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Using universal soil loss equation and soil erodibility factor to assess soil erosion in Tshesebe village, north east Botswana

Trust Manyiwa and Oagile Dikinya*

Department of Environmental Science, University of Botswana, Private Bag 00704, Gaborone, Botswana.

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Soil erodibility (K) factor in the Universal Soil Loss Equation (USLE), defines the resistance of soil to detachment by rainfall impact and/or surface flow force. Whilst there are a number of factors of erosion, this study aims to use erodibility factor and related length slope factor to assess soil erosional loss at field scale. To quantify soil erodibility the following properties were measured; texture, organic matter content and structural properties of the soil samples in eroded and non-eroded sites. Sub sampling was conducted in both eroded and non-eroded site and a total of six samples were collected in each site. In addition, slope length and slope angle were determined to evaluate the slope effect on the degree of soil loss associated with the K-factor. The measured or estimated K-factor value compared with the USLE K-based nomograph. The average soil erodibility (K-factor) was 0.031 and (t ha h ha^{-1} MJ^{-1}mm^{-1}) for eroded and non-eroded area, respectively. The high K-factor value in eroded area (almost doubled) was associated with low organic matter content (0.75%) compared to high organic matter in non-eroded (1.18%) as well as the significant slope (3°) in eroded than non-eroded areas (1°). The results also show that K-factor significantly ($P<0.05$) correlates with soil texture and organic matter due to their strong binding effect on aggregate stability and water infiltration hence enhanced particles' resistant to detachment. Interestingly there was no significant difference in K- factor values between eroded and non-eroded areas. Further, the K-factor based nomograph over-predicted the measured K-factor value by 10 times in eroded and 19 times in non-eroded soil, with a strong correlation in eroded (r^2=0.77) than in non-eroded (r^2=0.10).

Key words: Universal soil loss equation (USLE), soil erodibility, soil erosion, soil properties, eroded and non-eroded areas.

INTRODUCTION

Soil erosion is a major soil degradation threat in most vulnerable ecological systems especially in the fragile semi-arid environments like Botswana (where there is less biomass to sustain soil structural integrity). It is a serious problem associated with land use (Morgan, 1996). Soil erodibility (K-factor) has been used recently as an indicator of erosion (Parysow et al., 2003; Tejada and Gonzalez, 2006; Zhang et al., 2007) because of its susceptibility to particulate detachment and transport by erosion agents such as wind and water. In practice, K represents an integrated average annual value of the total soil and soil profile reaction to a large number of

* Corresponding author. E-mail:dikinyao@mopipi.ub.bw.

erosion and hydrological processes (Bonilla and Johnson, 2012). The K factor is one of the key parameters required for soil erosion prediction across the world (Zhang et al., 2007). Therefore assessment of erosional soil losses is the basis for effective conservation planning and management of the vulnerable ecosystems. There exist several models to predict the extent of water induced erosion (Brady and Weil, 2002, 2008) such as WEPP (La°en et al., 1991), EUROSEM (Morgan et al., 1992), and GUEST (Ciesiolka et al., 1995; Rose et al., 1997). EUROSEM and GUEST models have been developed to describe and quantify soil erosion processes and are particularly suitable for adaptation across arrange of scales in the landscape.The model deals with: the interception of rainfall by the plant cover; the volume and kinetic energy of the rainfall reaching the ground surface as direct through fall and leaf drainage; the volume of stremflow; the volume of surface depression storage; the detachment of soil particles by raindrop impact and by runoff; sediment deposition; and the transport capacity of the runoff (Morgan et al., 1992). On the other hand, WEPP is an American model based on a continuous simulation approach in which changing soil moisture conditions are modelled from daily calculations of the soil water balance. In this way, the conditions at the start of each rainstorm are predicted. The problems with continuous simulation models are that they require a large amount of input data on changing climatic and land use conditions over a year. These continuous simulation models are highly sensitive to the modelling of evapotranspiration and dynamic properties of the soils and they yield predictions for a large number of events that produce only small amounts of runoff and soil loss (Morgan et al., 1992).

However, the Universal Soil Loss Equation (USLE) has been useful in predicting the average rate of soil loss due to water erosion from agricultural lands (Wischmeier and Smith, 1978). In the early 1990s the basic USLE was updated and computerized to create an erosion prediction tool called the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997). The USLE/RUSLE soil loss prediction is dependent upon soil properties including texture, organic matter content and structure of the soil. The RUSLE uses the same basic factors of the USLE although some are modified and better defined. The predicted soil loss A is estimated using the following equation: A= RKLSCP, where; R=rainfall erosivity; K= soil erodibility; L= slope length; S = slope gradient or steepness; C= cover and management and P= erosion control practices.

Amongst the USLE factors,soil erodibility (K) factor is applicable to most tropical soils (El-Swaify and Dangler, 1976; Roose, 1977; Angima et al., 2003) and was found to strongly correlate with soil loss (Tejada and Gonzalez, 2006). The erodibility (K) factor reflects the ease with which the soil is detached by splash during rainfall and/or by surface flow especially on sloping areas (Angima et al., 2003). The two most significant and closely related soil characteristics influencing soil erodibility are infiltration capacity and structural stability (Millward and Mersey, 1999). These are largely influenced by soil texture, organic matter and soil plasticity. High infiltration capacity means that less water will be available for runoff and the surface is less likely to be ponded and more susceptible to splashing. In particular, soils which are highly permeable have high infiltration capacities (e.g. sandy soils)and are more prone to water erosion since the soil easily allows water to penetrate and therefore easily washed away (Zachar, 1982). On the other hand, stable aggregates resist the beating action of rain and thereby save soil even though runoff may occur. The factors that determine aggregate stability include bulk density, Atterberg limits as well as texture and organic matter content of soils (Toy et al., 2002).

Moreover, soils with larger sand and silt proportions are more vulnerable to water erosion due to lack of stability of soil particles (Toy et al., 2002). Similarly, soils with relatively low organic matter content are very vulnerable to water erosion (Brady and Weil, 2002) since organic matter increases the stability of soil. A 36% decrease in K-factor value was observed in organic matter amended soil in respect to the control (Tejada and Gonzalez, 2006). Furthermore, the susceptibility of soil to water erosion also depends on slope length (Toy et al., 2002) and is most prevalent in sloping areas (Angima et al., 2003). Liu et al. (2000), in their studies on 'slope length effect on soil loss for steep slopes' also reported the greater sensitive of slope effect to soil loss due to differences in rainfall. Whilst there are a number of factors of erosion, this study does not intend to cover all the factors of soil erosion. Rather it focuses on the erodibility or (K) factor and related factors of slope length (LS) factor in assessing soil erosion in typical tropical soil in fragile semi-arid environment Botswana. Thus the objective of the study was to use or apply erodibility K-factor as an indicator of erosion to assess erosion in Tshesebe village, north east Botswana. The village used as a case study is an agricultural area and was observed to be vulnerable to erosional losses as evidenced by gully formations in the area.

MATERIALS AND METHODS

Description of study area

The study area is located in Tshesebe village(20°45'0" N and 27°34'0" E, with an elevation of about 1170 m) in the North East District of Botswana (Figure 1). The area receives about 506 mm of rainfall, with the highest rainfall in December and January and receives nil rainfall on June and July. Generally the daily maximum temperatures range between 27.3 and 35°C, while the mean temperatures range between 6.1 and19.7°C (Radcliffe,et al 1990). The village lies in the ecological zone known as hardveld, characterized by predominance of tree Savanna and acacia scrub. The vegetation is thick along Ntsheriver and streams found in the area. Mophane trees (*colospermummophane*) and *terminaliasericia*are also very common in the area. The soils are predominantly imperfectly drained Luvisols and Arenosols

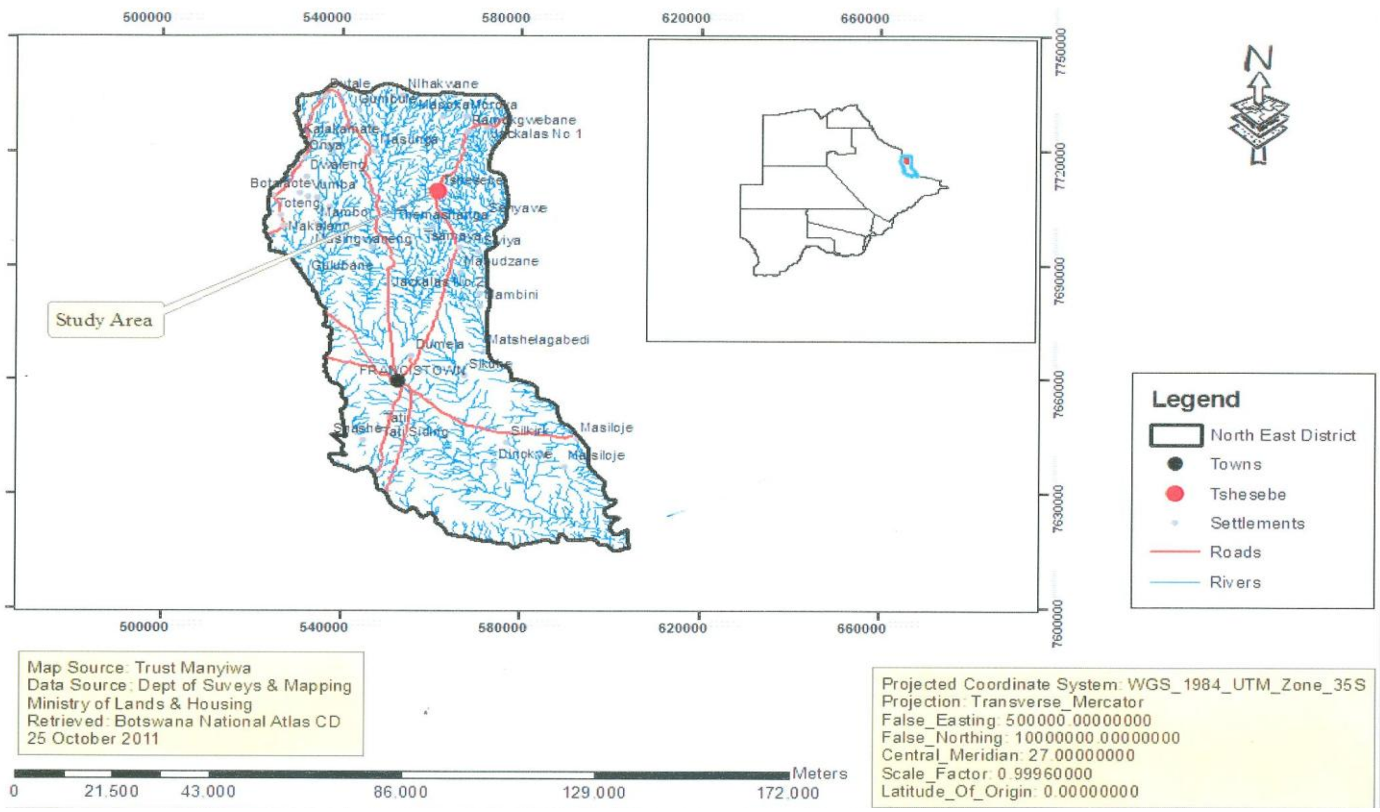

Figure 1. The study area.

(Anon, 1991). The geological parent material is gneiss (Radcliffe et al., 1990). Soil erosion is prevalent as evidenced by gully formations in the area.

Sampling and soil morphological properties measurements

Soil samples were collected from eroded and non-eroded surface soils that is, from sampling points; A1, B1, C1, D1, E1 and F1 and A2, B2, C2, D2, E2 and F2 from eroded area and non-eroded area (control sites), respectively. Sampling depth was 0 to 15 cm and 15 to 30 cm and the samples were mixed to form a composite sample. Samples from the eroded sites were collected on a line parallel to the slope direction. Samples were then passed on a 2 mm sieve for laboratory analysis. Soil morphological properties including soil structure type, class and permeability class were also collected based on FAO (2006), (Table 1).

The K-factor parameter determinations

Selected physical properties related to texture and structure of soils were measured including particle size analysis, soil bulk density, plastic limit and liquid limit and soil organic matter to quantify soil erodibility factor.

Particle size analysis

Soil texture was determined using the Hydrometer or the Bouyoucos method for mechanical analysis or particle size analysis by measuring the proportion of different sized particles in a soil and hence it's textural class. This is because for most agricultural purposes, the Bouyoucos method is sufficiently precise (Hanks and Ashcroft, 1970).

Bulk density and porosity

The core method was used to determine the soil bulk density and porosity. A cylindrical tube (5 cm long, 5 cm diameter) was driven into the soil to collect the samples. The bulk density and porosity of soil samples were estimated according to Rowell (1994).

Atterberg limits determination

Atterberg limits were measured using standard American Society for Testing and Materials (ASTM) devices (Faniran and Areola, 1978). Atterberg limits refers to the water content of fine grained soils at different states of consistency and are based on plastic limit (PL) and liquid limit (LL) and more importantly on plasticity index (PI). The plastic limit is the water content (in %), at which soil can no longer be deformed by rolling into 3.2 mm diameter without crumbling. While liquid limit is water content at which a soil changes from plastic to liquid behavior. The plasticity index is a measure of plasticity or the difference between the liquid limit and the plastic limit (that is, PI = LL-PL). The Casagrande Method was used to determine attaerberg limits (McBride, 1993).

Soil organic matter

Soil organic matter was determined using the Walkley-Black

Table 1. Surface soil structure, slope angle and length for both eroded and non-eroded areas.

Parrameter	Eroded	Non-eroded
*Soil structure	Granular	Crumb
*Soil structure class	1	1
*Permeability Class	2 = moderate to rapid	3 = moderate
Slope length (m)	20 m	9 m
Slope angle (°)	3°	1°

*Defined according to (FAO, 2006).

Method (Tiessen and Moir, 1993).

Statistically analysis

Statistically data analysis was done using methodology by Wheater and Cook (2003) for the t-test (paired and unpaired) and to check if there is any significant difference between eroded and non-eroded areas at significance level of P<0.05 (or 95% confidence limit). The t-test was computed according to the following equation:

$$t=\frac{\bar{x}_1-\bar{x}_2}{S\bar{x}_1-\bar{x}_2} \quad \text{....} \qquad (1)$$

Where, $S\bar{x}_1 - \bar{x}_2 = \sqrt{\frac{S_1^2}{\bar{n}_1} + \frac{S_2^2}{\bar{n}_2}}$ and $\bar{x}$= mean of samples, n = sample size and S = variance.

RESULTS AND DISCUSSION

Parameterization of erodibility factor

Soil particle size distribution, organic matter, structure and slope effects

Particle size analysis and respective soil textural class are presented in Table 2. Generally, the results show that sand content is generally high in all samples (Table 2). Soil textural class for soils in the eroded area is mainly sandy (at least 68%) characterized by weak structure and granular type (Table 1). The weak structure (granular) as evidenced by the relatively low organic matter (0.75% for eroded and 1.18% for non-eroded areas, Table 2) makes the soil susceptible to erosion in eroded areas. This was supported by Ball (1990) who reported an increase of erosion with decreasing organic matter. On the other hand, soil samples in the non-eroded area have more clay (27%) and are less susceptible to erosion. Similarly, the slope lengths and slope angles of the eroded area are high (20 m and 3°, respectively) as compared to those in non-eroded area (9 m and 1°). Slope length and slope angle contribute to the erodibility of soil as slope leads to colluvial deposited materials (Brady and Weil, 2002) and hence more erosional loses. This is because slope leads to materials being transported by mass movement, while in the non-eroded areas the slope is relatively flat and less material is transported hence less erosional losses as manifested by low K-factor values [0.031 (t ha h ha^{-1} $MJ^{-1}$$mm^{-1}$)].

Similarly, Table 2 shows that organic matter content is higher for non-eroded areas (1.18%) than eroded (0.75%) and it is in agreement with Charman and Murphy (1991) who stated that when organic matter is high, the soil will be less susceptible to erosion because of the binding effect of organic matter and therefore less vulnerability to particle detachment. The high organic matter in non-eroded area is high probably because of undisturbed litter as evidenced by presence of vegetation. This litter leads to the formation of humus which contributes to more organic matter in the non-eroded area (Brady and Weil, 2002).

Soil bulk density and porosity

Generally bulk density was higher in non-eroded than eroded sites because of surface structural loss (Figure 2a) whereas the porosity (which is indirectly proportionally to bulk density) was lower in non-eroded than eroded sites (Figure 2b). For instance, the average bulk density is 1.52 and 1.25 g/cm^3 for non-eroded and eroded area, respectively. The average porosity is 28 and 44% for non-eroded and eroded areas, respectively. This is because as particles are eroded soil material becomes loose, therefore reducing the bulk density and increasing soil porosity (Abu-Hamdeh and Al-jalil, 1999). The higher density is also attributed to high clay content (binding effect) in the non-eroded soil thus making it less vulnerable to erosion.

Plastic limit, liquid limit and plastic index

Plastic limit is the moisture content that defines where the soil changes from a semi solid to a plastic (flexible) state while the liquid limit is the moisture content that defines where soil changes from a plastic to viscous fluid state (Reddy, 1999). Plastic limit of the soil samples ranged 2.7

Table 2. Particle size distribution for eroded and non-eroded areas.

	Eroded area					
Sampling point	% clay	% silt	% sand	Textural class	Organic matter	
					%OM	%OC
A1	15	4	77	Sandy loam	0.50	0.29
B1	16	3	81	Sandy loam	0.74	0.43
C1	30	5	65	Sandy clay loam	0.58	0.34
D1	32	5	65	Sandy clay loam	0.52	0.30
E1	28	5	68	Sandy clay loam	0.80	0.46
F1	27	5	64	Sandy clay loam	1.35	0.78
Mean ($\bar{x}$)	25	5	77	Xxxxxxx	0.75	0.43
				Non-eroded area		
Sampling point	% clay	% silt	% sand	Textural class	Organic matter	
					%OM	%OC
A2	36	4	60	Sandy clay loam	0.80	0.46
B2	19	8	73	Sandy loam	1.49	0.86
C2	16	4	80	Sandy clay loam	1.13	0.65
D2	23	9	68	Sandy clay	1.10	0.64
E2	32	3	64	Sandy clay loam	1.40	0.81
F2	36	5	60	Sandy clay loam	1.21	0.70
Mean ($\bar{x}$)	27	6	68	Xxxxxxxxx	1.18	0.69

Where OM and OC is Organic matter and Organic carbon respectively.

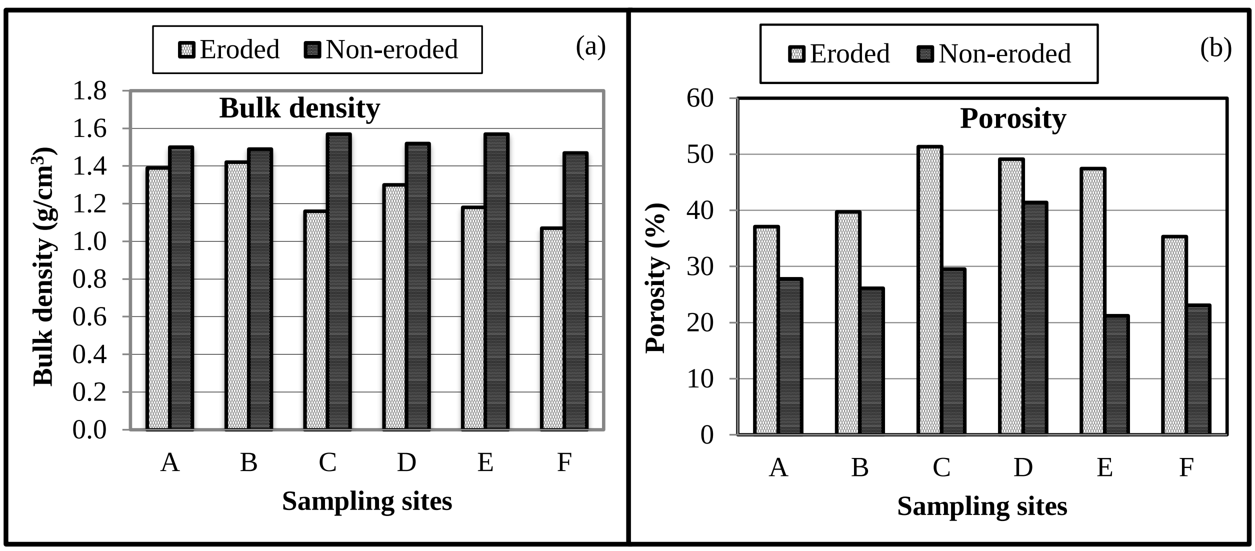

Figure 2. Soil bulk density (a) and porosity (b) for eroded and non-eroded sites.

to 6.8% in eroded and 3.1 to 6.8% in non-eroded. In general this reflects high structural stable soil material or high resistance to detachment in non-eroded sites and hence less vulnerability. In most cases % plastic limit and liquid limit are high in eroded than non-eroded areas and similar observation were reported by Nandi and Luffman (2012). The plastic index is high in eroded areas with an average of 16.3% (Figure 3) probably due the sandy nature of the soil (Table 2). This is in contrast withReddy (1999) who reported thatwhen the plastic index of a soil is high it will not be easily eroded. Other factors like slope angle also contribute to the erodibility of the soil. The results also indicate that non-eroded areas have low plastic limit but they are not easily eroded due to a flat area and some vegetation cover thus preventing erosion even though its plastic limit is low. Similarly the average plasticity index was 16.3 and 14.4%, respectively for eroded and non-eroded areas and this has an influence on soil erodibility. For instance, soils with low plastic limit have high organic matter Ball (1990) thus explaining large erodibility in eroded area (with relatively high low organic matter). Soils with high content of clay particles

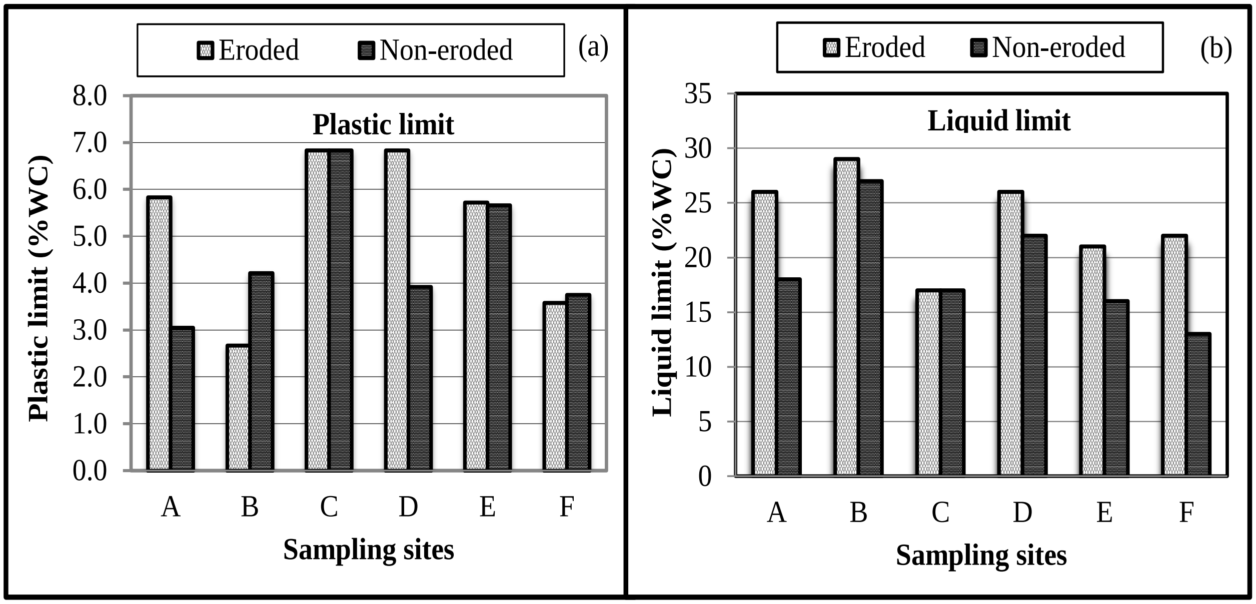

Figure 3. The plastic limit (a) and liquid limit (b) for both eroded and non-eroded areas.

normally have high liquid limit and plastic limit because of the binding potential of clay particles with instant retardation of detachment. While sand particles are easily merged together (because of no binding) hence they easily come together and lead to low plastic and liquid limit.

Table 3 shows that the eroded and non-eroded areas differ significantly in soil porosity, soil organic matter, plasticity limit, soil porosity, percentage sand, percentage clay and slope angle and slope length. This is attributed to that as soil is eroded top soil is washed away which is rich in humus and organic matter thus leading to a significant difference in soil organic matter between eroded and non-eroded areas. Erosion also washes away finer soil particles leaving sand particles in the eroded area compared to non-eroded area with less sand particles. Soil porosity differed due to difference in particle size distribution and therefore soil porosity influences plastic limit.

Quantifying and estimating soil erodibility factor

Direct measurement of erodibility (K) factor requires long-term data and time consuming, there exists few techniques developed to estimate the K factorvalues from readily available data on soil properties (Römkens et al., 1997; Zhang et al., 2008). Several monographs have been also developed to quantitatively estimate soil erosion based on soil properties at field or farm scale (Wischmeier et al., 1971; Wischmeier and Smith, 1978; Vaezi et al., 2011). To quantify the effects of the parameteric erodibility factors on erosion, the following equation was used (Williams et al., 1984):

$$K = \left\{0.2 + 0.3e^{\left[-\frac{0.256SAN(1-SIL)}{100}\right]}\right\} \left(\frac{SIL}{CLA} + SIL^{0.3} \; x \left(1.0 - \left(\frac{0.25C}{C+e}\right)\left(\frac{0.25C}{C+e}\right)\right.\right. (3.72 - 2.95)(1.0 - 0.7SN1 + e(-5.51 + 22.9SN1) \quad (2)$$

Where; SAN, SIL and CLA are %sand, %silt and %clay fractions, respectively, and C is the soil %organic carbon content (%) and SN1=(1-SAN/100).

Based on the computations from Equation 2, the K-factor value ranged from 0.013 to 0.055 (t ha h ha^{-1} $MJ^{-1}mm^{-1}$) for eroded and 0.012 to 0.026 (t ha h ha^{-1} $MJ^{-1}mm^{-1}$) for non-eroded soils. The results generally shows that the eroded areas have average higher K- factor values [0.031 (t ha h ha^{-1} $MJ^{-1}mm^{-1}$)] while non-eroded areas have lower K- factor values [0.018 (t ha h ha^{-1} $MJ^{-1}mm^{-1}$)]. According to Wawer et al. (2005), soils high in clay content have low K- factor values because they are resistant to detachment because of the binding effect of clay. This is evidenced by the high clay content for non-eroded (28.2%). Similarly, non-eroded soils are less affected by erosion due to high organic matter (1.2%) while eroded areas have relatively low organic matter content (0.75%). This organic matter binds the soil particles together and creates forces between particles and thus creating stability (Brady and Weil, 2008)(Figure 3).

Although the difference in the K-factor between eroded and non-eroded areas is not statistically significant, it is still worth to note that the two areas differ significantly in soil porosity, soil organic matter, plasticity limit, soil porosity, percentage sand, percentage clay and slope angle and slope length (Table 4).

The higher K- factor values for eroded areas indicate that the soils are more prone or susceptible to erosion (Wawer et al., 2005), probably because of high %sand in eroded areas (67.6%). The high sand content contributes

Table 3. Significant difference of parameterized erodibility (K) factor properties for eroded and non-eroded areas at P>0.05.

Property	*Eroded* ($\bar{x}$), (n=6)	Variance (S_1^2)	*Non-eroded* ($\bar{x}$), (n=6)	Variance (S_2^2)	Computed t-value	Significant difference (t-test)
Bulk density	1.25	0.16	1.52	0.03	1.79	Not significant
Porosity	43.30	5.71	28.20	1.22	2.51	Significant
Plastic limit	7.17	4.32	4.57	5.25	3.13	Significant
Liquid limit	23.50	6.84	18.80	5.23	0.44	Not significant
Plasticity index	16.33	5.57	14.43	6.99	2.09	Not significant
%Organic matter	0.75	0.32	1.18	0.25	2.68	Significant
% Sand	67.60	10.14	66.40	8.12	4.58	Significant
% Silt	5.30	2.25	5.45	2.30	0.14	Not significant
% Clay	26.90	8.49	28.20	8.95	3.75	Significant
Slope angle and slope length	9°and 20 m	12.02	1^o 9 m	5.66	14.57	Significant

Table 4. Significant difference of K-values for eroded and non-eroded areas at P>0.05.

Values	Eroded	Non-eroded	t-value	Significant difference (t-test
($\bar{x}$), (n=6	0.031	0.018	1.91	Not significant
Variance (S_1^2)	0.015	0.005		

to less binding of aggregates hence easily eroded. Similarly the low clay content (27%) resulted in increased K- factor value of eroded soils since clay particles hold soil particles together and make them resistant to detachment (Zhang et al., 2007). On the other hand the high K- factor value in eroded soils was primarily due to low organic matter content (0.75%) because organic matter has the capacity to bind soil particles together (Brady and Weil, 2008). Other than relatively low clay and organic matter in non-eroded areas, the high K- factor value is a result of granular soil structure since it is generally more stable than and crumb structure (Daum, 1996).

To evaluate the effectiveness of USLE-K model, comparison between the measured (Williams et al., 1984) erodibility data with the (Wischmeier et al., 1971) nomograph data was done. The nomograph (which relates K to soil properties) was developed by Wischmeier et al. (1971) with the following equation form:

$$100K = 2.1 \times 10^4 \times (2 - OM) \times M^{1.14} + 3.25 \times (St\text{-}2) + 2.5 \times (Pt - 3) \quad (3)$$

Where, OM = Organic matter content (%), M = Silt plus fine sand content (%), St = Soil structure code (very fine granular = 1, fine granular = 2, coarse granular = 3, blocky, platy or massive = 4), Pt= Permeability class (rapid = 1, moderate to rapid = 2, moderate = 3, slow to moderate = 4, slow = 5, very slow = 6).

The equation was chosen because the K-factor is a lumped parameter that represents an integrated average annual value of the soil profile reaction to the processes of soil detachment and transport by raindrop impact and surface flow (Renard et al., 1997). Consequently K-factor is best obtained from direct measurements on natural plots (Kinnell, 2010). However, this is an infeasible task on national or continental scale. To overcome this problem measured K-factor values have been related to soil properties. The most widely used relationship is the soil-erodibility nomograph of Wischmeier and Smith (1978) (Table 5).

Conclusion

The results have shown that erodibility factor K significantly correlates with slope length, organic matter and %clay fractions as well as with structural properties including plastic limit, plastic index, bulk density and soil porosity. Generally the erodibility K-factor values were high in eroded than non-eroded areas. The average K-factor value in eroded area was 0.031 (t ha h ha^{-1} $MJ^{-1}mm^{-1}$) with a range of 0.013 to 0.055 t h (t ha h ha^{-1} $MJ^{-1}mm^{-1}$). Similarly the average K-value in non-eroded area was 0.018 t h $(MJmm)^{-1}$ with a range of 0.012 to 0.026 (t ha h ha^{-1} $MJ^{-1}mm^{-1}$). Soils in the eroded areas with limited organic matter and subsequently high erodibility values hence large proportionately erosional losses. Interestingly there was no significant difference in K- factor values between eroded and non-eroded areas at P<0.05. Further, the K-based nomograph over-predicted the measured K-factorvalue by 10 times in eroded and 19 times in non-eroded soil, with a stronger correlation in eroded (r^2=0.77) than in non-eroded (r^2=0.10).

Table 5. The comparison of nomograph-based estimates of erodibility factor (K_{nom}) and measured erodibility factor (K_{meas}) for eroded and non-eroded.

Sampling point	Eroded			Non-eroded		
	K_{meas}	K_{Nom}	K_{Nom}/K_{Meas}	K_{meas}	K_{Nom}	K_{Nom}/K_{Meas}
A	0.027	0.30	11.1	0.017	0.30	17.6
B	0.013	0.24	18.5	0.019	0.41	21.6
C	0.021	0.31	14.8	0.026	0.30	11.5
D	0.043	0.31	7.2	0.012	0.45	37.5
E	0.055	0.45	8.2	0.013	0.27	20.8
F	0.026	0.31	11.9	0.020	0.31	15.5
Mean	0.031	0.32	10.3	0.018	0.34	19.1

K_{meas} – computed from the Williams 1984 equation and KNo_m – nomogaph (Wischmeier et al., 1971).

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REFERENCES

Abu-Hamdeh N, Al-jalil HF (1999). Hydraulically powered soil core sampler and its application to soil density and porosity estimation. Soil. Tillage Res. 52:(1-2):113-120.

Angima SD, Stott DE, O'Neill MK, Ong MK, Weesies GA (2003). Soilerosion prediction using RUSLE for central Kenyan highland conditions. Agric. Ecosyst. Environ. 97(1-3):295-308.

Anon A (1991). Soil Map of the Republic of Botswana.Soil Mapping and Advisory Services.FAO/UNDP/Botswana Government, Gaborone.

Ball A (1990). Soil Properties and Their Uses.John Wiley and Sons. London.

Bonilla CA, Johnson OI (2012). Soil erodibility mapping and its correlation with soil properties in Central Chile. Geoderma: 189–190, 116–123.

Brady CN, Weil RR (2008). The Nature and Properties of Soils. 14th Edition, Prentice Hall: New Jersey.

Brady CN, Weil RR (2002). The Nature and Properties of Soils. 13th Edition, Prentice Hall: New Jersey.

Ciesiolka CAA, Coughlan KJ, Rose CW, Escalante MC, Hashim GM, Paningbatan EP, Sombatpanit S (1995). Methodology for a multi-country study of soil erosion Manage. Soil Technol. 8:179-92.

Charman PE, Murphy BW (1991). Soils Their Properties and Management. Oxford University Press: New York.

Daum DR (1996). Soil compaction and conservation tillage. Conservation Tillage Series 3: U.S. Department of Agriculture: Agricultural Research Service.

El-Swaify SA, Dangler EW (1976). Erodibilities of selected tropical soils in relation to structural and hydrologic parameters. In: Foster, G.R. (Ed.), SoilErosion Prediction and Control. Soil and Water Conservation Society, Ankeny, IA, USA, pp. 105–114.

Faniran AO, Areola O (1978). Essentials of Soil Study (With Special Reference to Tropical Areas) London: Heinemann. Appendix: Laboratory Techniques of Soil Analysis, pp. 237-266.

FAO (2006). Guidelines of soils description, 4th ed. Rome. United Nations.

Hanks RJ, Ashcroft GL (1970).Physical properties of soil, Logan, Utah.

Kinnell PIA (2010). Event soil loss, runoff and the Universal Soil Loss Equation family of models: a review. J. Hydrol. 385:384e397.

La°en JM, Lane LJ, Foster GR (1991). WEPP: A new generation of erosion prediction technology. J. Soil Water Conser. 46(34):8.

McBride RA (1993). Soil consistency limits. In: M.R Carter (ed) "Soil Sampling Methods *of* Analysis," Lewis Publishers, Boca Ratan, FR: pp. 519-529.

Millward AA, Mersey JE (1999). Adapting the RUSLE to model soil erosion potential in a mountainous tropical watershed. Catena 38(2):109-129.

Morgan RPC, Quenton JN, Rickson RJ (1992). EUROSEM: Documentation Manual.' (Silsoe College: Silsoe, UK).

Morgan RPC (1996). Soil erosion and conservation. Addison-Wesley Boston MA.

Nandi A, Luffman E (2012). Erosion Related Changes to Physicochemical Properties of Ultisols Distributed on Calcareous Sedimentary Rocks. J. Sustain. Develop. 5:8.

Parysow P, Wang G, Gertner G, Anderson A (2003). Spatial uncertainly analysis for mapping soil erodibility on joint sequential simulation. Catena 53:65–78.

Radcliffe DJ, Venema JH, De Wit PV (1990). Soils of North Eastern Botswana. Government of Botswana.

Reddy K (1999). Engineering Properties of Soils Based on Laboratory. UIC.

Renard KG, Foster GA, Weesies GA, McCool DK (1997). Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE).'Agriculture Handbook No: 703: USDA: Washington, DC.)

Römkens MJM, Young RA, Poesen JWA, McCool DK, El-Swaify SA, Bradford JM (1997). Soil erodibility factor (K), in: Renard, K.G., Foster GR, Weesies GA, McCool DK, Yoder DC (Compilers), Predicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised Universal Soil Loss Equation (RUSLE). Agric. HB No. 703, USDA, Washington, DC, USA, pp. 65–99.

Roose EJ (1977). Application of the Universal Soil Loss Equation of Wischmeier and Smith in West Africa. In: Greenland, J., Lal, R. (Eds.). Conservation and Soil Management in the Humid Tropics. Wiley, Chichester, England, pp. 177–187.

Rose CW, Coughlan KJ, Ciesiolka CAA, Fentie B (1997). Program GUEST. (Grifth University Erosion System Template).In `A New Soil Conservation Methodology and Application to Cropping Systems in Tropical Steeplands'. (Eds K. J. Coughlan and C. W. Rose.) ACIAR Technical Report.

Rowell DL (1994). Soil Science: Methods and Applications, Longman Scientific and technical, England.

Tejada M, Gonzalez JL (2006). The relationships between erodibility and erosion in a soil treated with two organic amendments. Soil. Tillage. Res. 91:186–198.

Tiessen HJ, Moir O (1993). Total and organic carbon. In: Soil Sampling and Methods of Analysis, M.E. Carter, Ed. Lewis Publishers, Ann Arbor, MI. pp. 187-211.

Toy JT, George RF, Kenneth GR (2002). Soil Erosion.John Wiley & Sons Inc. New York.
Vaezi AR, Bahrami HA, Sadeghi SHR, Mahdian MHS (2011). Developing a nomograph for estimating erodibility factor of Calcareous soils in north west of Iran. Int. J. Geol. 4(5):93–100.
Wawer R, Nowocieñ E, Podolski B (2005). Real Calculated K-USLE Erodibiliity Factor for Selected Polish Soils. Polish J. Environ. Stud. 14(5):655-658.
Williams JR, Jones CA, Dyke PT (1984). A Modeling Approach to Determining the Relationship between erosion and productivity. Transactions of the ASAE 27(1):129-144.
Wheater CP, Cook PA (2003).Using Statistics to Understand the Environment. Routledge: New York.
Wischmeier WH, Smith DD (1978). `Predicting Rainfall Erosion Losses: A Guide to Conservation Planning.'Agriculture Handbook No. 537. (USDA: Washington, DC.).
Wischmeier WH, Johnson CB, Cross BV (1971).A soil erodibilitynomograph for farmland and construction sites. Soil Water Conser. 26:189–193.
Zachar D (1982). Soil Erosion. Prentice Hall, Upper Saddle River: New Jersey.
Zhang KL, Shu AP, Xu XL, Young QK, Yu B (2008). Soil erodibility and its estimation for agricultural soils in China. J. Arid Environ.11:1-10
Zhang ZG, Fan BE, Bai WJ, Jiao JY (2007). Soil anti-erodibility of plant communities on the removal lands in hilly-gully region of the Loess Plateau. Science Soil Water Conser. 5:7-13.