. The northern and southern beaches appear narrow.

May 1964 – Significant changes in morphology was observed. The mouth is open at the northern bank of the mouth. As it is in the dry season, the barrier sand bar is, as expected, larger because of lower discharge and increased fluvial sediment deposition. Floods occurred in May 1959 and January 1963, causing the sand bars to have been eroded from its previous condition (1953). An increase in the sizes of the northern and southern beaches is observed.

June 1972 – A decrease in the size of the sand bar at the mouth is observed. The sand bar is confined to the southern part of the mouth and a large opening is observed. As it is dry season, it is not expected to see the sand bar to be so small in size. A large discharge of 1400 million m^3 was recorded in Mandini during March 1972 and floods occurred in January to March 1966. The width of the northern and southern beaches decreased significantly.

February 1983 – The sand bar at the mouth significantly increased in size, leaving only a small opening in the northern part of the mouth. The large size of the sand bar is unexpected to see during rainy season. Low discharges and rainfall values are recorded for January 1983 and floods occurred in October 1977. The northern and southern beaches have increased in width.



July 1989 - The sand bars at the mouth have dramatically increased in size. Progradation of the sand bars occurred, extending 200 – 300 m into the ocean. Hurricanes Demoina and Imbuia caused heavy floods in 1984 and a catastrophic flood occurred on the east coast of South Africa in September 1987. The sizes of the northern and southern beaches have increased substantially.

May 1991 – Significant changes are seen from 1989. The southern sand bar has increased in size and retreated landward slightly. The northern part has formed an outlet with a central sand bar. This image was taken in the dry season and the effects of the 1987 floods are still seen. The northern and southern beaches have increased in width.

December 1999 – The sand bars at the mouth formed new positions and the northern and southern sand bars on the mouth have been changed completely, forming an outlet at the northern part of the mouth. This image was taken during wet season. Floods occurred in January 1996 and October 1999. The northern beach has slightly decreased in width and the northern beach significantly increased in width.

March 2006 – On the northern part of the mouth, sandbars were significantly eroded away and on the southern side, the addition of an elongated sandbar with separate inlet is observed. Beaches have decreased in width. The mouth is still at the northern part of the mouth, with a sand barrier extending from the southern part of the mouth towards past the centre of the mouth. The northern and southern beaches have dramatically decreased in width.

Figure 4: A time series of the mouth, sandbar and beaches at the Tugela estuary from 1989 to 2006, where:

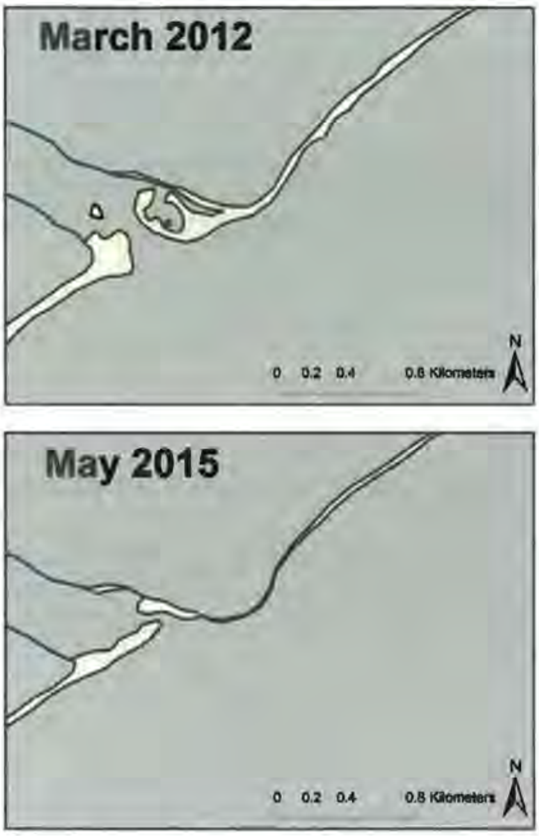


Figure 4: A time series of the mouth, sandbar and beaches at the Tugela estuary for 2012 and 2015

March 2012 – Dramatic changes are seen in the river mouth. The sand bar on the southern part of the mouth increased in width, but decreased in length (almost forming a cubic structure), while the northern part of the mouth formed a complex structure (almost of circular form) with a main outlet. A relatively dry rainy season was observed in the Tugela catchment in the 2011/2012. The width of the northern and southern beaches has increased slightly, particularly towards the north. A storm surge in 2007 also caused erosion along the coast.

May 2015 –The sand bar on the southern part of the mouth has elongated northward and the mouth position is again on the northern side. The sandbanks on the north of the mouth have disappeared. The extent of sand to the north of the mouth replicates the 1972 record.

4 CONCLUSION

The Tugela River mouth is a highly dynamic river-dominated estuary influenced by factors from land and sea. The observation and analysis of satellite images and aerial photographs from 1953 to 2015 showed clear geomorphic changes at the river mouth. Many factors caused changes at the sand bars of the river mouth, as well as the beaches to the north and south of the mouth. The fluvial sediment of the river directly supplies sediment for the beaches and the mouth's sand barrier (Olivier and Garland, 2003). At the mouth peninsula, the main factors that caused geomorphic changes were sediment deposition (from fluvial and marine origin), as well as the effect of floods, which also caused an increased amount of sand bar erosion and fluvial sediment deposition through oceanic processes such as longshore drift and wave action. Beaches to the north and south of the mouth were directly influenced by increased amounts of fluvial sediment caused by floods and periods of high rainfall and discharge. The impacts of increased/decreased discharge were seen, especially in episodic events such as floods.

Through this study the impact of rainfall variation on coastal geomorphic features are also seen. With increased channeling of water from the Tugela River for human use and increased rainfall variability due to climate change, geomorphic change at the estuary is likely to become more unpredictable in future.

5 REFERENCES

Begg, G.W., 1978. The Estuaries of Natal. Natal Town and Regional Planning Report, 41.

Blignaut, H. (2015) Geomorphic changes at the Tugela River mouth: a time series analysis. Unpublished honours project, University of Pretoria.

Cowling, R. M., Richardson, D. M. and Pierce, S. M., 2004. *Vegetation of Southern Africa*. Cambridge University Press.

Dartmouth, 2003. 2001 Global Register of Extreme Flood Events. http://www.dartmouth.edu/~floods/Archives /2001sum.htm

Dartmouth, 2006. 1996 Global Register of Major Flood Events http://www.dartmouth.edu/~floods/Archives /1996sum.htm

Day, J. H., 1981. *Estuarine ecology with particular reference to Southern Africa*. Balkema, Rotterdam, 390pp.

Garland, G., and Broderick, D., 1992. Changes in the extent of erosion in the Tugela catchment, 1944–1981. *South African Geographical Journal* 74(2): 45-48.

Lichter, M. and Klein, M., 2011. The effect of river floods on the morphology of small river mouths in the southeastern Mediterranean. *Zeitschrift für Geomorphologie* 55(3): 317-340.

Olivier, M. and Garland, G.G. (2003). Short-term monitoring of foredune formation on the east coast of South Africa. *Earth Surface Processes and Landforms* 28: 1143–1155.

Orme, A.R., 1980. Barrier and lagoon systems along the Zulu land coast, South Africa. *Coastal Geomorphology*, George Allen & Unwin Ltd., London.

Perissinotto, R., Nozais, C. and Kibirige, I., 2002. Spatio-temporal dynamics of Phytoplankton and Microphytobenthos in a South African temporarily-open system. *Estuarine, Coastal and Shelf Science* 55: 47-58.

Turpie, J.K. and Lamberth, S.J., 2010. Characteristics and value of the Thukela Banks crustacean and linefish fisheries, and the potential impacts of changes in river flow. *African Journal of Marine Science* 32(3): 613-624.

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Runoff modelling and land-use change in the Siyaya River catchment

Mivan Howard

Department of Geography, Geoinformatics and Meteorology, University of Pretoria

Abstract: A runoff modelling study was conducted on the Siyaya River catchment located immediately south of the town of Mtunzini in northern Kwa-Zulu Natal. An assessment of the trends in land-use change, rainfall and runoff was undertaken with the use of aerial photography, satellite imagery and the WRSM/Pitman Model for simulation of water movement. Findings indicate that between 1940 and 2015, extensive land-use change has occurred and the runoff regime has been significantly altered. Indigenous forest was converted to sugar cane in 1946, sugarcane was later converted to eucalyptus plantations in 1990. Residential development extended into the catchment in the northern fringe in the 1990's and mining activities have been underway since early 2000's despite strong opposition from community and conservation societies. The natural state of the catchment and river is severely compromised and transformed by agricultural, mining and residential land-use activities. Modelling indicates that land-use change has significantly altered the runoff regime in the catchment. Removal of natural vegetation and wetlands has led to excessive runoff, erosion and siltation in the catchment and river.

1 INTRODUCTION

The complex, dynamic nature of estuarine systems is maintained by a sensitive interplay of physical and biological factors. Consideration of human influence is also essential during research. In the early 1900's the Siyaya River was a benchmark for naturally pristine coastal catchments. By the 1940's, land use in the catchment began to change drastically and rapidly and land use has changed extensively over the last 75 years.

Before 1940, the entire catchment was indigenous coastal forest. In 1946, land use shifted to sugar cane and farmers applied primitive ploughing practices. Sugar cane cultivation continued and by 1978 the entire Siyaya catchment was used for the cultivation of cane but the lagoon was surrounded by undisturbed indigenous forests. Between the years 1940 and 2015 the Siyaya River catchment experienced significant change in type and thus extent of land-use. This research focused specifically on rainfall and runoff in relation to land-use change. The data required for this study was in the form of previous research conducted in the catchment, historical aerial photographs, satellite images, rainfall data, land-use data and runoff values modelled and simulated by the WRSM/Pitman Model.

A series of significant land-use changes was traced between 1940 and 2015. The baseline of 1940 was selected due to the land-use of the catchment being indigenous forest at that time. The aim of the study was to model runoff and track land-use change in the Siyaya River catchment between 1940 and 2015. The intention of the research was to investigate trends of changing land-use and changing runoff in relation to each other. Specific research activities were to determine the type and extent of land-use in the catchment, to simulate water movement through the Siyaya River catchment using the WRSM/Pitman Model and to report on trends in land-use and runoff. Objectives were undertaken on a time step of 10 years as defined by available information and years when significant land-use changes occurred.

2 LOCATION AND STUDY AREA

The Siyaya River catchment is situated at 28° 58' S and 31° 45' 45" E in the northern region of Kwa-Zulu Natal, on the east coast of South Africa, immediately south of the coastal town of Mtunzini. The relief of the area is low lying coastal hills with the heights between 100m and 300m above sea level. The Siyaya River flows through valleys formed by low coastal dunes and the gradient of the hills is gradual with few steeper sections. Bedrock in the catchment is comprised of shales and sandstones of the Vryheid Formation containing intrusions of Karoo dolerite. The Berea Formation forms red sands in the upper parts of the catchment (Mackay, 1996).

Figure 1: The study area; Siyaya River catchment in 2015.

Land use in the study area currently includes sugar cane, eucalyptus plantations, residential development, mining and small remnants of indigenous forest along the stream and in designated conservation areas. At the time of the study, the mouth of the Siyai River was closed to the sea (Figure 2).

Figure 2: Siyaya Estuary River bed, February 2016 (closed to sea).

3 METHODS

The WRSM/Pitman Model has been applied extensively throughout Africa. Hughes (1995), for example, assessed the Pitman model when used in dry catchments but noted that the calibration struggled in relatively dry catchments. The model is utilized in this study

3.1 LAND USE

To allow understanding of land-use, visual observation of the catchment was undertaken. This continued with photography and assessment of historical aerial photography and satellite images. Literature on the catchment provided land-use types and extent (physical area between 1940 and 1977).

Further assessment of historical aerial photographs and satellite images (1977-2015) was conducted. These images were visually assessed and analysed in ArcGIS software to determine the land use area for different periods. Each historical aerial photograph was imported into GIS and the area measurement function was applied to each land-use. This provided physical area measurements for each land-use type on a 10-year time step.

3.2 RAINFALL

The South African Weather Services (SAWS) provided monthly rainfall data for the years 1975 – 2015. Rainfall averages for the Mtunzini area were recorded by private sources between 1940 and 2015. Private measurements were recorded by locals and individuals and reported in research from 1926 onwards.

3.3 RUNOFF

Using inputs of rainfall and physical area covered by land-use types, the Pitman model was able to simulate total surface runoff for several different land-use periods in the catchment. This mathematical model was used to simulate the movement of water through an interlinked system of routes and modules. A river is represented as a linear entity to which routes and modules can be added.

To begin simulating water movement, a diagram of the river system must be drawn. The catchment was manually drawn for each of study years, with different land-use areas linked by river sections at each time step. A new network was then created in the program and the 'start simulation' and 'end simulation' years were input. Routes and modules that water flowed through were input, this used different land-use areas as data. Rainfall data was input as 'rainfiles' that allowed incorporation of yearly rainfall into the program. Once land-use modules and rainfall data was input, the simulation could be run and that generated a total catchment runoff value for each desired year.

4. RESULTS

1940 – 1950
In 1940, the entire catchment was undisturbed indigenous coastal forest (Garland, 1982). By 1946 sugarcane farmers began clearing and ploughing land (Oceanographic Research Institute, 1991).

1950 – 1960
By 1950, siltation of some river sections had occurred. The catchment was still described as 'pristine' and 'undisturbed' (Siyaya Project Newsletter, 1981). Wetland clearing led to severe siltation (Garland, 1955). Sugarcane farming expanded.

1960 – 1970
Problems associated with sugarcane farming intensified. Siltation, excessive runoff, swamp destruction, encroachment of commercial and invasive plants and water pollution by agricultural chemicals (Begg, 1978).

1970 – 1980
By 1977, the Siyaya River mouth had migrated or moved about 740m north-eastward along the coast (Weisser, 1982). This was attributed in part to dune advancement. Sugarcane cultivation continued to expand throughout the catchment.

1980 – 1990
Sugarcane cultivation expanded to cover the majority of the catchment (Benfield, 1984). Removal of vegetation, drainage of wetlands and material mass movements contributed to degradation of the catchment (Mackay, 1996).

1990 – 2000
Significant residential development took place in the catchment (Mackay, 1996). In 1990 Mondi South Africa acquired more than 60% of the catchment, Mtunzini Sands mining company owned more than 15%, the rest was owned by the Parks Board or private owners (Mackay, 1996). Indigenous forest was replanted in conservation areas. Sugarcane and timber plantations covered the majority of land.

2000 – 2010
Sugarcane land-use area decreased as Mondi expanded timber productions. Heavy mineral mining operated from 2001 to 2012 (Exxaro, 2013)

2010 – 2015
Sugarcane and timber production continued to dominated land-use in the catchment. Heavy mineral mine closed in 2012, intensive exploration for a mixed mineral mine was undertaken. New mining operations broke ground in 2013.

The historical land-use progression in the Siyaya River catchment was rapid and fascinating. The catchment is a physically small geographic area that was initially entirely covered in indigenous forest (1940). Between 1940 and 1950 the catchment was described as an undisturbed coastal paradise with large expanses of natural coastal vegetation and deep, clear streams. Even until 1960, the area surrounding the Siyaya River was renowned as being naturally stable and intact. In 1946 sugarcane farming broke ground in the catchment. Prior to this, the modelled runoff data indicates a naturalised runoff regime. The majority of rainfall was infiltrating into the ground material ut runoff as a percentage of rainfall has increased over time (Figure 3). It is proposed here that indigenous leaf litter and plant material collected on the soil in the catchment and that this coupled with root systems of natural coastal vegetation retained rainfall, prevented runoff and increased infiltration. This would have dispersed rainfall and reduced erosion (Li, 2006).

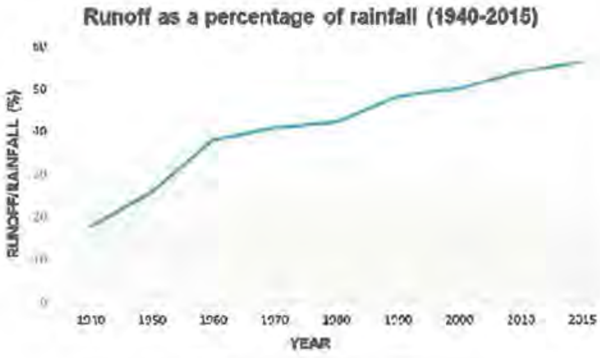

Figure 3: Graph of Runoff as a percentage of Rainfall (1940-2015).

5. CONCLUSION

The type and extent of land-use in the Siyaya River catchment has changed considerably between 1940 and 2015. During this period, an increasingly greater percentage of rainfall was converted to runoff and infiltration of rainfall was greatly and progressively reduced. Trends in land-use of the Siyaya River catchment show an increasingly anthropogenic influence on the area between 1940 and 2015.

Increasing human activities are mirrored by increasing runoff values. Sugarcane cultivation between 1946 and 1990 had significant and severe consequences for the state of the catchment. Timber plantations and conservation efforts increased infiltration and slowed runoff between 1990 and 2010. Management practices and environmental consideration on the part of Mondi Timber allowed the re-establishment of indigenous forest areas.

Findings are concurrent with local and international literature and research but a full study of the catchment is proposed. Research conducted in China and Europe supports the concept that anthropogenic activity significantly alters runoff regime. Further study in southern Africa confirms the link between land-use variability and runoff variability.

The anthropogenic influences investigated in the study are not necessarily directly linked to alterations in runoff regime and the results are due to a possible combination of activities over a period of time. As the land-use in the catchment became more anthropogenically influenced, runoff increased and infiltration decreased. The catchment has been in a severely compromised state for many decades.

5. REFERENCES

Attignon S E, Weibel D, Lachat T, Sinsin B, Nagel P, Peveling R, 2004. Leaf litter breakdown in natural and plantation forests of the Lama forest reserve in Benin. *Applied Soil Ecology* 27: 109–124.

Begg G, 1978. The estuaries of Natal. *Natal Town and Regional Planning Report* 41.

Dunne T, Zhang W, Aubry B F, 1991. Effects of Rainfall, Vegetation, and Microtopography on Infiltration and Runoff. *Water Resources Research Journal* 27: 2271–2285.

Exxaro Resources Limited. An independent report on the mining assets of Exxaro Resources Limited 2010. (Accessed October 2016) http://www.exxaro.com/pdf/icpr/a/mining_assets/heavy_minerals.htm.

Heydorn A E F, 1986. Assessment of the state of the estuaries of the Cape and Natal in 1985/86. *South African National Scientific Programmes Report* 130.

Hughes D A, 1995. Monthly rainfall-runoff models applied to arid and semiarid catchments for water resource estimation purposes. *Hydrological Sciences Journal* 40: 751-769.

Kosmas C, Danalatos N, Cammeraat L H, Chabart M, Diamantopoulos J, Farand R, Gutierrez L, Jacob A, Marques H, Martinez-Fernandez J, Mizara A, Moustakas N, Nicolau J M, Oliveros C, Pinna G, Puddu R, Puigdefabregas J, Roxo M, Simao A, Stamou G, Tomasi N, 1997. The effect of land use on runoff and soil erosion rates under Mediterranean conditions. *Catena* 29: 45-59.

Le Maitre D C, Versfeld D B, Chapman R A, 2000. The impact of invading alien plants on surface water resources in South Africa: A preliminary assessment, CSIR Division of Water, Environment and Forestry Technology.

Li Y Y, Shao M A, 2006. Change of soil physical properties under long-term natural vegetation restoration in the Loess Plateau of China. *Journal of Arid Environments* 64: 77–96.

Lørup J K, Refsgaard J C, Mazvimavi D, 1997. Assessing the effect of land use change on catchment runoff by combined use of statistical tests and hydrological modelling: Case studies from Zimbabwe. *Journal of Hydrology* 205: 147–163.

Mackay C F, 1996. The Benthos of the Siyaya Estuary: Species Composition, Density and Distribution, Department of Zoology at the University of Zululand.

Ndiritu J, 2009. A comparison of automatic and manual calibration using the Pitman model. *Physics and Chemistry of the Earth* 34: 729–740.

Sarukkalige P R, 2011. Characteristics of Stormwater Runoff in Different Land Use Areas, International Conference on Environmental Science and Development.

Shi P J, Yuan Y, Chen, 2007. The effect of land use on runoff in Shenzhen City of China. *Acta Ecologica Sinica* 21:1041-1049

Weisser P J, Parsons R J, 1981. Monitoring Phragmites australis increases from 1937 to 1976 in the Siyai Lagoon (Natal, South Africa) by means of air photo interpretation. *Bothalia* 13: 553 – 556.

Weisser P J, Garland I F, Drews B K, 1982. Dune advancement 1937—1977 at the Mlalazi Nature Reserve, Mtunzini, Natal, South Africa, and a preliminary vegetation-succession chronology. *Bothalia* 14: 127-130.

Dune dymamics and sand movement at the Thukela River mouth, Matigulu-Nyoni estuary and the Umlalazi estuary

Jozua Esterhuizen
Department of Geography, Geoinformatics and Meteorology, University of Pretoria

Abstract: This study investigates the migration or movement of the northern Kwa Zulu Natal coastal sand dunes over the past seventy two years. The area under investigation includes the Thukela river mouth, Amatikulu-Nyoni estuary and the Umlalazi estuary that are situated 100 and 130km north of Durban. The objectives of the study is to do observation on the movement of the relevant dunes and associated coastline over a time period of 70 years to analyze and make the correct decisions and assessing the changes of the impact and the effect on the community and infra structures. Preliminary results are presented that contain survey data of the dynamics of the shoreline and associated dunes on the coast.

1 INTRODUCTION

Most of the catchment areas in KwaZulu-Natal (KZN) have high discharges and the river-dominated outlets are classifies as estuaries (see Cooper, 2001). The whole coastline of South Africa is also subjected to high, breaking waves on the beaches (littoral), tides, cliffs and shores, wind (aeolian) as well as river discharge (Tinley, 1985; Elkington, 2012). When sand dunes encroach the human environment it is important to know what cause the changes and what the relations are between the human and natural driving forces, and the importance of these driving forces such as waves, wind, rise in sea level, climate change and the greenhouse effect: these are very important shaping instruments of a coastline (Palmer et al., 2011).

Two elements that have a direct influence on the sand movement are waves and wind. The size of waves is determined by the littoral effect of the speed it drags over the surface of the sea. The Agulhas current follows the outer edge of the continental shelf just off the South African coastline (Bosman et al., 2007). Palmer (2011) and Bosman (2007) note that the water temperature in the Agulhas is about six degrees warmer than the sea water surrounded the current. It happens often that the wind gathers energy from the warmer ocean and forms tropical storms in the Mozambique Channel, moving in a south eastern direction towards the KZN coast.

2 STUDY AREA

The study area is from the Thukela (Tugela) River northwards, including the Amatigulu River estuary (29° 06' 44.25" S; 31° 36' 52.23" E) and the Umlalazi river estuary (28° 56' 41.13" S; 31° 48' 56.63" E) on the KZN north coast. These three sites or terrains have been identified for monitoring the shoreline and dune movement. The most southern site of the Thukela River is situated approximately one hundred kilometers from the city of Durban and the most northern site, the Umlalazi is approximately 40 kilometers south of Richards Bay.

The Thukela Catchment:

This is the largest catchment area with the biggest river in the KZN province with his origin in the Drakensberg at a height of 3100m above sea level (Olivier and Garland, 2003).

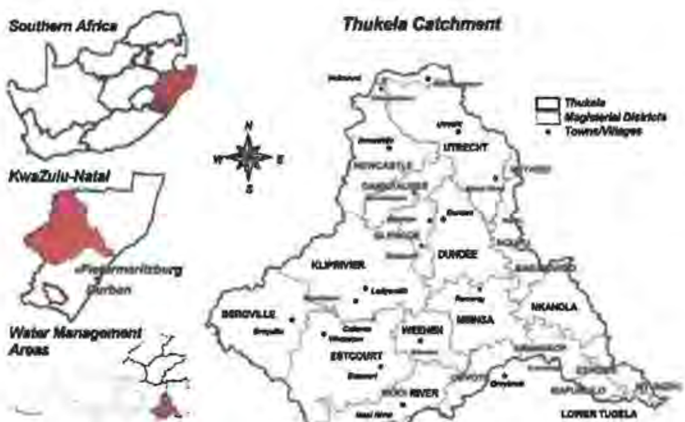

Figure 1: The catchment of the Thukela River (after Schulze et al., 2005).

The profile of the Thukela falls very steeply from 3100m for about 900m to a middle course and flattens out in a lower course about 200km from the coast and meandering through the landscape until it reaches the coast. The sandbank at the Thukela varies from season to season and it consists of loose sand (Engelbrecht, 2008) and the mouth is almost always open to the sea.

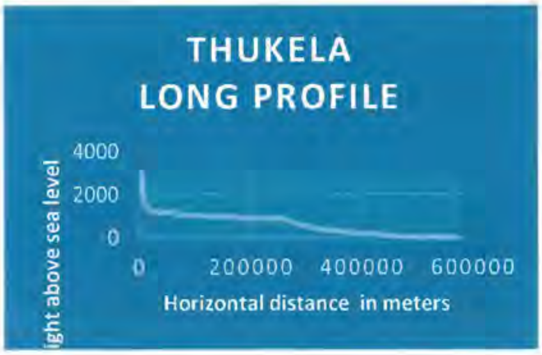

Figure 2: The long profile of the Thukela River

The Amatigulu (Matigulu) estuary:

Amatigulu- Nyoni River estuary is situated north of the Tugela, in a protected area of the Ezemvelo KwaZulu-Natal Wildlife. It is a river dominated estuary that is periodically closed as a consequence of the low river flow (Green et al., 2012). On the Figures below it is clear that the Matigulu barrier is more unstable and less vegetated than the Nyoni barrier. Engelbrecht (2008) also argued that it is because of the "constant migration" of the mouth that makes the sand more unstable for vegetation to establish on the dune.

The estuary is classified as subtropical, open barred and medium to a large (Whitfield, 2000). The Matigulu also has sand influx on the coast during the flood season (Engelbrecht, 2008). The Matigulu/Nyoni catchment is eighty four to hundred and eight kilometers in length and has a drainage system of about 900km^2 (Begg, 1978) (Figures 3, 4).

During flood and rainy seasons the mouth opens up for the sea to enter where the barrier is on its weakest and lowest in height. The estuary at the Amatigulu where the mouth is temporarily closed is subjected to marine influence such as salt water from the sea and, fresh water from the river and sediment (Leopold, 1953).

The very long sand barrier is approximately 6 kilometers stretching south-east to north-west. It consists of sand supplied by the Thukela River that is twenty kilometers southward. The southern part of the sand barrier is stabilized with Casuarina vegetation.

Figure 3: The Amatigulu estuary in 1983

Figure 4: The Amatigulu estuary in 2013

The Umlalazi Estuary:

The Umlalazi has a steep profile in the upper regions and a length of approximately forty to sixty kilometers. Floods have occurred in this river where the levels risen to about five meters above sea level (Begg, 1978).

The estuary is hidden behind a 3.5 kilometer sandbar. Next to the beach runs a shore current at 250° north that transports materials from the Thukela to the sandbar where the waves attack the sandbar at an angle of about 90° (Begg, 1978).

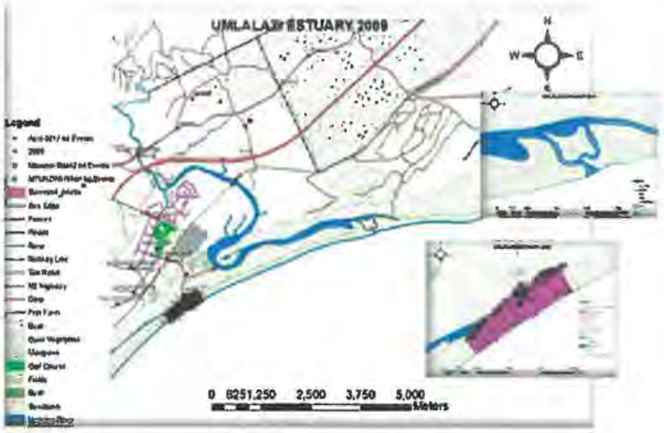

Figure 5: The Umlalazi estuary in 2009.

3 METHODS

A 2009 satellite photo was geo-referenced in a map format and used as the base photo for determining the quick assessment in dune changes. For the research on the three relevant sites, aerial photographs were also used in the form of digital copies, provided from the Chief Directorate: Surveys and Mapping. Physical surveys and fieldwork has been done to compare the dune and sand movement over the specific time period of the survey. In this research the study is from 1953 and 1957 to the present at 2016.

In normal circumstances the land surveyor determine beforehand the flight plan and the placing of the pre-ground control points or also called pre-marks. Most of the time the three dimensionally determining of the pre-marks have been taken place before, during and after the aerial photo flight. In the case of this research study, it is the contrary. Only after receiving the photos from the Survey and Mapping office the control points could be selected on the photo and identified on the ground.

Control points were identified from the oldest aerial photography. For the Thukela and the Amatigulu sites the 1953 photos were used and for the Umlalazi site the 1957 aerial photos. Landmarks were identified on the photos that are still exist during the time of the research; like train bridges, road and street intersections, definite spots on the photo that could be identified on the ground. These points are then determined independent three dimensionally (in Y X Z format) to the nearest 0.005 meters. (half centimeter accuracy).

In this study different methods are used to determine the above mentioned parameters. These coordinates could be obtained by using different surveying methods – the conservative total station and prism method and or the GPS method. Each of these two methods have their own merits on when using the one and or the other. Through inspection of the terrain in the beginning of October 2015 it was found to be best to use both methods but mainly working with the GPS and with the total station as a standby instrument. The reason for this argument is that trigonometrically beacons in these areas are very scarce, or unsafe to visit and some of them are severely damaged and disturbed. However, the open dunes were surveyed with the GPS.

Figure 6: GPS on trig Red Hill on the north shore of the Thukela River.

At the Thukela River the control points for the dune movement were based on 2 trig beacons, Aloes II on the southern side of the river and Red Hill north of the river. With the surveying of the ground control points on the northern and southern shores the two trig beacons were connected to each other to compare the accuracy.

At the Amatigulu estuary only a RTK GPS was used to find the correct control points on the 1953 photo recently on the ground. A survey was also done to determine the position of the barrier as it is recent. The survey was closed at the Baton Rouge trig beacon in the northern part of the Amatigulu terrain.

At the Umlalazi estuary a physical survey took place on a predefined terrain of about 700m x 250m during March and October 2016 and April 2017. With the March survey a Nikon DTM 522 total station with an accuracy of 3" was used. During the October 2016 and April 2017 the points were taken with a Carlson GPS. In Figure 6 the area is shown where the survey points were taken. The data is manipulated by Model Maker Version 12.01 to calculate the relevant area and volumes of each survey time.

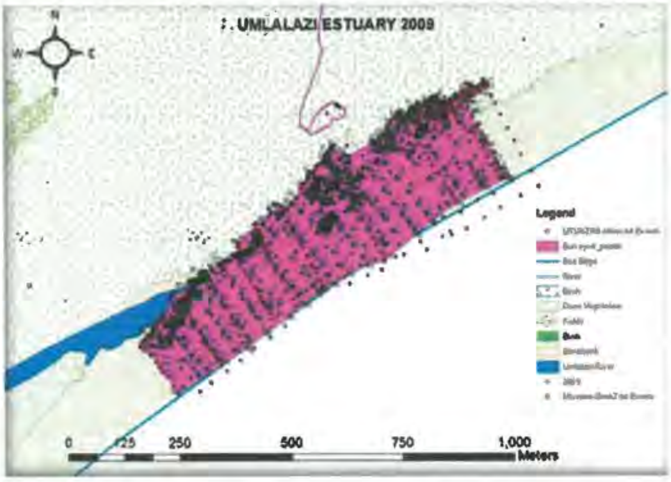

Figure 6: Points take during March, October 2016 and April 2017.

4 PRELIMINARY RESULTS

Several method were used to determine dune movement. Observation from and comparing of old photography with very recent photography and the survey data. During the geo-referencing of the 1957 aerial photograph all the control points and as well as the assessment points that were surveyed on the beach were plotted on the aerial photo of 1957, as seen on Figure 7.

Figure 7: In this rectified photo the polygon of surveyed points is in the south eastern corner.

Different time period photos from 1972 up to 2013 were used to determine if there was bush encroachment towards the beach and sand encroaching in the direction of the forest. Only the one photo, 685_0C1_03096 could be used because the 685_0C1_03097 in the Umlalazi flight series and it does not cover the terrain properly and it is of poor quality. Factors cause the sand to increase as in Figure 8 is the wind drift of a constant blow from the south western side that is approximately at 220⁰ to 230⁰ according to the South African coordinate system. At the bight in the coastline the degrees turn approximately to 250⁰ to 260⁰. The assumption could be made that two main factors for sand movement at the Umlalazi beach, the one factor might be natural cause by aeolian processes and the other one a human disturbance factor.

As stated above, wind is blowing against a direction of approximately 220⁰. Human disturbance could be responsible for loosening the sand and make it easier for the wind to blow the sand in a certain direction. It is noticeable that "sand flames" occur predominantly in the area between 31⁰45'26.29 E; 28⁰58'14.52 S; and 31⁰47'51.68 E; 28⁰57'03.80 S. It is also noticeable that the main axis of all these flames are mostly parallel to each other against an approximate 220⁰. The assumption of the result of the phenomenon is that the sand is moving faster in a northern direction and is encroaching the forest since 2009 up to when the survey took place in 2017 (eight years) with an average of seventy meter, more or less ten meters per year as seen in Figure 8.

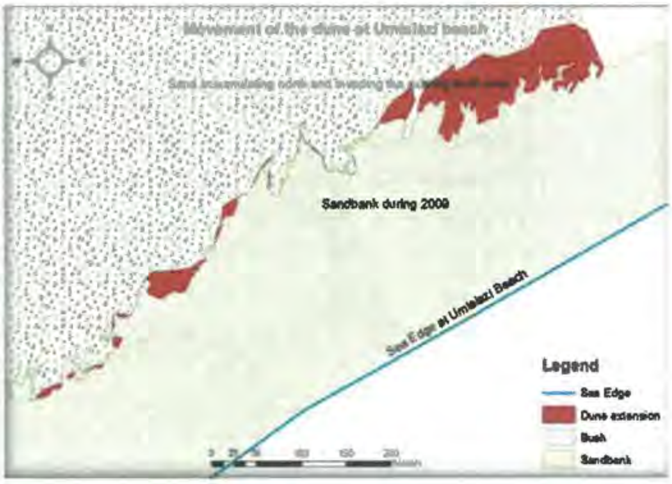

Figure 8: The red area shown the sand encroaching the forest since 2009 up to 2017.

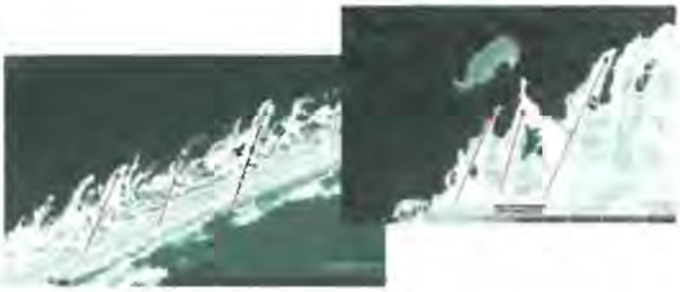

Figure 9: The human disturbance at Umlalazi is a great factor in the moving of the sand.

With the physical survey of the terrain at the Umlalazi beach during the three time periods the following results were obtained:

March 2016:	142 361m^3
October 2016:	144 636m^3
April 2017:	160 724m^3

Cumulative sand volumes are shown in Figure 10. The reason why the above assumption on human disturbance and expansion of the dunes into the forest can be made is that 41% of the year the wind blows inland and only 28% in the direction of the sea.

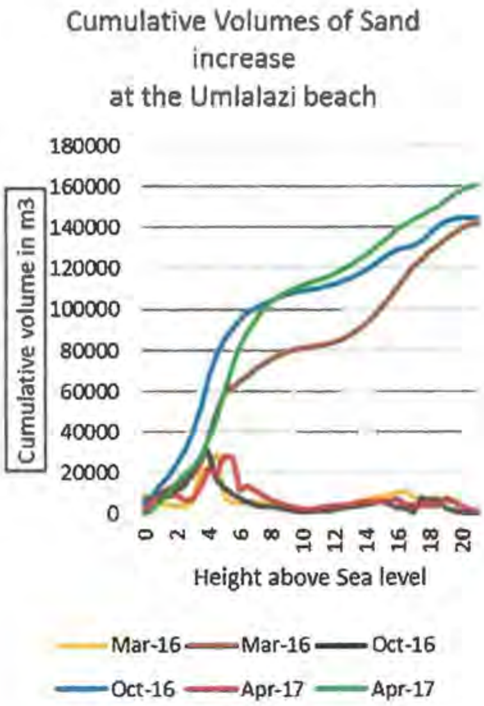

Figure 10. The graph represent the accumulated sand volumes from March 2016 to April 2017

5 CONCLUSION

All three estuaries and their sandbanks protecting them from the ocean are highly dominated by the rivers feeding and flowing into them. When the rivers are in flood cause of high rainfall in the catchment areas, especially the Thukela River, they push sand deep into the sea and then transported by the longshore drift flowing close to the coast in a northern direction. These sediments are then washed out on the beaches by the wave energy energized by the wind speed. Preliminary findings show substantial dune and coastline dynamics for all three sites.

6 REFERENCES

Begg, G. W., 1978: The Estuaries of Natal. Natal Town and Regional Planning Report. Petermaritzburg: The Natal Town and Regional Planning Commission.

Bernhard, W.H., Jr, 1993: Global Warming Unchecked, Signs to watch for, ISBN 0-253-31178-0.

Cooper, J.A.G., 2001: Geomorphological variability among micro tidal estuaries from the wave –dominated South African coast. *Geomorphology*, 40: 99-122.

Elkington, L., 2012: morphology, patterns and process in the Oyster Bay headland bypass dunefield. South Africa MSc thesis, Rhodes University.

Engelbrecht, H., 2008: Changes in the Matigulu /Nyoni Estuary: A time series analysis.Unpublished Honours project, Department of Geography and Geoinformatics, University of Pretoria.

Green, A., Cooper, J.A.G., LeVieux, A., 2012: unusual barrier/inlet behaviour associated with active coastal progradation and river-dominated estuaries. *Journal of Coastal Research,* Special Issue 69: 35 – 45.

Leopold, L.B., 1953: Downstream Changes of Velocity in Rivers. *American Journal of Science*, 251: 606 – 624.

Olivier, M.J., Garland, G.G., 2003: short-term monitoring of foredune formation on the east coast of South Africa, *Earth Surface Process and Landforms* 28: 1143-1155.

Palmer, B., van der Elst, R. and Parak, O: (2011) *Understanding our coast: a synopsis of KZN's coastal zone*. KwaZulu-Natal Department of Agriculture, Environmental Affairs and Rural Development, Pietermaritzburg, 32pp.

Tinley, K.L., 1985: *Coastal dunes of South Africa*. CSIR, South African National Scientific Programmes Report No. 109, Pretoria, South Africa, 300pp.

Whitfield, A.K., 2000: Available Scientific Information on individual South African Estuarine Systems. WRC Report No: 577/3/00. Water Research Commission, Pretoria: 217pp.

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The environmental context of severe soil erosion in the Mbilane-Ntendeka District of Ulundi, KwaZulu-Natal

Heinz Beckedahl

Department of Geography, Environmental Science and Planning, University of Swaziland

1 INTRODUCTION AND CONTEXT

A total land area of some 595 000 ha in South Africa has been affected by gullies, with KwaZulu-Natal being the third most seriously affected province in the country. This translates to a total area of nearly 93 000 ha in the province being affected, principally due to in excess of 2500 large gully systems (Le Roux et al., 2010 and Mararakanye and Le Roux, 2012), as reflected in Figure 1.

The Mbilane-Ntendeka area was initially visited early in December, 2015, and essentially consists of five sites, as shown in Figure 2. Common themes that came through from discussion with community members while visiting the area were the following:

a. Water scarcity (not surprising given the severity of the drought in the area!);

b. The gullies restrict free and safe movement within the community and represent areas for criminal elements to hide;

c. Erosion potentially threatens people's dwellings and gardens and pollutes the water with sediment;

d. Gullies are places where litter collects, resulting in an unsightly and, more importantly, unhealthy environmental condition;

e. Poverty and unemployment are high in the area, hence there are few resources available.

It is important to emphasize that, while the plight of the affected community is tangible and real, not all the issues will be resolved by rehabilitating the erosion in the area. It is therefore imperative that integrated, comprehensive solutions are found, which will however at least to some extent, require inter-departmental collaboration.

Further, it must be emphasizes that, while the erosion is severe and undoubtedly presents a problem for the community, the gullies have been historic water courses for millennia and it is not practical to change this (please see Figure 3i and 3ii).

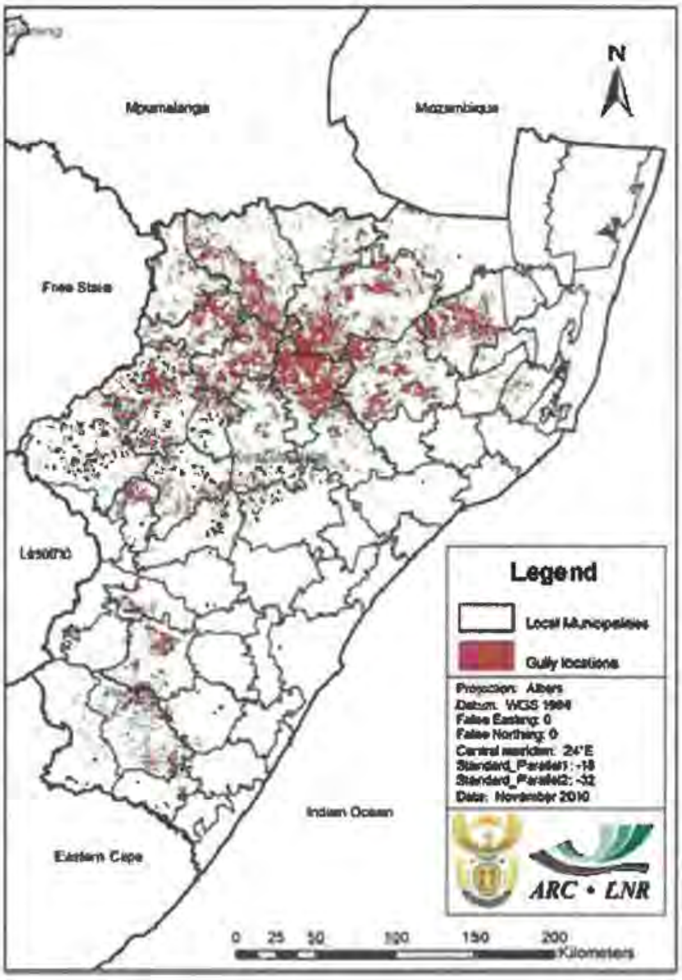

Figure 1: Map of the location of gully systems in KwaZulu-Natal. (Kindly supplied by Dr J. Le Roux, University of Free State, after Mararakanye and Le Roux, 2012).

Figure 2: A map of the Mbilane-Ntendeka area of Ulundi, (derived from Goole Maps), showing the gullies (orange). The important water courses are shown by the bright blue broken lines.

Note that the gullies lead into the water courses, highlighting what has often been cited, namely that erosion and sediment production will lower the water quality for an entire region. The values entered in purple are the length of the gully system as measured off the Google Image.

Figure 3i: One of the gully sidewalls, showing evidence that this was a water course in the geological past.

Figure 3ii: The gully sidewall, indicating (A) as the soil cover developed over colluvial material (B), with the scour-and-fill structures (C), all of which lies above the weathered sapprolite (D). E is the base of the gully system, which is some 5m deep.

2 DEALING WITH THE WATER MANAGEMENT ISSUES:

The first step to managing and rehabilitating the erosion will need to be to manage the rain water in the catchment through rain water harvesting. The lower the total quantity of water that can flow over the landscape and down the gullies, the lower will be the potential erosive impact of rainfall. For this reason, residents in the area need to be encouraged (and assisted where necessary) with the installation of rain water tanks to capture the runoff from roofs, and to prevent this water from contributing to the 'quick-flow' component of storm runoff. Although the PVC JoJo-type tanks are ideal, they are also costly and probably beyond the means of many residents. A simple alternative is to build a tank from bricks that are then plastered with a cement plaster that has a water-proofing agent within it. This will enable the capture of rain water for watering gardens and livestock and, if treated with a little bleach or boiled, will also be available for domestic consumption.

The second aspect of the rain water harvesting process will be to keep as much of the water on the ground in the catchment as possible, to allow for infiltration rather than runoff. There is much literature available on the subject, but in essence all rain water harvesting systems rely on keeping the vegetation cover on the ground as high as possible (difficult at the moment because of the drought), and to roughen the surface as much as possible to prevent runoff. This is generally achieved by creating small (only 10 to 20 cm deep) half-moon ridges-and-trenches at regular intervals across the slope to capture small volumes of water. At the head of the crescent, it is then possible to plant subsistence crops, or grass for livestock (see Figure 4).

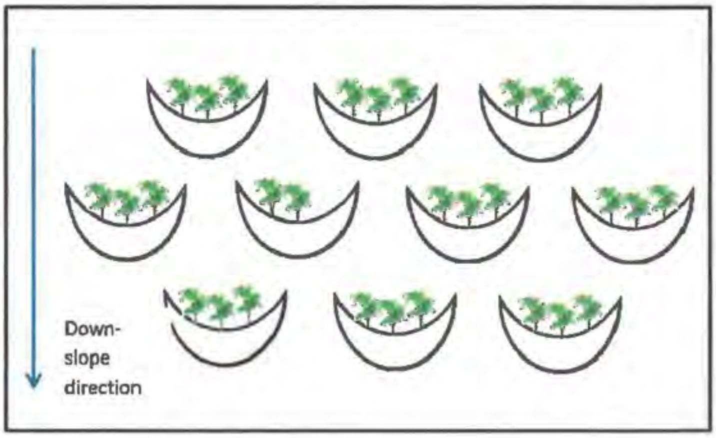

Figure 4: A schematic illustration of a water harvesting system to capture water on the upper slopes of the catchment, and thus aid infiltration and reduce runoff.

Although the upper reaches of the catchment are at present severely overgrazed and will therefore contribute to the erosion problem, some of this must be ascribed to the current drought and poor grazing condition. Notwithstanding this situation, the rainwater harvesting system advocated will assist in recovery as water availability permits. It will, however, be important for the community to plan grazing strategies into the future as well, as it is likely that the shortage of water will persist for some time.

While this report only focuses on one area in the Ulundi district, the problems discussed here are symptomatic of many of the severe gully sites in the province. An overview of the Ulundi area with specific sites is shown in Figure 2. The principles discussed here can, however, be applied in many of the similar situations around the province (and probably the country), provided that soil and climatic conditions are similar.

3 THE GULLIES AND SAFE MOVEMENT WITHIN THE COMMUNITY

The gullies in the Mbilane area pose a serious risk to the community in terms of movement (as opposed to erosion) at two levels. The first is in the context of poor underfoot conditions in that the sidewalls of the gullies (or dongas) are steep and the systems up to as much as 8m in depth. A fall can result in serious injury, or (as was regrettably the case shortly before our visit), the death of a toddler. The second risk posed by dongas is in terms of the discharge itself. Even with water harvesting, the volume of water during storm discharges can be appreciable, and can result in people losing their footing and then being swept down the donga by the fast flowing water, again with injury to people or worse as a consequence.

Unfortunately, the reality is that irrespective of what rehabilitation systems are used on the existing gullies or dongas, none of them will alleviate this problem. Apart from the great expense associated with gabion systems built almost up to the level of the surrounding ground level, they do not silt up to that level. The consequence is that people are left with a narrow, precarious walkway to traverse, and still face the problem of high discharge. The answer to the problem of ease of movement within the community lies outside of the gambit of responsibility of the Department of EDTEA, and would need the involvement of Public Works to design and build cost effective pedestrian bridges across the dongas where needed.

4.1 THE THREAT POSED BY SOIL EROSION

The threat posed by donga erosion falls into four categories:

I. Disruption of free movement within the community, coupled with the threat of fast flowing deep water during storm runoff.

II. A deepening of the system through scour and down-cutting.

III. A widening of the sidewalls through slope instability, undercutting and sidewall collapse, and

IV. Headwall retreat of either the main donga, or of tributary headcuts.

i. The disruption has already been discussed and will not be repeated.

ii. Erosion through scour and down-cutting:
Vertical erosion takes place as a result of flowing water with a high stream-power (i.e. a high erosive capability). The speed of flow is directly related to both the volume of water flowing (hence the earlier comments about reducing the risk by reducing the amount of water that is available), and the gradient of the base of the donga or gully system. The most effective way to combat this vertical scour is by use of low gabion walls. Past practice has often seen the use of rip-rap (or sheets of gabion-like material spread along large sections of the gully floor). The fundamental principles still apply: Rehabilitate this type of situation by reducing the stream-power (or energy available for erosion); harden the base of the donga so that the flowing water cannot scour into it (flowing water will not cut into a well-constructed gabion wall, thus it cannot cut further even if the gabion does not extend over large areas of the gully bottom); and finally, prevent any sediment from being removed from the base by re-establishing a vegetation cover as soon as possible.

iii. Gully sidewall instability:
As the depth of a donga or gully increases through scour, so the sidewalls of necessity become steeper, until they exceed the angle of repose and start to collapse under gravity. Alternately, where the gully changes direction, the flow of fast moving water will undercut the outer bank of the donga, leading to over steepening and hence collapse under gravity. Changes in direction in a gully system therefore require armouring (or protection) to prevent such undercutting. Critical also is to ensure that the carrying capacity of the base of the system during storm flow is sufficient to pass through the notched weir at the top of the low gabion wall, else the water will rise up to the top of the gabion and undercut the sidewalls above the structure, ultimately leading to failure.

iv. Erosion by gully extension through headwall retreat:
The most concentrated flow of runoff from the catchment above the donga or gully will be at the gully head. At this point, the water experiences a rapid increase in energy as it falls over the lip of the headwall into the gully, hence a strong increase in erosive power. This is coupled with the splash-pool effect where the water that has just entered the donga now falls onto the base and in so doing splashes back against the headwall, undercutting it. The net effect of the two is that the headwall is prone to regular collapse, resulting in a head ward extension of the entire gully system.

4.2 REHABILITATING THE THREAT POSED BY SOIL EROSION

Rehabilitating erosion through scour and down-cutting:

Past practice has often seen the use of rip-rap (or sheets of gabion-like material spread along large sections of the gully floor. While effective, this system is not cost-effective, nor aesthetically pleasing. Low gabion walls of 1,5 m (of which 0.5 m is keyed into the base of the system) by contrast, can achieve the same effect, yet at a fraction of the cost (see Figure 5).

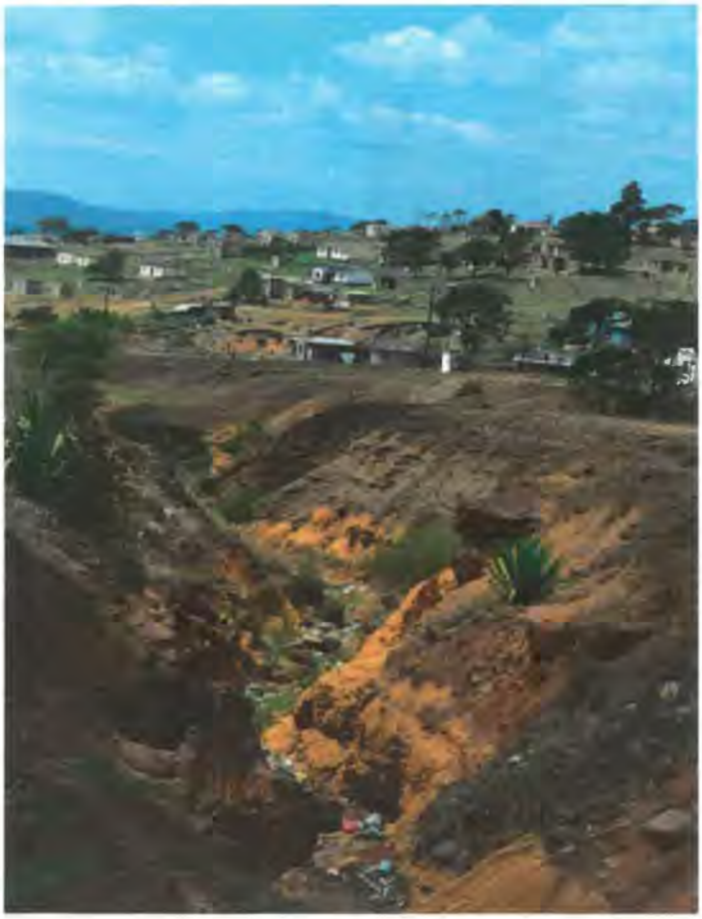

Figure 5.i: A view down gully at site 1. Note the depth of the donga system. A high gabion structure here would not be cost-effective.

The gabion itself prevents further vertical incision, while the weir notch in the low wall is still used to direct the position (and hence direction) of flow in such a way as to keep the highest volume (and so most erosive flow) away from the base of the sidewalls. The fundamental principles still apply as they did for the rip-rap: Rehabilitate this type of situation by reducing the stream-power (or energy available for erosion); harden the base of the donga so that the flowing water cannot scour into it (flowing water will not cut into a well-constructed gabion wall, thus it cannot cut further even if the gabion does not extend over large areas of the gully bottom); and finally, prevent any sediment from being removed from the base by re-establishing a vegetation cover as soon as possible.

As the base of the donga is no longer scoured, vegetation re-establishes itself relatively easily. Very important with this method is, however, that due attention is paid to the low gabion walls being properly keyed in to about one third of the length of the gabion wall on each side (or a minimum of 1,5 m), and that the surrounding soil is non-dispersive.

Figure 5.ii: A view down the same gully at site 1. Note the proposed shallow gabion system, intended only to prevent down cutting in the donga system, and to direct the flow of water away from the sidewalls.

Figure 6 The sidewalls of the main gully retreat, to the extent that they then threaten the stability of dwellings and infrastructure (upper and lower image). Note that the 'step' some 1,5 m away from the boundary fence is already up to 1m high in places (lower image).

5 R EFERENCES

Mararakanye N, Le Roux JJ. 2012: Gully erosion mapping at a national scale for South Africa. *South African Geographical Journal*, 94(2): 208-218.

Le Roux JJ, Nkambule VT, Mararakanye N, Pretorius DJ. 2010: *Provincial mapping of gully erosion at the field scale using high resolution satellite imagery (SPOT 5)*, ARC-ISCW report no GW/A/2009/04. ARC-Institute for Soil, Climate and Water, Pretoria.