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Soil properties influencing erodibility of soils in the Ntabelanga area, Eastern Cape Province, South Africa

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ABSTRACT
Soil erosion has serious off-site impacts caused by increased mobilization of sediment and delivery to water bodies causing siltation and pollution. To evaluate factors influencing soil erodibility at a proposed dam site, 21 soil samples collected were characterized. The soils were analyzed for soil organic carbon (SOC), exchangeable bases, exchangeable acidity, pH, electrical conductivities, mean weight diameter and soil particles' size distribution. Cation exchange capacity, exchangeable sodium percentage, sodium adsorption ratio, dispersion ratio (DR), clay flocculation index (CFI), clay dispersion ratio (CDR) and Ca:Mg ratio were then calculated. Soil erodibility (K-factor) estimates were determined using SOC content and surface soil properties. Soil loss rates by splashing were determined under rainfall simulations at 360 mmh^{-1} rainfall intensity. Soil loss was correlated to the measured chemical and physical soil properties. There were variations in soil form properties and erodibility indices showing influence on soil loss. The average soil erodibility and SOC values were 0.0734 t MJ^{-1} mm^{-1} and 0.81%, respectively. SOC decreased with depth and soil loss increased with a decrease in SOC content. SOC significantly influenced soil loss, CDR, CFI and DR ($P < .05$). The soil loss rate was 5.60 t/ha per 8 minute rainstorm of 360 mmh^{-1}. Addition of organic matter stabilize the soils against erosion.

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KEYWORDS
Soil erosion; siltation; soil organic carbon; characterization; simulation

Introduction

Soil erosion is the most widespread form of land degradation worldwide (Bridges & Oldeman 1999). The high heterogeneity of soil erosion causal factors combined with often generalized data is an obstacle for effective control (Cai et al. 2004). Effective controlling of soil erosion still remains a challenge in most parts of the world especially in the developing countries. In South Africa, about 85% of land is threatened by soil erosion (Van Rensburg 2008) and the estimated average soil erosion rates are more than 4.1 t/ha/yr (Lu et al. 2003). Soil erosion has serious off-site effects related to increased mobilization of sediments and delivery to rivers and dams. A case is where the storage capacity of the Welbedacht Dam near Dewetsdorp in the Free State, South Africa, was rapidly reduced by more than 86% from its original storage capacity within 20 years of its completion in 1973 (DWA 2011). Regardless of such soil erosion background, the Government of South Africa through the Department of Water Affairs has proposed to build a multi-purpose dam along the Tsitsa River in Ntabelanga. Soil erosion data collected at large spatial context characterized the soils in the area as highly unstable and easily erodible. The Ntabelanga area has various soil types with varying degrees of sensitivity to soil erosion (Van Tol et al. 2014). High rates of soil erosion in the area will shorten the dam lifespan through siltation if unchecked (Parwada & van Tol 2016). Efforts to reduce soil erosion in Ntabelanga are failing (Laker 2004). The soil sedimentation problem may get worse in future due to population increase and denudation processes associated with climatic changes (Le Roux et al. 2008). Considering the increasing threat of sedimentation of water bodies, it is important to identify source areas and key processes of sediment transport from the field to the reservoirs.

Soil erodibility is the susceptibility of soil to erosion, which closely relates to a range of soil physical and chemical properties (Vrieling 2006; Ezeabasili et al. 2014). The soil physical properties may influence soil erosion through changing soil infiltration capacity and soil shear strength (Li et al. 2010). Soil organic carbon (SOC) content and Fe oxides content may affect soil erodibility through changing soil

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aggregation. Sun et al. (2013) selected the degree of aggregate dispersibility and the ratio of collapsing rate to infiltration rate as indices to predict the possibility of the occurrence of erosion (Sun et al. 2013). Other researchers prefer to use soil erodibility (incorporating aggregate stability) factor as a simpler and more feasible factor for erosion prediction (Dimoyiannis et al. 2006; Yan et al. 2010). The breakdown of unstable aggregates results in pore collapse, finer particles and microaggregates that play significant roles in soil erosion (Yan et al. 2010).

Chemical dispersion of clay particles and slaking or physical disintegration of soil aggregates increase water runoff (Amezketa et al. 2004). The relative importance of dispersion and slaking depends on various soil properties, particularly soil exchangeable sodium percentage (ESP), the rate of soil wetting and drying, and the electrical conductivity (EC) of the applied water. Dispersion of soil clays is induced by low electrolyte concentrations (lower than the soil's flocculation value) and high sodium adsorption ratio (SAR) and pH values in the soil (Reinks et al. 2000). Soil erosion has been directly linked to the rate and volume of water-dispersible clay in a soil. Potential soil erosion in areas of very high rainfall has been estimated using water-dispersible clay and its indices (Amezketa et al. 2004; Igwe & Agbatah 2008). The clay dispersion ratio (CDR) derived from the clay content, water-dispersible clay (WDC) and the dispersion ratio (DR) being an index from water-dispersible silt and clay and their corresponding total forms has also been successfully used to predict erosion by water (Igwe & Udegbunam 2008). Igwe (2005) concluded that the CDR and the DR were good indices for predicting erodibility in some soils. Whilst a wide range of soil properties have been linked to the rate at which soil disperses, Igwe et al. (1995) concluded that organic carbon and Fe oxides are important in controlling flocculation and deflocculation in soil.

The causes of soil erosion are mostly generalized but for effective control measures and technologies, sound knowledge on the specific site and soil properties is required (Ojo 2000). Site and soil characteristics change over short distances and time hence specific site characterization is essential before prescribing soil conservation measures, road construction and dam construction. Currently, there are limited data on the intrinsic soil properties in Ntabelanga, hence the need to characterize the soils in this regard. In this study, we hypothesized that in Ntabelanga, soil erodibility is more influential to soil erosion than erosivity. Therefore, the objectives of this study were to (1) characterize representative soils around the proposed dam site for both chemical and physical properties and (2) determine soil erodibility indices and their relationship with the level of soil loss.

Materials and methods

Description of the study area

The study was conducted in the Ntabelanga area in the Eastern Cape Province of South Africa and is located about 626 km south of Pretoria. Ntabelanga is located on 31° 7′ 35.9″ S and 28° 40′ 30.6″ E and falls within the South Eastern Uplands Aquatic Ecoregion and the Mzimvubu to Kieskamma Management Area (WMA). It is in the sub-escarpment Grassland and sub-escarpment Savanna Bioregions (Mucina & Rutherford 2006). Ntabelanga receives an annual rainfall total of about 749 mm, with most of it falling in December and January. The lowest (15 mm) average rainfall is received in June and the highest (108 mm) in January. The area is underlain by sedimentary rocks of the Tarkastad subgroup and Beaufort karoo supergroup with post karoo doleritic intrusions. There are also traces of mudflake conglomerates. Sub-humid grasslands in Ntabelanga, even with their dense grass cover, suffer from severe gully erosion (Sonneveld et al. 2005). The area is characterized by highly unstable soils that are prone to erosion as evidenced by extensive areas of severe gully erosion on the inter-fluvial areas adjacent to stream channels. The erosional and piping characteristics in Ntabelanga are suggestive of the presence of dispersive soils (DWA 2013).

Site selection and soil sampling

Twenty-one soil samples were randomly collected from nine profiles representing the dominant soil forms (G horizon, Katspruit, Oakleaf, Valsrivier, Hutton, Sterkspruit and Glenrosa) and horizons in the area (Soil Classification. Taxonomic System for South Africa 1991). The soil profiles and horizons varied in depth; six were deeper than 30 cm and three shallow (i.e. <30 cm). Some of the sampling points were severely eroded and lacked the A-horizon and others were rocky just below the A-horizon. Depending on the soil profile depth, soils were sampled from 0–5, 5–30, 30–50 and 0–50 cm (Figure 1).

Soil erodibility estimates (K-factor) for the sampled locations

The measurement of the *K*-factor was done using the soil erodibility nomograph as proposed by Wischmeier

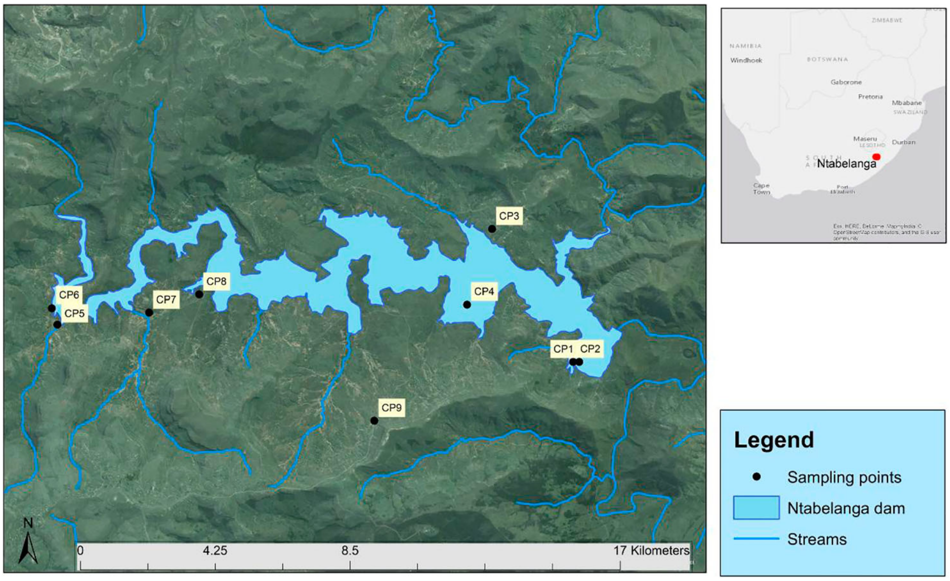

Figure 1. Location of the sampling points.

et al. (1971) (Equation 1). The algebraic approximation of the nomograph includes five soil parameters (texture, organic matter content, coarse fragments, surface structure and permeability) (Wischmeier & Smith 1978; Renard et al. 1997).

$$K = \left[\frac{(2.1\times 10^{-4}\times M^{1.14}(12-\mathrm{OM})+3.25(s-2)+2.5(p-3))}{100}\right]\times 0.1317, \qquad (1)$$

where K is the soil erodibility estimate, M is the textural factor = ($m_{\mathrm{silt}}+m_{\mathrm{vfs}}$) × (100-$m_{\mathrm{c}}$), m_{c} = [%] clay fraction content (<0.002 mm) m_{silt} = [%] silt fraction content (0.002–0.05 mm), m_{vfs} = [%] very fine sand fraction (0.005–0.1), OM = [%] the organic matter content, s = soil structure class and p = permeability class

Soil structural classes were assigned according to the method proposed by Rawls et al. (1983). The textural factor M in Equation 1 and the organic matter content (%) were obtained from soil analysis (Table 1).

Laboratory analysis of soil samples

The effects of quantitative chemical properties such as the different exchangeable bases (Ca, Mg, Na and K), ESP, SAR and other mineral oxides on soil loss from sampling depth were evaluated. The soil samples were air dried, sieved through a 2-mm mesh and analyzed in triplicate.

Basic chemical and physical properties were determined on the sieved soil (<2 mm). Soil particle size distribution was determined by the hydrometer method as described by Okalebo et al. (2000). The soils were first dispersed with distilled water (H_2O) without any dispersing agent. A second portion of the sample was treated with dithionite-citrate-bicarbonate as described by Aguilera and Jackson (1953) to remove Fe_2O_3 for proper dispersion. This was followed by addition of sodium hexametaphosphate (calgon) before physical agitation of the suspension and taking of the measurements. Soil pH and ECs were measured in a soil water suspension (ratio of 1:5) using a TPS meter as described by Okalebo et al. (2000). Total exchangeable acidity ($H + Al^{3+}$) was determined directly through extraction with 1 mol L^{-1} ammonium acetate solution at pH 7, followed by titration. Indices of dispersion were calculated using an adaptation of Middleton's dispersion ratio (So & Cook 1993). SOC was determined by the modified Walkley-Black method (Chan et al. 2001) and exchangeable bases were determined by the method of Thomas (1982). ESP and SAR were calculated using the following equations;

$$\mathrm{ESP} = \frac{\text{Exchangeable Na}^{+}}{\mathrm{Ca}^{2+}\mathrm{Mg}^{2+}+\mathrm{K}^{+}+\mathrm{Na}^{+}\mathrm{Al}+\mathrm{H}}\times 100 \qquad (2)$$

$$\mathrm{SAR} = \frac{\mathrm{Na}^{+}}{\sqrt{\dfrac{\mathrm{Mg}^{2+}+\mathrm{Ca}^{2+}}{2}}} \qquad (3)$$

The microaggregate stability indices were calculated as follows:

$$\mathrm{DR} = \frac{\%\mathrm{Silt}+\%\mathrm{Clay}_{(\mathrm{H_2O})}}{\%\mathrm{Silt}+\%\mathrm{Clay}_{(\mathrm{DCB})}} \qquad (4)$$

Table 1. Surface soil structure class, permeability class and erodibility factor (*K*) of the Ntabelanga soils.

Location	Horizon	Soil form	Surface soil structure class	Permeability class	*K*-factor (t ha h ha^{-1} MJ^{-1} mm^{-1})
CP1	ot.s	Ka	(2) Fine granular	(2) Moderate fast	0.0465
CP2	ml.s	Bo	(1) Very fine granular	(6) Very slow	0.0596
CP3	ot.s	Oa	(2) Fine granular	(4) Moderate low	0.0519
CP4	ot	Va	(1) Very fine granular	(2) Moderate fast	0.0982
CP5	ot	Hu	(1) Very fine granular	(2) Moderate fast	0.1036
CP6	ot	Ss	(4) Blocky	(4) Moderate low	0.0876
CP7	so	–	(4) Blocky	(6) Very slow	0.0866
CP8	ot	Ka	(1) Bery fine granular	(6) Very slow	0.0477
CP9	ot	Gs	(3) Very coarse	(2) Moderate fast	0.0693

Note: ot = orthic A, ml = melanic A, vp = pedocutanic B, re = red apedal B, so = saprolite (N.B. was found on the surface), gh = G horizon, Ka = Katspruit, Oa = Oakleaf, Va = Valsrivier, Hu = Hutton, Ss = Sterkspruit, Gs = Glenrosa.

$$\mathrm{CFI} = \frac{[\%\mathrm{Clay}_{(\mathrm{DCB})} - \%\mathrm{Clay}_{(\mathrm{H_2O})}]}{\%\mathrm{Clay}_{(\mathrm{DCB})}} \times 100 \qquad (5)$$

The CFI is an effective index in predicting soil erodibility and a good microaggregate index (Igwe et al. 1995). Soils high in CFI are well aggregated and will not be easily dispersed in water.

$$\mathrm{CDR} = \frac{\%\mathrm{Clay}_{(\mathrm{H_2O})}}{\%\mathrm{Clay}_{(\mathrm{DCB})}} \times 100 \qquad (6)$$

The higher the CDR and DR, the more the ability of the soil to disperse and lost in runoff.

$$\mathrm{Ca}^{2+}:\mathrm{Mg}^{2+}\ \text{ratio} = \frac{\mathrm{Ca}^{2+}}{\mathrm{Mg}^{2+}} \qquad (7)$$

Aggregate stability

Soil samples were air dried and large clods were broken by hand. The air dried material was passed through a 5-mm sieve. Visible organic materials and debris were discarded. The samples were then oven dried at 105°C for 24 hours. Aggregate stability was measured according to Le Bissonnais (1996).

After oven drying, 5 g of soil samples were immersed in 50 mL deionized water for 10 minutes. Three replicates were used per sample. The water was sucked off with a pipette, and the material was gently transferred to a 50 µm sieve previously immersed in ethanol. The sieve was gently moved up and down in ethanol five times to separate the fragments <50 µm from those >50 µm. The remaining >50 µm fraction was oven dried at 105°C for 24 hours and gently sieved by hand on a stack of sieves of 2000, 1000, 500, 200, 100 and 50 µm pore size. The weight of each fraction was then measured, the weight of the soil fraction <50 µm was calculated as the difference between the initial weight and the sum of the weight of the other six fractions and expressed as the mean weight diameter (MWD). The MWD was calculated using the following equation (Hillel 2004)

$$\mathrm{MWD} = \sum_{i=1}^{n} w_i x_i, \qquad (8)$$

where x_i = mean diameter of the ith particular size range of aggregates separated by sieving and w_i = the weight of aggregates in ith size range as a fraction of the total dry weight of the sample analyzed.

Soil loss simulation

Soil loss was determined by rainfall simulation. Rainfall was applied as 8 minute single rainstorm at 360 mmh^{-1} intensity. Three runs of rainfall simulations were conducted per sample. A rainfall simulator for erosion tests (LUW, Eijelkamp Equipment, 6897 ZG Giesbeck, the Netherlands) was used. The simulator had 49 capillary tubes and applied raindrops of 5.9 mm in diameter. The splash cups containing the soil were slowly pre-wetted from the bottom with tap water until saturated and then placed under the rainfall simulator. The samples were subjected to simulated rainfall at 360 mmh^{-1}. The high-intensity rainfall was used to compensate for the short falling distance of 0.4 m, of each simulated raindrop and the resulting low volume specific kinetic energy of the applied shower as suggested by Martin et al. (2010). The time-specific energy of the simulated rain was 1440 J m^{-2} hr^{-1}. Natural rainfall events with this time-specific kinetic energy approximate natural rainfall intensities of about 60 mmh^{-1} (Martin et al. 2010). After each rainstorm, the splash cup was removed from the splash plate. Splashed sediment was washed out of the plate into a jar, oven dried at 105°C for 24 hours and weighed. The weight was converted from soil loss in grams per splash cup area (0.07 m^2) to tonnes per hectare. The following formula was used:

$$S = \frac{D}{100 \times A}\,\text{t/ha per 8 minute rainstorm of 360 mmh}^{-1}, \qquad (9)$$

where S is the sediment yield in t/ha, D is the measured sediments from the splash plate in grams and A is the surface area of the splash cup.

Statistical analysis of erodibility

Pair-wise correlations between soil loss and the observed soil properties were done using JMP. 11.0.0 Statistical software (SAS Institute, Inc., Cary, NC, USA, 2010).

Results and discussion

The higher the soil erodibility estimate value the higher the rate of soil loss. The average erodibility estimate (K-factor) of the soils was 0.0734 t ha $\mathrm{ha^{-1} MJ^{-1} mm^{-1}}$. The soil forms, ranked according to their levels of erodibility, were as follows: Hu>Va>Ss>Gs>Bo>Oa>Ka (Table 1).

The highest and lowest soil erodibility estimates were observed in Hutton and Katspruit soil forms, respectively (Table 1). Generally, the Hutton soil forms are not characterized by the dominance of smectitic clays minerals (Fey & Gilkes 2010) with a low erodibility. Singer (1994) reported decreasing aggregate stability with increasing smectite and inversely with kaolinite content. Again Wakindiki and Ben-Hur (2002) noted soils that contain smectite in contrast to the soils that contain kaolinite are more susceptible to water erosion. The Katspruit soil forms are characteristically poorly drained (Van Huyssteen et al. 2010) with moderate to high erodibity. The results were not consistent with these observations meaning erodibility of the soils was not influenced by the clay mineralogy.

Most soil forms had acidic reaction at all sampled depths and Bo was alkaline in the 5–30 cm depth range. The exchangeable Ca^{2+} and Mg^{2+} which promote aggregation dominated the exchange complexes of the soils. However, the measures of soil sodicity (ESP and SAR) of the soils were low (Table 2). Sodicity is associated with clay dispersion (CD) and high soil erodibility.

Sodic soils are considered to have SAR of > 13 and EC > 4 $\mathrm{dSm^{-1}}$. The EC of the soil ranges from 17.3 to 108 $\mathrm{\mu Sm^{-1}}$, showing salinity. Worldwide, a soil is considered to be sodic if the ESP is > 15 though an ESP value of > 5 is considered sodic (http://www.dpi.nsw.gov.au); in soils with lower electrolyte levels were the soils that can disperse at lower ESP (Amezketa et al. 2003). The balance between the various exchangeable cations and the concentration of total salts (measured by EC) determines whether clay will disperse in water. Soils that are non-saline and with ESP > 5 are prone to dispersion. Donstova and Norton (2002) did not find a threshold value of Ca:Mg ratio at which Mg had no specific effects on soil dispersion. However some chemical tests showed that Ca:Mg ratio < 2 indicates a tendency to disperse (http://www.dpi.nsw.gov.au). The Ntabelanga soils had an average Ca:Mg of 1.721 which indicates tendency of dispersibility. This can also be well supported by the diagonal relationship between Na and Mg on the periodic table in terms of soil properties. Soils high in exchangeable Mg disperse like sodic soils, hence the essence of using the Ca:Mg ratio in assessing erodibility.

Primary particle size analysis indicates that most of the soils belong to the fine sand and silt textural classes (Table 3). Few sites showed higher clay content. This suggests that very little force is required to detach and transport the soil particles, making them susceptible to erosion. Most of the soil samples showed very little percentage clay content with the highest being 33% and the lowest 4% (Table 3).

Clay (%) content showed a general decrease with depth on soils forms Katspruit, Oakleaf and Bo Abut increased with depth on soils forms Valsrivier, Hutton and Sterkspruit (Table 3). On average, the soils contained high sand (49%) and low clay particles (19%). The presence of clay material provides the required bondage between the varying soil particles, resulting in the formation of more stable aggregates which makes them less susceptible to erosion. The absence of clay reduces the tendency of soil particles to bind together and form aggregates that are resistible to the shearing force of flowing water, thus making the soil vulnerable to soil erosion. This tallies with findings by Parfitt et al. (2002) that there is a positive correlation between aggregate stability and clay content of soils. On the other hand, Toy et al. (2002) observed that soils with more sand and silt proportions than clay at the surface cap at the surface promote runoff, and are hence erodible. This could explain why the soils in Ntabelanga are highly susceptible to water erosion.

The soils were low (<2%) in SOC content which decreased with depth. The average SOC content for the soil in the study area ranged from 0.29 to 1.61%. Kemper and Koche (1966) and Greenland et al. (1975) suggested that a critical level of SOC is 2%, below which soil structural stability will suffer a significant decline.

The dispersion ratio (DR) values ranged from 0.26 to 1.46 with an average of 0.78. According to Middleton (1930), soils having a dispersion ratio greater than 0.15 are erodible in nature. This result, therefore, indicates that the soils from the study area are susceptible to erosion. The higher the CDR and DR, the more the

Table 2. Selected chemical properties of soils in the Ntabelanga area.

Location	Soil Depth range (cm)	Horizons	Soil forms	pH	Na^+	K^+	Ca^{2+}	Mg^{2+}	CEC	ESP	SAR	EC
					cmolc/kg							
CP1	0–5	ot.s		5.6	2.6	3.77	37.1	25.0	3.38	3.86	1.01	27.6
	5–15	ot	Ka	5.2	3.6	0.98	31.5	19.1	5.61	6.02	1.57	30.1
	15–30	gh		5.1	4	0.74	26.4	20.7	8.3	6.7	2.59	32.1
CP2	0–5	ml.s		6.7	1.4	1.24	53.3	35.1	33.9	1.15	0.47	26.0
	5–30	ml	Bo	7.1	2.3	1.08	57.2	35.2	29.7	1.84	0.98	50.1
	30–50	vp		5.9	1.9	0.75	43.4	28.9	42.3	1.59	0.64	40
CP3	0–5	ot.s		5.4	1.6	4.29	32.6	21.4	7.81	2.46	0.56	30.4
	5–25	ot	Oa	4.9	2.0	1.59	27.9	14.3	7.95	3.78	1.12	106
	25–50	re		5.3	2.0	1.46	28.7	25.6	5.46	3.25	1.7	17.3
CP4	0–5	ot		6.2	1.5	8.49	48.8	24.6	3.58	1.91	0.52	18.6
	5–20	ot	Va	5.8	1.0	2.7	48.3	19.4	7.41	1.37	0.48	17.9
CP5	0–5	ot		5.6	1.4	7.24	44.1	12.8	2.47	2.31	0.59	35.4
	5–30	ot	Hu	5.6	1.6	2.82	41.5	20.6	3.13	2.43	1.31	18.7
	30–50	re		5.9	1.9	3.6	55.1	27.3	42.3	1.48	1.47	18.3
CP6	0–50	ot		6.7	6.4	1.63	44.1	38.0	11.4	6.43	1.43	23.9
	50–80	pr	Ss	6.7	5.9	1.29	44.6	39.7	13.8	5.67	1.35	40.4
CP7	–	so	–	7.6	9.2	1.36	54	31.6	15.6	8.33	3.17	108
CP8	0–5	ot		6.2	3.6	3.35	47.3	29	6.95	4.1	1.06	41.6
	5–30	ot	Ka	5.2	4.8	1.25	29.9	18.7	9.07	7.67	1.45	37
	30–50	gh		6.3	14	1.53	35.3	33.8	7.37	15.47	3.14	80.5
CP9	0–30	ot	Gs	6.2	1.0	6.05	53.1	23.3	12.1	1.09	0.18	41.5
Mean				**6**	**3.5**	**2.72**	**42.1**	**25.9**	**13.3**	**4.23**	**1.27**	**40.1**
CV%				**13**	**88**	**78.9**	**22.96**	**28.58**	**70.73**	**84.52**	**87.24**	**64.67**

Note: ot = orthic A, ml = melanic A, vp = pedocutanic B, re = red apedal B, so = saprolite, gh = G horizon, Ka = Katspruit, Oa = Oakleaf, Va = Valsrivier, Hu = Hutton, Ss = Sterkspruit, Gs = Glenrosa.

ability of the soil to disperse and the more the soil loss. Igwe (2003) indicated that soils with high DR have the potential to erode more easily than those with lower DR. The soils showed a DR index of 0.35 or more in all the sampled depths. The clay dispersion ratios (CDRs) ranged from 0.35 to 0.88, which according to Igwe et al (1999) were relatively higher, implying that the soils erode easily. MWD decreased with depth while soil loss (SL) increased with soil depth (Table 3). MWD is an index that characterizes the structure of the macroaggregate by integrating the aggregate size class distribution into one number. Clay flocculation indices (CFIs) of the soils were low and a direct inverse of CRD. CFI values range from 0.13 to 0.65 with an average value of 0.38 and 37% coefficient of variation.

Table 3. Particle size distribution, aggregate stability and dispersion indices of soils in the Ntabelanga area.

Location	Depth (cm)	Horizons	Soil forms	Sand	Silt	Clay	SOC	MWD (mm)	DR	CFI	SL	CDR
					(%)							
CP1	0–5	ot.s		57	19	24	0.86	0.68	0.79	0.47	5.89	1.79
	5–30	ot	Ka	52	27	21	0.69	0.92	0.56	0.79	3.03	1.01
	30–50	gh		54	24	22	0.60	0.49	1.07	−0.1	11.03	2.04
CP2	0–5	ml.s		14	59	27	0.98	0.77	0.79	0.31	5.2	1.15
	5–30	ml	Bo	22	66	12	0.90	1.49	0.83	0.2	2.21	0.98
	30–50	vp		17	63	20	0.59	0.79	0.95	0.06	7.64	1.25
CP3	0–5	ot.s		45	26	29	1.43	2.20	0.44	1.19	1.61	0.92
	5–30	ot	Oa	47	28	25	0.97	1.29	0.26	1.39	0.76	0.5
	30–50	re		47	33	20	0.54	0.66	0.64	0.58	3.06	1.03
CP4	0–5	ot		83	12	5	0.90	1.67	0.65	0.5	1.55	0.92
	5–30	ot	Va	63	26	11	0.93	1.90	0.62	0.54	1.22	0.88
CP5	0–5	ot		83	12	5	0.29	0.32	1.35	−0.5	9.25	1.92
	5–30	ot	Hu	82	14	4	0.47	0.33	1.17	−0.2	8.3	1.5
	30–50	re		74	18	8	0.59	0.35	0.81	0.28	6.03	1.17
CP6	0–50	ot		44	39	17	0.47	0.66	1.46	−0.7	19.62	2.1
	50–80	pr	Ss	36	38	26	0.32	0.33	1.31	−0.5	22.72	2.21
CP7	–	so	–	34	45	21	0.39	1.10	0.66	0.5	2.54	0.99
CP 8	0–5	ot		41	26	33	1.54	2.03	0.39	1.38	1.15	0.88
	5–30	ot	Ka	40	28	32	1.15	1.35	0.45	1.18	1.75	0.96
	30–50	gh		41	31	28	0.70	1.17	0.56	0.84	2.01	1.06
CP9	0–30	ot	Gs	57	26	17	1.6	2.07	0.7	0.5	1.09	1.15
Mean				**49**	**32**	**19**	**0.81**	**1.07**	**0.78**	**0.41**	**5.60**	**1.26**
CV %				**34**	**49**	**46**	**46**	**57**	**78**	**37**	**105**	**22**

Note: ot = orthic A, ml = melanic A, vp = pedocutanic B, re = red apedal B, so = saprolite, gh = G horizon, Ka = Katspruit, Oa = Oakleaf, Va = Valsrivier, Hu = Hutton, Ss = Sterkspruit, Gs = Glenrosa, SOC = organic matter, MWD = mean weight diameter, DR = dispersion ratio, CFI = clay flocculation index, SL = soil loss (t/ha), and CDR = clay dispersion ratio.

Table 4. Relationship between soil loss and some soil physical properties.

	Soil loss	SOC	Sand	Clay	Silt	AGS	CDR	CFI
SOC	−0.603**							
Sand	−0.027	−0.139						
Clay	0.085	−0.052	−0.903**					
Silt	−0.878	0.402	−0.668	0.285				
AGS	−0.656	0.855**	−0.120	0.007	0.238			
CDR	0.887**	−0.544**	0.143	−0.096	−0.154	−0.660**		
CFI	−0.813**	0.702**	−0.155	−0.111	0.540**	0.683**	−0.836**	
DR	0.863**	−0.665**	0.161	0.056	−0.457	−0.685**	0.892**	−0.980**

Note: AGS = aggregate stability, values with **were significant at $P < .05$.

The dispersion ratio was positively and significantly correlated to soil loss; as the DR increased, the rate of soil loss also increased (Table 4).

Clay flocculation index (CFI) showed a negative significant correlation with soil loss. CFI also correlates significantly with CR, CDR and SOC and may be the best index to describe the degree of soil loss. The implication of this is that CFI alone could be used to predict soil erosion hazard and as CFI increases there is a corresponding increase in erosion hazard. CRD negatively correlated with CFI, SOC and MWD, thus confirming the role played by clay and organic matter content in the aggregation of soil. A review of soil science literature suggests that soils with SOC levels of 5% should achieve stability (http://www.treepower.org/soils). Bann and Field (2010) also noted that addition of organic matter to duplex soils increased soil porosity, thereby increasing infiltration and water-holding capacity of the soil and less potentially erosive runoff.

The aggregate stability showed a positive linear relationship to SOC (Figure 2).

Soil loss was significant and negatively correlated with organic carbon (%) and MWD. These results are congruent to Elliot's (1986) findings that organic carbon concentration increases with increasing aggregate size and stability. In another research, Toy et al. (2002) found that stable soil aggregates resist the beating action of rain, thereby saving soil even though runoff may occur. Soils with relatively low organic matter content are more vulnerable to water erosion (Brady & Weil 2002) as organic matter increases the stability of soil.

Soil loss was weakly correlated with ESP, SAR and cation exchange capacity (CEC) (Figure 3). The relation between soil loss, ESP and SAR was expected, because the threshold values were not attained, i.e. ESP>15 and SAR >13 (Table 2).

The dispersion of soils and the subsequent potential sealing and runoff are promoted by low concentrations, high SAR and pH values of electrolyte (Amezketa et al. 2003). The SAR of the soils was $<$ 13 and the EC was >4 dSm^{-1} so the soil dispersion was not due to the effects of Na^+ and this could explain the weak correlation.

Soil loss was significantly ($P < .05$) and negatively correlated with total organic carbon and aggregate stability. No other significant correlations were

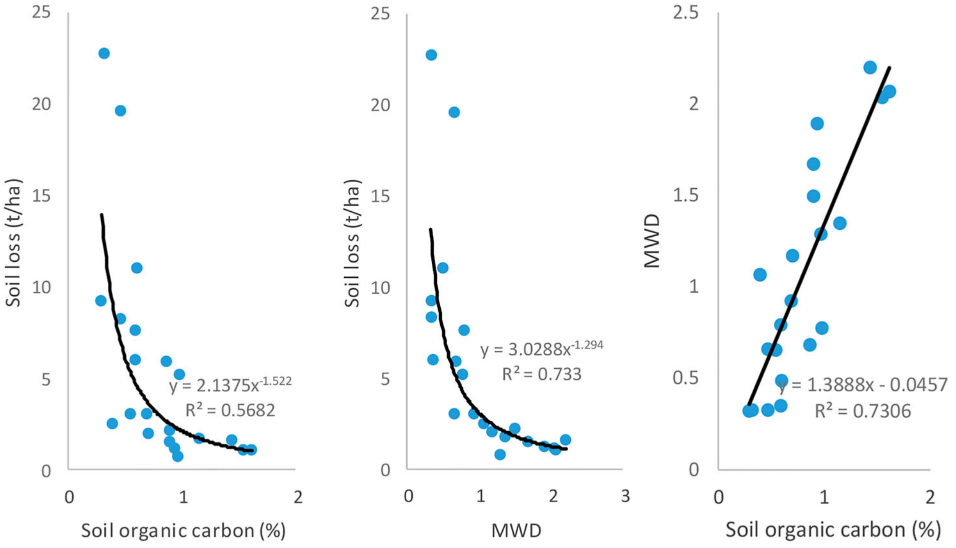

Figure 2. Relationship of SOC, MWD and soil loss.

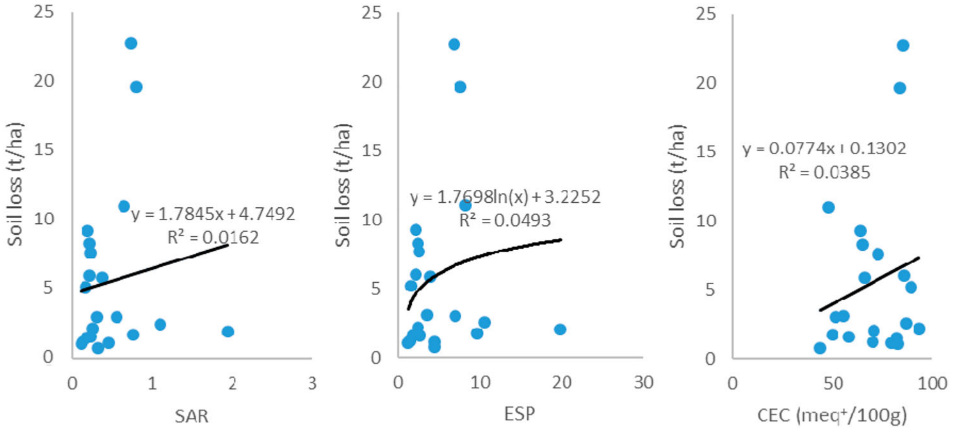

Figure 3. Relationship of soil loss with ESP, sodium adsorption ratio and CEC.

Table 5. Relationship between soil loss and some soil chemical properties.

	SOC	ECC	EC	AGS	Ca^{2+}	Mg^{2+}	K	Na	SAR	ESP	pH
SL	−0.60**	−0.24	0.01	−0.66**	−0.03	−0.01	−0.006	0.04	0.10	0.09	0.20
AGS	0.85**	0.15	−0.18	1.00	−0.38	−0.42	−0.28	−0.48	−0.33	−0.11	0.06
SOC	1.00	−0.03	−0.08	0.85**	−0.28	−0.31	−0.16	−0.50*	−0.45*	−0.23	−0.12
CDR	−0.54*	−0.33	−0.09	0.66*	−0.07	−0.06	−0.09	0.05	0.12	0.10	0.10
CFI	0.70**	0.33	−0.18	−0.81**	−0.19	−0.17	−0.09	−0.13	0.003	0.13	−0.31
DR	−0.67**	−0.34	0.11	0.86**	0.12	0.11	0.04	0.08	−0.01	−0.09	0.25

Note: SL = soil loss, SOC = total organic carbon, AGS = aggregate stability.
Pair values with * and ** were significant at $P < .001$ and $P < .05$, respectively.

observed between soil loss and other measured soil properties (Table 5).

Aggregate stability was positively correlated to total organic carbon. The results showed a linear relationship between soil aggregate stability and total organic matter. This agrees with Ekwue (1990) and King and Evans (1986) who also found the same linear relationship.

The results showed that Ntabelanga is dominated by sandy soils low in clay content. On average, the soils were classified as loam (49% sand, 32% silt and 19% clay). The soils are low in total organic carbon (<2%) and soil loss was classified as low (5 to 12 t/ha in 8 min single rainstorm of 360 mm h^{-1}). The low organic carbon greatly influenced the soil erodibility. Soil loss was inversely related to SOC and MWD. Soil loss increased with reduced levels of SOC (%). The greater the soil loss, the lower the SOC (%). Soil loss was reduced with an increase in the MWD.

Soil erodibility indices such as MWD, CD, CDR and CFI were influenced by the SOC of the soils. The MWD (mm) increased with increased levels of SOC while the DR and CDR increased with a decrease in the SOC. CFI of the soils showed to increase with an increased level of SOC. The SOC increased as the SAR value increased.

The soils were characterized by low ESP and SAR values. Most of the soils that contained low amount of exchangeable Na^+ did not influence the soil loss. The soils were not sodic.

It is evidenced from this study that high rates of soil loss in Ntabelanga is mainly due to the low content of organic carbon in the soil. Therefore in order to stabilize the soils against water erosion, land management practices that promote accumulation and addition of organic matter in the soils may be recommended.

Disclosure statement

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