

Evaluation and mapping of soil erosion susceptibility: an example from Kenya

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Abstract. The erosion susceptibility of the Erosion Research Farm at Kabete Campus was mapped using a qualitative parametric method. A grid soil survey of the 4 ha farm was combined with a map of slope gradients, slope segments being delineated by breaks in slope. Rainfall erosivity and soil erodibility were also measured. Areas with the greatest erosion susceptibility according to this method were those occupying convex slope positions and slopes of more than 30%. Field observations and soil loss measurements generally supported the erosion susceptibility rating map produced by this method. The soil and erosion susceptibility maps were useful for planning erosion control measures and for selecting suitable sites for runoff plot experiments.

Keywords: Erosion, susceptibility, evaluation, mapping, erosivity, erodibility, soil

INTRODUCTION

The seriousness of soil erosion in many parts of Kenya (Barber, 1983) demands knowledge of vulnerability of soils to erosion. Soil erosion susceptibility depends on relatively permanent factors such as climate, topography and soil properties, and is therefore an inherent characteristic of the land (Bergsma, 1973; Morgan, 1988). It shows the risk of erosion to be expected without protection afforded by vegetation cover, and in the absence of soil conservation practices.

In Kenya, efforts have been made to assess erosion susceptibility using qualitative methods in which slope length and gradient, soil erodibility and climatic erosivity are rated on a scale of low to high risk (e.g. Gelens *et al.*, 1976; Braun & Van der Weg, 1977; Gachene & Weeda, 1984). A disadvantage of this system is that each factor is given equal weighting. In particular, the method underestimates the erosion susceptibility of areas with long slope lengths (Braun & Van der Weg, 1977).

In this study, the erosion susceptibility of a 4 ha area was mapped at a large scale. First a detailed soil map was produced. A qualitative parametric method, similar in some respects to the method proposed by FAO (1979) for assessing soil degradation risk, was then used to assess erosion risk. This approach is rather tedious and time consuming, but it gives a more realistic assessment of comparative erosion susceptibility than that currently being used in Kenya (Gachene & Barber, 1983).

MATERIALS AND METHODS

The study area

The Erosion Research Farm is located at Kabete Campus, College of Agriculture and Veterinary Sciences, University of Nairobi, approximately 12 km WNW of Nairobi city and at an altitude of about 1940 m above sea level. It has a

rainfall record of 18 years and has two rainfall seasons: the long rains (March–May) and the short rains (October–December). Mean annual rainfall is approximately 1006 mm. According to the Kenya Soil Survey agroclimatic zonation (Sombroek *et al.*, 1980), the climate of the area is semi-humid (average annual rainfall/average annual potential evaporation (r/E_o) of 58%).

The 4 ha farm is underlain by Nairobi trachytes of Tertiary age and has undulating to hilly topography. A small area in the west is part of a minor river valley with flat to very gently undulating depositional topography. Most of the area is covered by grasses and shrubs; the rest has been recently cleared to evaluate different types of terracing.

A soil map of scale 1:1400 was produced (Fig. 1), classifying the soils by the FAO/UNESCO system (FAO, 1990). The dominant soils are Humic Nitisols (soil mapping unit NTu). Slope gradients were measured with a clinometer and slope lengths were measured with a tape. The lengths of slope segments were measured from a cutoff drain or diversion ditch (an open trench with an embankment on the lower side) downslope at right angles to the contours, and were delineated by breaks in slope gradient (Fig. 1). Soil samples from each map unit were taken for routine laboratory analysis using the methods outlined by Hinga *et al.* (1980).

Evaluating erosion factors

The erosion factors and hence the erosion susceptibility were evaluated by a qualitative parametric approach based on some of the factors used in the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978). The erosivity (R) factor (t/ha/cm rainfall per year) was calculated from the following regression:

$$R = 0.029KE - 26.0 \quad r = 0.95, n = 11 \quad (1)$$

where KE is the kinetic energy of rain falling at intensities greater than 25 mm/hr for 15 minute periods (Moore, 1979). The KE values for the farm were obtained from the

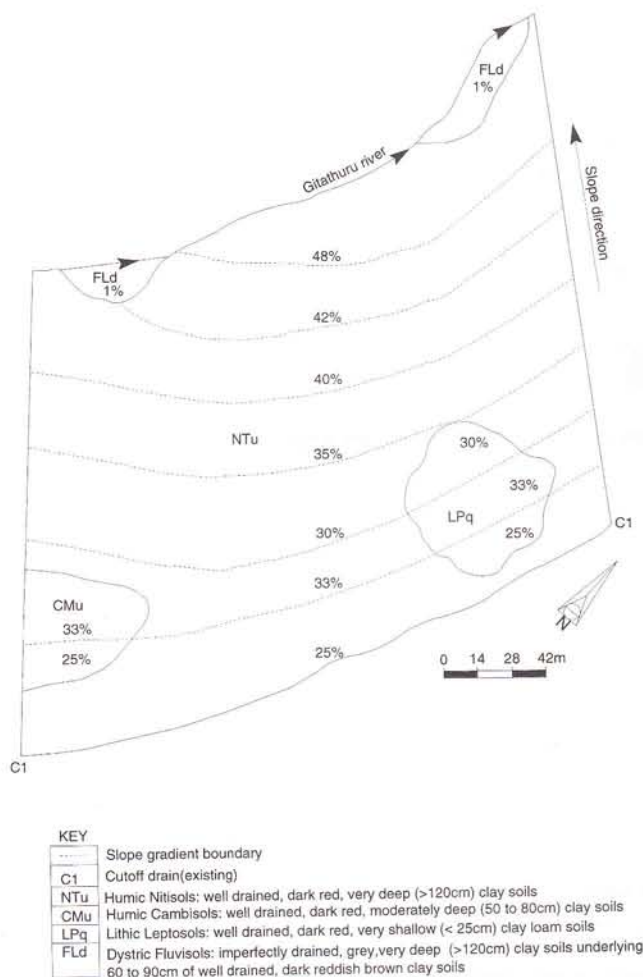


Fig. 1. Soil/slope gradient map of the Erosion Research Farm.

following regression on mean annual rainfall (x) in mm/yr (Moore, 1979).

$$KE = 3.96x + 3122 \quad r = 0.55, n = 35 \quad (2)$$

The relative erodibilities (k) of 14 Kenyan soil types with different physical and chemical properties and parent materials were previously determined under artificial rainfall conditions by Gachene (1982). The properties found to influence the relative erodibility most strongly were dispersion ratio (DR), per cent clay (C) per cent organic matter (OM) and bulk density (BD). The following regression equation involving these four soil factors predicts the relative erodibility factors of well drained, non-swelling soils:

$$Y = 0.297 + 0.069DR - 0.001C - 0.011 OM - 0.148BD$$

$$r = 0.95, n = 14 \quad (3)$$

where Y is the predicted relative erodibility factor (k) and BD is expressed in g/cm^3 . This was used to calculate k for the soils of the Erosion Research Farm.

The topographic evaluation (LS) for each slope segment was calculated using the method of Foster & Wischmeier (1974). For slope segment ' i ' in a sequence of segments from the crest line (the cutoff drain) to the drainage line, the LS factor is given by the following relationship:

$$LS_i = S_i(\lambda_i^{m+1} - \lambda_{i-1}^{m+1}) / [22.13^m(\lambda_i - \lambda_{i-1})] \quad (4)$$

Table 1. Erosion susceptibility classes

Rating	t/ha/cm rainfall/yr	Erosion susceptibility
1	0-400	very low
2	400-800	low
3	800-1200	moderate
4	1200-1600	high
5	>1600	very high

where S_i is the percentage slope of segment ' i ' given by

$$S_i = 0.065 + 0.045S + 0.0065S^2 \quad (5)$$

λ_i is the distance from the crest line to the bottom of segment ' i ' (m), λ_{i-1} is the distance (m) from the crest line to the bottom of segment $i-1$ (the segment above segment i) and m is an exponent assumed to equal 0.5 (Foster & Wischmeier, 1974). The LS factors were evaluated for each slope segment unit in a series of traverses selected to cover the whole of the area from the cutoff drain to the valley bottom. For each downslope segment, the LS equation (Equation 4) takes into account the contribution of runoff from upslope units. In this evaluation procedure soil loss increases logarithmically with both increasing slope gradient and slope length. The R , k and LS factors were multiplied together and then rated as in Table 1.

RESULTS AND DISCUSSION

The slope gradient/soil map is shown in Figure 1. The erosion susceptibility values were then assigned to five classes as shown in Figure 2. This qualitative parametric method of mapping erosion risks probably gives a better index of erosion susceptibility than the approach currently used in Kenya (Gachene & Barber, 1983), because it is a much more detailed method. The R factor used seems to be the best index of erosivity presently available in Kenya (Moore, 1979; Rowntree, 1983) because of limited rainfall data. The k factors are probably valid in relative terms. No reliable data have yet been obtained in Kenya for the USLE erodibility (K) factor (Wischmeier *et al.*, 1971) of different soils, and so the accuracy of using Wischmeier's nomograph to predict the erodibility factors of Kenyan soils is unknown. The USLE erodibility nomograph has been widely used in USA but its applicability under tropical conditions has not yet been fully established (El-Swaify & Dangler, 1977; Ngatunga, 1981; Foster *et al.*, 1982; Gachene, 1982; Kilewe, 1987). Thus until reliable data become available for real K factors for Kenyan soils, it is suggested that the multiple regression equation (Equation 3) be used for predicting the relative erodibility factors for non-swelling, well drained Kenyan soils. This equation takes into consideration some important soil factors which have a direct bearing on soil erosion. The organic matter content, percentage clay and DR are indicators of aggregate stability and bulk density indicates infiltration characteristics. The LS factors are presumably valid as there is no reason why the LS relationship established in the USA should be different elsewhere (Foster & Wischmeier, 1974; Foster *et al.*, 1982). LS reflects the influence of slope and relief on the detaching and transporting capacities of overland flow, and these are basically determined by energy-force relationships.

There is a trend of increasing erosion susceptibility from

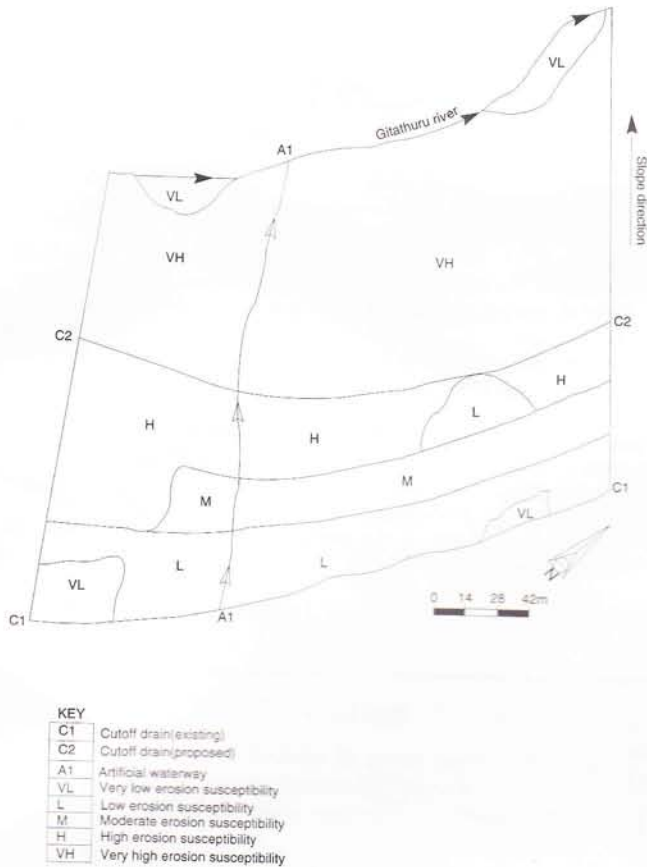


Fig. 2. Soil erosion susceptibility map of the Erosion Research Farm.

the cutoff drain to the drainage channel. Most of the slopes in this area are convex, so it is the steep, convex slope segments which are most susceptible to erosion. In areas with no vegetative cover, there were signs of rill and inter-rill erosion. Bergsma (1973) and Morgan (1980) have also observed that most erosion occurs on convex slopes and that lower-lying areas are sites of deposition. Areas with soils of map unit FLd (Fig. 1) were sites of deposition. A soil profile dug in this unit had imperfectly drained, very dark grey horizons underlying 60 to 90 cm of well drained, dark reddish brown soil (Gachene, 1989). The red soil has been transported by overland flow from the adjacent steeply sloping areas.

Although the method reported here is tedious and time consuming, it does accurately pin-point the most erosion-sensitive areas to which attention should be paid when designing soil and water conservation measures. For example, it is recommended that a second cutoff drain should be constructed along the boundary separating areas with high and very high erosion risks (Fig. 2). This would prevent large overland flows down the slope, which create rills and gullies if unchecked.

During the fieldwork, areas mapped as having very high erosion risks (Fig. 2) had no surface litter except where it had accumulated above trees and patches of grass, and rill and inter-rill erosion were common especially on cultivated areas. Similar signs of erosion were also observed in areas mapped as having high erosion risk. On upper slope positions there were few signs of inter-rill erosion and loose soil

remained in micro-depressions. In areas classified as highly susceptible to erosion, Gachene (1994) recorded an average soil loss of 130 t/ha from bare plots during the 1992 long rains. These plots showed rill and inter-rill erosion. The 1992 long rains were slightly more than average and the area had been cleared of grasses and shrubs. This suggests that in future erosion will increase as soil structure continues to deteriorate under bare conditions.

Using the soil erosion risk map and soil survey information, an artificial waterway was constructed (Fig. 2) for discharging excess water from the terraces and cutoff drain. This was planted with grass to avoid the risk of gully formation. In areas with very high erosion risk, small check dams were constructed across the waterway. Areas of unit LPq were mapped as having low to moderate erosion risk but have shallow soils with many rock outcrops (Nairobi trachytes); it is recommended that these areas should be left under natural vegetation.

CONCLUSION

As no generally accepted procedure has yet been established to assess and map erosion susceptibility, this study should prove useful in Kenya and other countries for assessing soil erosion risk. The approach gives an assessment of the comparative erosion susceptibility of land as supported by field observations and data on soil loss measurements. However, further data on soil erodibility and rainfall erosivity are needed in order to more accurately predict erosion susceptibility in the field.

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REFERENCES

- BARBER, R.G. 1983. The magnitude and sources of soil erosion in some humid and semi arid parts of Kenya and the significance of soil loss tolerance values in soil conservation in Kenya. In: *Soil and water conservation in Kenya* (eds D.B. Thomas & W.M. Senga), Institute for Development Studies Occasional Paper 42, pp. 20–26.
- BERGSMAS, E. 1973. *Erosion factors, Part II*. International Institute for Aerospace Survey and Earth Sciences, 9/71. Revision 8/77.
- BRAUN, H.M.H. & VAN DER WEG, R.F. 1977. *Proposals for rating of land qualities*. Internal Communication 7, Kenya Soil Survey, National Agricultural Laboratories, Kenya.
- EL-SWAIFY, S.A. & DANGLER, E.W. 1977. Erodibilities of selected tropical soils in relation to structural and hydrological parameters. In: *Soil erosion: prediction and control* (ed. G.R. Foster), Soil Conservation Society of America Special Publication 21, Ankeny, Iowa, pp. 105–114.
- FOOD AND AGRICULTURE ORGANIZATION 1979. *A provisional methodology for soil degradation assessment*. FAO, Rome.
- FOOD AND AGRICULTURE ORGANIZATION 1990. *Soil map of the world, Revised Legend*. World Soil Resources Report 60, FAO, Rome.
- FOSTER, G.R. & WISCHMEIER, W.H. 1974. Evaluating irregular slopes for soil loss prediction. *Transactions of the American Society of Agricultural Engineering* 17, 305–309.
- FOSTER, G.R., MOLDENHAUER, W.C. & WISCHMEIER, W.H. 1982. Transferability of US technology for prediction and control of erosion in the tropics. In: *Soil erosion and conservation in the tropics*, Special Publication 43, American Society of Agronomy and Soil Science Society of America, Inc., Madison.
- GACHENE, C.K.K. 1982. *Assessing the relative erodibility of some Kenyan soils using a rainfall simulator and the prediction of relative erodibility factors*. MSc Thesis, University of Nairobi.

- GACHENE, C.K.K. 1989. *Soils of the Erosion Research Farm, Kabete Campus*. Department of Agricultural Engineering, University of Nairobi.
- GACHENE, C.K.K. 1994. *Effect of soil erosion on soil properties and crop response in Central Kenya*. Reports and Dissertations, Swedish University of Agricultural Sciences.
- GACHENE, C.K.K. & BARBER, R.G. 1983. A preliminary report on an evaluation and detailed mapping of the erosion susceptibility at Kaloleni, Kilifi District. In: *Soil and water conservation in Kenya* (eds D.B. Thomas & W.M. Senga), Institute for Development Studies Occasional Paper 42, pp. 87–104.
- GACHENE, C.K.K. & WEEDA, A. 1984. The land quality: resistance to erosion—its application in the Iuni catchment area, Machakos District, Kenya. Paper presented at the International Workshop on Land Evaluation for Land Use Planning and Conservation in sloping areas, International Institute for Aerospace Survey and Earth Sciences, Enschede, The Netherlands, 17th–21st Dec. 1984.
- GELENS, H.F., KINYANJUI, H.C.K. & VAN DER WEG, R.F. 1976. *Soils of the Kapenguria area*. Report R2, Kenya Soil Survey.
- HINGA, G., MUCHENA, F.N. & NJIHA, C.M. 1980. *Physical and chemical methods of soil analysis*. National Agricultural Laboratories, Ministry of Agriculture, Nairobi.
- KILEWE, A.M. 1987. *Prediction of erosion rates and the effects of topsoil thickness on soil erodibility*. PhD Thesis, University of Nairobi.
- MOORE, T.R. 1979. Rainfall erosivity in East Africa. *Geografiska Annaler* 61A, 147–156.
- MORGAN, R.P.C. 1980. Evaluation of erosion risks and erosion mapping. In: *Assessment of erosion* (eds G. Boodt & D. Gabriels), John Wiley & Sons, Chichester, pp. 107–110.
- MORGAN, R.P.C. 1988. Erosion hazard assessment. In: *Soil erosion and conservation* (ed. D.A. Davidson), John Wiley & Sons, New York, pp. 63–110.
- NGATUNGA, E.L. 1981. Analysis of soil parameters affecting field and nomograph determined erodibility factors of Mlingano soils. Paper presented at 5th Annual General Meeting of Soil Science Society of East Africa, Nakuru, Kenya, November 1981.
- ROWNTREE, K.M. 1983. Rainfall erosivity in Kenya—some preliminary conclusions. In: *Soil and water conservation in Kenya* (eds D.B. Thomas & W.M. Senga), Institute for Development Studies Occasional Paper 42, pp. 1–19.
- SOMBROEK, W.G., BRAUN, H.M.H. & VAN DER POW, B.J.A. 1980. The exploratory soil map and agro-climatic zone map of Kenya. Report E1, Kenya Soil Survey, Nairobi.
- WISCHMEIER, W.H. & SMITH, D.D. 1978. *Predicting rainfall erosion losses—a guide to conservation planning*. Agriculture Handbook 537, Government Printing Office, Washington, D.C.
- WISCHMEIER, W.H., JOHNSON, C.B. & CROSS, B.V. 1971. A soil erodibility nomograph for farmland and construction sites. *Journal of Soil and Water Conservation* 26, 189–193.

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Soil pH decline in relation to rotation, tillage, stubble retention and nitrogen fertilizer in S.E. Australia

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Abstract. The decline in topsoil (0–0.1 m) pH (CaCl_2) over 11 years (1979–90) was measured in a rotation, tillage, stubble and nitrogen fertilizer experiment on a Chromic Luvisol at Wagga Wagga in S.E. Australia. The rotations consisted of annual wheat cropping (WW) with and without nitrogen fertilizer (100 kg N/ha/year), alternating lupin–wheat (LW) and subterranean clover–wheat (CW). The initial mean pH at the site was 4.9 and the experiment was preceded by subterranean clover-based pasture for most of the previous 19 years. An initial rapid decline in soil pH under all treatments over the first 8–9 years was followed by a 2–3 year period when no further decline was detected. The annual rate of pH decline over the first 8–9 years varied from 0.06 for WW to 0.09 units for WW with added N fertilizer. Apparent steady-state for WW after 11 years was approximately 0.5 pH units higher than for WW with added N fertilizer. There was no difference between CW and LW in the rate of decline or in the apparent steady-state reached. Six years' stubble burning in a LW rotation promoted a slightly higher pH than where stubble was retained. However, there was no significant effect of tillage in either LW or CW rotations. By 1990 the addition of N fertilizer to WW had increased the concentration of exchangeable aluminium by 100% and of manganese by 24%. The inclusion of a legume in the rotation increased the concentration of aluminium but did not affect manganese. However, burning stubble in the LW rotation slightly decreased manganese concentrations.

Keywords: Soil pH, rotations, nitrogen fertilizers, stubble, burning, tillage

INTRODUCTION

Soil acidification is a major cause of lost farm production throughout the world (Wright *et al.*, 1991). In southern

Australia soil acidity may be limiting yield from over 14 million hectares; areas receiving 500 mm rainfall or more are particularly at risk (Coventry, 1985; Helyar *et al.*, 1988; Cregan *et al.*, 1989). Natural ecosystems may acidify slowly, but by increasing inputs and removing produce, agriculture can cause major imbalances and more rapid changes in the soil. Crop product removal, organic matter increase and