Catena 147 (2016) 245–257

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Examination of soil and slope factors as erosion controlling variables under varying climatic conditions

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ARTICLE INFO

Article history:
Received 19 January 2015
Received in revised form 24 June 2016
Accepted 24 June 2016
Available online 20 July 2016

Keywords:
Clay mineralogy
Climate
Delineation
Fine sand
Humid
Sodium

ABSTRACT

Soil erosion is an environmental problem that has reached alarming proportions in many parts of South Africa. Understanding the complex interactions between climate, slope and soil factors is important to ensure that soil erosion is controlled and that soil resources are used sustainably. The objectives of the study were to (i) determine soil and slope variables controlling soil erosion in different climatic units and (ii) establish guidelines for the delineation of land with high potential for cropping. The degree of soil erosion was determined from field observation and existing erosion maps. The slope gradient and length were calculated from Digital Elevation Models. Numerical values of soil and slope factors were regressed against the degree of erosion using step-wise regressions. Soils in humid regions were found to be stable, irrespective of parent material, and their stability was controlled by oxides of iron and aluminium, and kaolinite. Dolerite derived soils were the most stable while mudstone and shale derived soils were vulnerable to erosion in arid, semi-arid and subhumid regions. Fine and very fine sand fractions were most important in controlling erosion of soil in arid and semi-arid climate while kaolinite and sesquioxides were more important in subhumid areas. Critical slope limits varied with soil type. Guidelines for the delineation of arable land were formulated which guided the identification of high priority land for crop development.

1. Introduction

In South Africa, about 400 million m^3 of soil is lost annually to soil erosion (FAO, 2004) and it is estimated to be >20 times the global average per capita soil loss (Laker, 1990). This problem is more severe in the former ‘homelands’ of South Africa (Kakembo and Rowntree, 2002), particularly in the Nkonkobe Municipality and other parts of Eastern Cape Province (Maswana, 2001). Extremely serious soil erosion damage is evident in these former homelands, due to errors in demarcation of arable land as a result of incorrect assessment of the erodibilities of soils (Laker, 1990, 2004).

Soil erosion threatens economic and physical survival, and could lead to household and national food insecurity. South Africa has embarked on a land reform programme aimed at equitable redistribution of land among the country's different population groups. Crop based development projects are being envisaged in different regions of the country, including the Nkonkobe Municipality. Success of these projects depends on the quality of available soil resources, among other factors. Sustainable use of local soil resources requires correct identification and delineation of arable land, paying particular attention to the soil's vulnerability to erosion. Land degradation and conversion of cropland for non-food production could reduce the available cropland by 8–20% by 2050 (Nellemann et al., 2009). This creates a need to predict and combat land degradation by understanding the critical factors affecting the process (Mulibana, 2000).

Soil erosion is a function of many variables, chief among them being rainfall intensity, parent material, soil characteristics, topography, vegetation, land use and management. The effects of these important variables are well documented (Laker, 2004; Mulibana, 2000; Weaver, 1988). However, most of these studies do not give detailed relationships between soil erosion and important soil variables such as particle size distribution, clay mineralogy, composition of sesquioxides and cations and their interactions. Kakembo (2000) highlighted the need to examine a range of soil erosion controlling variables giving due attention to soil characteristics.

Manyevere et al. (2014) reported that farmers identified soil erosion as one of the factors that led to land abandonment in Nkonkobe Municipality. According to farmers, texture, especially the ‘sandy soils’, and shallow depth were the main factors leading to high erosion. The effect of such factors on the degree of erosion under varying climatic conditions is not clearly understood. Pioneer work by D'Huyvetter (1985) established maximum permissible slope limits at which different soil forms in parts of Nkonkobe Municipality can be cultivated without causing severe erosion. The study deduced the relationships between soil

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http://dx.doi.org/10.1016/j.catena.2016.06.035
0341-8162/

erosion and (i) texture (clay and silt content), (ii) contents and ratios of the three key exchangeable cations (magnesium, sodium and calcium), (iii) soil depth – in the case of shallow soils, (iv) parent material and (v) slope gradient and length. However, D'Huyvetter's study assumed a homogenous climate and as such different conclusions could be reached if the variability of climate in the Municipality is taken into account.

There has been contrasting views on how soil variables could affect erosion as climate changes from drier regions to more humid areas of the Municipality (Laker, 1990, 2004; Smith, 1990; Weaver, 1988). Weaver (1988) found that the degree of erosion decreased as the rainfall erosivity increased in a transect from Middledrift to the Amatola mountains of Nkonkobe Municipality, and concluded that this did not make sense. Throughout the transect, rainfall was in the form of aggressive thunderstorms and rainfall erosivity increased purely due to increased rainfall. However, increased rainfall resulted in higher degrees of pedogenesis and consequently more stable soils, as well as a denser vegetative cover, thus this could override the effect of rainfall erosivity (Laker, 1990, 2004). Smith (1990) established that highly weathered soils of humid regions were more stable than the less weathered soils of drier regions. Neither the study of D'Huyvetter (1985) nor that of Weaver (1988) included the effects of clay mineralogy and iron oxides, which have been reported to be dominant factors controlling erosion in many soils of South Africa, including the Eastern Cape (Bühmann et al., 2006; Stern et al., 1991). A striking observation in many South African soils is the presence of large quantities of quartz in the clay fraction, which is usually absent in other soils around the world (Bühmann et al., 1996, 2006).

It is important to examine the impact of such important soil properties on erosion intensity in the different climatic conditions prevailing in the Nkonkobe Municipality. This would help in the demarcation of areas that are either stable or susceptible to erosion, thus enabling land suitability evaluations for long term sustainability of crop production in the area. The objectives of the study were to (i) determine soil and slope variables controlling soil erosion in different climatic units and (ii) establish guidelines for the delineation of land with high potential for cropping in the Nkonkobe Municipality.

2. Materials and methods

This study was carried out in the Nkonkobe Municipality which is characterized by small isolated micro-reliefs resulting in unique microclimates and a situation of neighbourhood between the aridity zones. The study area covered four aridity zones which were categorized according to World Meteorological Organisation statutes (WMO, 2001). The study boundaries covered latitudes 32° 21′ and 33° 07′ South and 26° 24′ and 27° 13′ East (Fig. A.1). The area receives most of its rainfall in summer with very little in winter (Schulze, 1997).

The north of the Municipality is dominated by the humid Amatola and Katberg Mountain regions where mean annual precipitation is between 1000 and 1400 mm. The Kat River catchment consists of two main units, namely, the sub-humid upper catchment (700–900 mm) found below the Katberg Mountains and the semi-arid area around Fort Beaufort. Small areas of arid microclimate are also found in the Upper Catchment of the Kat River. Mean precipitation in the semi-arid Seymour is around 560 mm, while that at Fort Beaufort is around 500 mm.

The transect of Tyume River catchment stretches between the escarpment of the Amatola Mountains in the sub-humid areas below the Hogsback Mountains through the semi-arid region at Lovedale and Pleasant View near Alice, which receive 580 mm and 611 mm annual precipitation, respectively. In humid to sub-humid areas, the soils have a high cropping potential. Alluvial soils are found mainly in semi-arid zones, on terraces along the Tyume river and on floodplains of seasonal streams, where most cultivation is carried out. Doleritic intrusions are also found on higher ground, especially in the east (Laker, 1978). The arid zone is found further south along the Keiskamma River around Middledrift. It is made up of a combination of dry river valleys with mean annual precipitation at Middledrift of about 500 mm, which drops to 390 mm at Dank den Goewerneur. This arid unit is almost exclusively used for extensive grazing. The main parent material on the river terraces is alluvium, with mudstones, shales and dolerite intrusions dominating in the land away from alluvial terraces.

2.1. Extent of soil erosion

Soil erosion risk maps produced by Hill Kaplan Scott., Associates (1977) were used to predict the extent of soil erosion in the Municipality. The maps were constructed using climatic, pedological, topographical and socio-economic variables. The socio-economic variables were land use and population pressure (Fig. A.2).

Delineation of the erosion units was done on aerial photos based on soil erosion features such as gully rill and sheet erosion. The mapping units were then digitized to give spatial erosion maps.

The accuracy of predicted soil loss was evaluated using field observations and aerial photographs, captured by an airplane in July 2009. Field observations were done through a snap survey where soil erosion features such as sheet, rill and gully erosion were used to code the degree of erosion. The aerial photos were mainly used for navigation and to identify erosion features. The description of the extent of erosion is given in Table A.1. The erosion degree was coded using the simplified erosion degree scale of D'Huyvetter with 4 classes. D'Huyvetter (1985) pointed out that with the traditional 12 class scale it is virtually impossible to get enough data sets per class to enable statistical analysis to be done hence the 4 classes. The description of the extent of erosion is given in Table A.1.

2.2. Soil maps and sampling

The land type map for the area (3226 King William's Town) and its accompanying memoir tables, obtained from the Institute for Soil, Climate and Water of the Agricultural Research Council (ARC-ISCW) of South Africa, was used as reference map. The memoir tables give the percentages of different soils on the different terrain morphological units in each land type (Land Type Survey Staff, 2001). A follow-up field verification exercise was conducted at a sampling intensity of one auger for every 200 m as recommended for semi-detailed surveys (WRB, 2014). Site and soil profile descriptions were done for representative soil profiles for each soil form encountered. Twenty six soil profiles were dug, fully described and sampled in topsoil and subsoil horizons. Soil classification was done according to the South African taxonomic classification system (Soil Classification Working Group, 1991) and the World Reference Base for Soil Resources system (WRB, 2014). Geographic co-ordinates of the sampling points were captured using Global Positioning System (GPS). Soil samples were collected from each horizon of each soil profile, air-dried and sieved (<2 mm) before laboratory analyses. Sub-soils were used in soil classification and calculations for determining the leaching and luvic status of the soils.

2.3. Soil laboratory analyses

2.3.1. Soil chemical analyses

Soil pH and electrical conductivity (EC) were determined in 1: 2.5 soil: water (w/v) ratio using a pH meter (pH meter 330 SET-1, 82,362) and an EC meter (Cond.330i/ SET 82362), respectively. Exchangeable bases (Ca, Mg, K, and Na) were extracted in 1.0 M ammonium acetate (pH 7) and determined using the Atomic Absorption Spectrophotometer (AAS) (The Non-Affiliated Soil Analysis Work Committee, 1990). Free iron oxides were analysed using the citrate- bicarbonate- dithionite (CBD) extraction method (Jackson et al., 1986). Total carbon determinations were done by dry combustion using the LECO- Truspec Autoanalyser (LECO, 2003).

2.3.2. Determination of particle size distribution

Particle size distribution was determined after dissolution of calcium carbonate ($CaCO_3$) with 2 M hydrochloric acid (HCl) and decomposition