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Linking landforms and land use to land degradation in the Middle River Njoro Watershed

Zackary G. Mainuri[1] and James O. Owino[2]

Abstract

Land degradation is the decline in the productive capacity of an ecosystem. This mainly occurs due to processes induced by human activities, such as deforestation, poor farming practices, or enhanced industrial growth leading to various land degradation processes such as, flooding, drought and accelerated erosion. The objective of the study was to link landforms and land uses to land degradation. Soils in the catchments were distinguished on the basis of Physiographic, parent material/ geology and soil characteristics. Eight soil mapping units were identified in the area. The validity of the identified soil mapping units were checked in the field using auger hole, mini pits, road and erosion cut observations. Representative profile pits were sighted in the major mapping units. The profile pits were described according to FAO (1977) and Kenya Soil Survey (1987). Soil classification was done according to FAO/UNESCO (1997). Soil mapping units were found to follow soil physiographic units/ land forms. Soils on mountains and hills were found to be somewhat excessively drained, shallow to moderately deep. Those from uplands and plateaus were well drained, deep to very deep. Soils on plains fell on two extremes; those that were well drained, deep to very deep and those that were imperfectly drained to poorly drained, moderately deep to very deep. Physical, chemical and biological land degradation was found to take place in the different physiographic units/ land forms at varying degrees. Soil erosion, nutrient depletion and vegetation depletion were found to be the most important degradation processes. Soil, physiographic units, soil susceptibility and hazard maps were drawn and their classes in the different landforms established.

KeyWords: Land use, Landform, Land degradation

1 Introduction

Land degradation is defined as the decline in the productive capacity of an ecosystem due to processes induced by human activities, such as introduction of large scale irrigation, deforestation, or enhanced industrial growth leading to various land degradation processes including, flooding, drought, and accelerated erosion (UNEP, 1993). Soil erosion reduces soil productivity (Aboud, 1992; Anyango, 2000) on agricultural lands. Soil erosion by water occurs due to complex interactions of sub processes of detachment and transport of soil material by raindrop impact and overland flow and of deposition causing sedimentation of water bodies (Karanja et al., 1986); thus adversely affecting the aquatic life. Soil and water are very important resources in agricultural production. In order to increase and sustain productivity in both crops and animals, proper land management is essential. The design and implementation of proper land management strategies, however, presupposes the identification of the problems related to soil and water that limit agricultural production. Agriculture plays a crucial role in economic development of the country directly and through linkages with other sectors. Growth in agriculture and improved rural incomes has a significant and direct impact on the reduction of overall poverty. Land use influence on hydrology has generated interest worldwide, especially in developing countries, where forest areas have been converted to other land uses including, agriculture and

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grazing. These processes lower the current and potential capability of land to produce goods and services (FAO, 1979). While it is true that human activities, through different types of land use and management, trigger and accelerate degradation, it is also true that some processes of land degradation occur naturally. The major types of soil degradation in the study area are physical including erosion, chemical including fertility decline, and biological including organic matter decline and deforestation. Land degradation in the form of decline in soil fertility due to erosion and crop harvesting has led to continuous decline in crop production to an alarmingly low level. This is attributed to land subdivision, intensive cultivation and urbanization which have resulted in the conversion of large-scale farms into small-scale farms and the gradual diminishment of plantation forests (Chemilil, 1995).

The population in the River Njoro Watershed has continued to grow. For example, within a period of twenty years between 1979 and 1999 the population in Nakuru district, in which the River Njoro Watershed is found, increased twofold; from 523,000 to 1,197,000 persons (GoK, 2001). This high population growth rate and the accompanying land fragmentation have strained land resources (Mathooko, 2001) resulting in massive soil erosion and other forms of land degradation. While aspects of land degradation have been successfully tackled, most past research to address these problems have fallen short of solving the problems of land degradation especially under smallholder production systems. This increasing influence of land use change poses a threat to the conservation of soils in the watershed.

Changes in land use has the potential of influencing the flow of surface runoff to the stream network and infiltration in a watershed (Ziegler and Giambelluca, 1997). For instance, surfaces with low infiltration capability such as overgrazed or intensively cultivated land act as source areas for overland flow in areas where it is otherwise rare. Other surfaces having high infiltration capability may serve as buffers by infiltrating surface runoff generated directly upslope (Ziegler et al., 2000). Detailed knowledge of runoff sources and buffers is therefore important in understanding the hydrology of watersheds. Knowledge of soils with respect to their extent, distribution, characteristics, degradation risks, and use potential is the objective of this study in order to optimize land resource use in the River Njoro watershed.

2 Research methodology

2.1 *Study area*

The Middle River NjoroWatershed is located at the Central Rift Valley zone within the Kenyan part of the East African Rift System. It lies between longitudes 35˚05′E and 36˚05′E, and latitudes 0˚15′S and 0˚25′S. The area watershed covers about 8,500 hectares, and is located about 200 km northwest of Nairobi in Nakuru County. The catchment lies between altitudes 1,600 m above sea level (asl) and 3,000 m asl (Fig. 1). The Njoro River has its source from Mau escarpment and drains into Lake Nakuru.

According to Sombroek et al. (1982), the catchment area covers agro-climatic zones (ACZ) I – IV which have mean annual rainfall (r) to mean annual potential evaporation (Eo) ratios (r/Eo) of > 0.8 – 0.5. These zones range from humid to semi-arid with very high to medium potential for plant growth. Rainfall ranges from 800 mm in agro-climatic zone IV to 2,700 mm in agro-climatic zone I, while potential evaporation ranges from 1,200 mm in ACZ I to 2,200 mm in ACZ IV. Mean annual temperatures range from 10˚C in ACZ I to 18˚C in ACZ IV.

The area is covered by volcanic rocks, ranging in age from tertiary quaternary to recent, basically consisting of pyroclastic rocks of recent volcanoes. The rocks are predominantly agglomerates, sediments, welded tuffs, and phonolites on mountains, ciders, pumice, sanidine minerals, basaltic tuffs and black ashes on hills, plateaus, uplands, plains and valleys and alluvium and lacustrine and fluviatile sediments derived directly from them (Sombroeck et al., 1982). The soils and geology of the area are influenced by the volcanic nature of the Rift valley. The River Njoro watershed is covered by loamy soil in the upper forested parts having developed from ashes and other pyroclastic rocks of recent volcanoes and deep to very deep well drained to moderately deep loamy sandy clays (vitric andosols). The lower reaches of the watershed are covered by erosive lacustrine soils (Chemilil, 1995) which have been developed on these pyroclastic rocks. The drainage classes range from poorly drained, moderately well drained, well drained to excessively drained, with textures ranging from loam, clay to clay loam and structures in the range of moderately strong to strong.

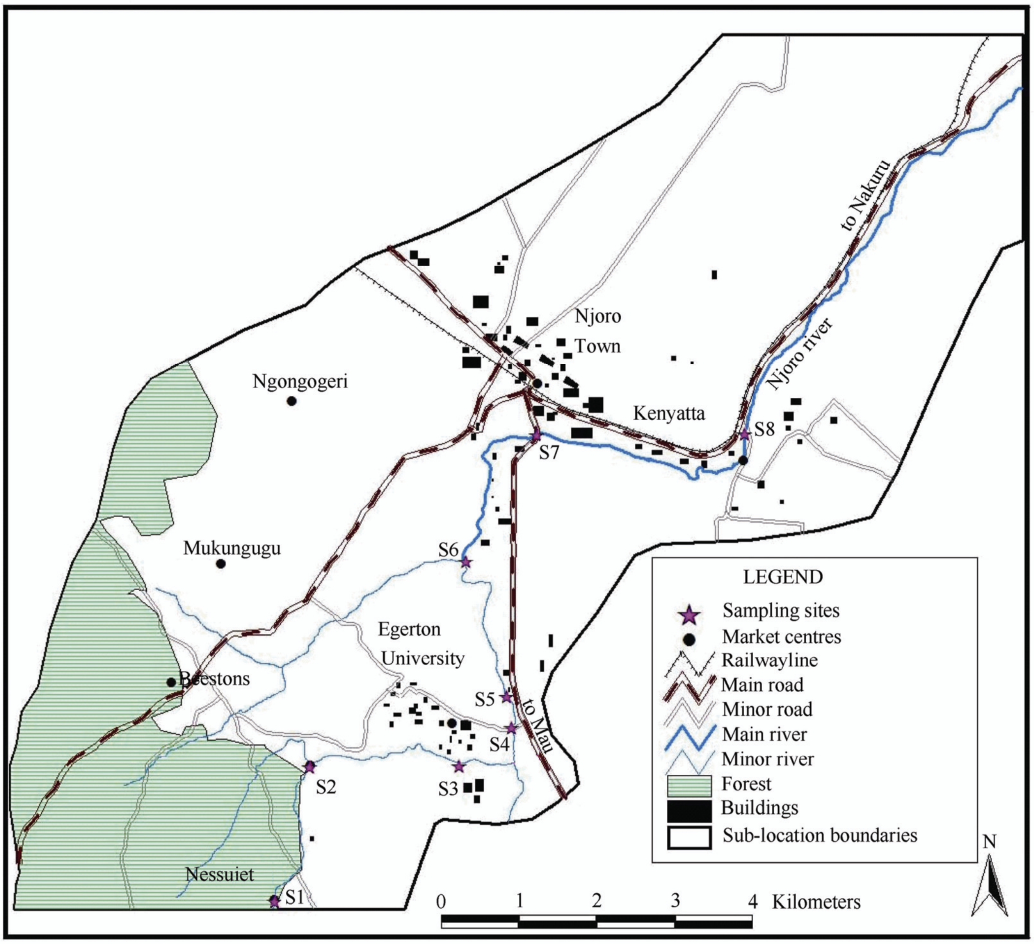

Fig. 1 The River Njoro Watershed (Source: Mainuri, 2012, unpublished)

2.2 *Methods*

2.2.1 Soil survey and mapping

The existing Exploratory Soil Map of Kenya (E1 Report) at a scale of 1:1,000,000 (Sombroek et al., 1982) was studied and the major soil units were identified. The validity of the identified soil mapping units was checked in the field at a scale of 1:50,000 using auger hole, mini pits, road and erosion cut observations. Representative profile pits were located in the major mapping units. The profile pits were described according to FAO (1977) and Kenya Soil Survey (1987). Soil classification was done according to FAO/UNESCO (1997). Composite samples were taken around each profile pit for fertility analyses. Topsoil samples were taken for determination of bulk density and hydraulic conductivity using core rings while other topsoil samples were taken for determination of aggregate stability, texture and organic carbon. The analyses were done according to Hinga et al. (1980). Soil fertility decline were assessed through changes in organic carbon (OC), pH, nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and micronutrients.

2.2.2 Physical land degradation evaluation

Assessment of the soils susceptibility to erosion was carried out according to Weeda (1987). This involves a qualitative evaluation of slope angle, slope length, crop cover, and soil and climate factors. These factors are rated individually on a scale where the lowest number normally taken as 1 is associated with a low risk of erosion and the highest number with a high risk of erosion. Final rating of soil susceptibility to erosion is obtained by the summation of the sub ratings of individual factors of climate (rainfall), slope (topography), and soil.

Final rating	Class	Sum factors	Final rating	Class	Sum factors
1	low	5–6	3	high	10–14
2	moderate	7–9	4	very high	15–18

Rainfall erosivity, soil erodibility and topography factors were rated to arrive at low, moderate, high and very high erosion susceptibility classes. Erosion hazard assessment for each mapping unit was arrived at by taking into account the rating of susceptibility to erosion and combining it with the type of land use, soil surface cover including any observed conservation practices. Field visual observation of erosion features helped in the correlation and validation of the hazard class. The erosion hazard classes were none, slight, moderate and severe.

Soil compaction, surface sealing and crusting were assessed through the observed bare soil surface due to overgrazing and clearing, and the occurrence of surface sealing and crusting. Measured permeability indicated vulnerability to these processes. Fig. 2 (a and b) below shows the extent of degradation in some parts of the Middle River Njoro Watershed.

(a) (b)

Fig. 2 Extent of land degradation in parts of the River Njoro Watershed

2.2.3 Chemical and biological degradation

Soil fertility decline was assessed through changes in organic carbon (OC), pH, nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and micronutrients.

Biological degradation is indicated by changes in the distribution of organic carbon in the different land uses, and the clearance of forests and woody species in the different agro-climatic zones. Soil organic matter, temperature and moisture determine the type and population of microbial organisms. Therefore, the different agro-climatic zones with their respective temperature zones are reflective of the possible microbial variations within the catchments.

3 Results and discussion

3.1 *Soils*

The soils in the Middle River Njoro Watershed are distinguished on the basis of Physiographic, parent material/ geology and soil characteristics. Six major physiographic units (Fig. 3) and six major soil mapping units (Fig. 4 and Table 1) were identified in the area. Soil mapping units followed soil physiographic units. Mountains and major scarps have slopes greater than 30%. The soils of this geomorphic unit are developed on volcanic ashes and other pyroclastic rocks of recent volcanoes (mapping unit MO). The soils are somewhat excessively drained, shallow to moderately deep, brown to dark brown, firm and slightly smeary, strongly calcareous, stony to gravely clay loam; in many places saline and/or sodic and with inclusions of lava fields. The soils are classified as Calcaric Regosols, partly lithic phase.

Hills and minor scarps have slopes which are greater than 16%. The soils of this geomorphic unit are either developed on ashes and other pyroclastic rocks of recent volcanoes (mapping unit Hie1) or undifferentiated Tertiary volcanic rocks (mapping unit Hie2). Soil mapping unit Hie3 is complex of somewhat excessively drained to well drained, shallow to very deep, dark brown to greyish brown, friable and smeary clay loam; in places with a thick humic topsoil, rocky and stony. The soils are classified as Mollic Andosols and Ando-Eutric Cambisols, lithic and rudic phase, with Rock outcrops. Soils of mapping unit Hie4 are well drained to moderately well drained, shallow to moderately deep, dark brown, firm, stony, clay loam to clay; in places with a humic topsoil. They are classified as Eutric Regosols and Verto-Luvic Phaeozems.

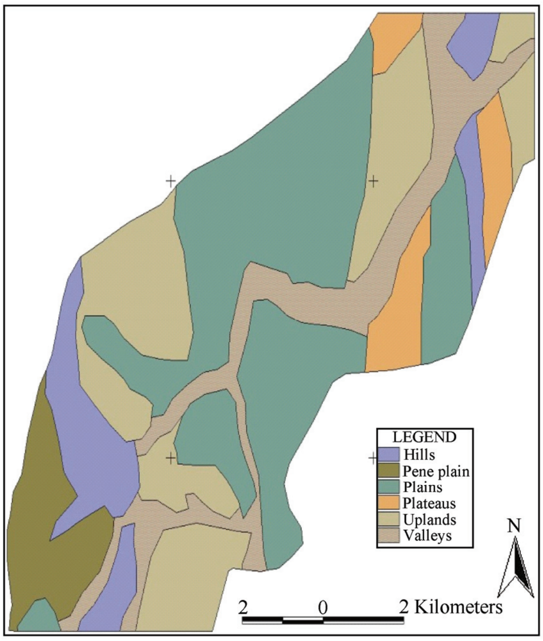

Fig. 3 Physiographic units

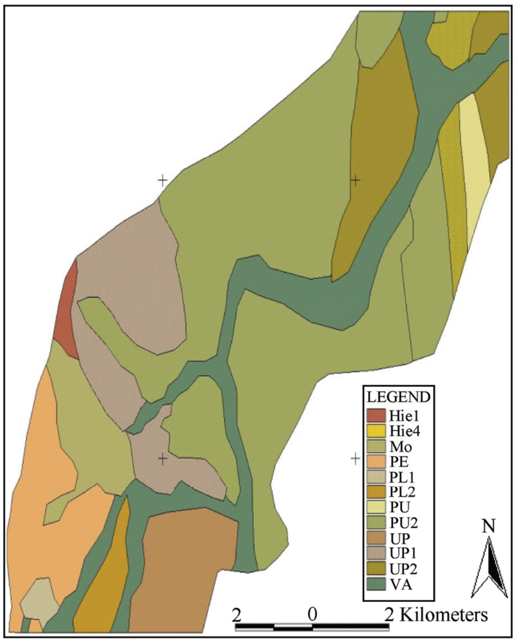

Fig. 4 Soil mapping units

Table 1 Soil legend

Hie1– Mollic Andosols Hie2 –Ando-Eutric cambisols Hie3 –lithic and rudic phase Hie4 –Eutric Regosols/Phaeozems Mo (mountains)–Calcaric Regosols, partly lithic phase PL1(Plains) – Mollic Andosol	PL2/PL3AL–Phaeozem/Stagnic solonetz PU, PU1, PU2, PU3, (Plateaus) Humic–Andosols/Vitric Andosols/Eutric Leptosols	UP, UP1, UP2 (Uplands)—Mollic Andosols VA (Valleys)—A complex of Ando-Haplic Phaeozems and Gleyic Cambisols

The plateaus are undulating with slopes of between 5% – 8% (mapping unit PU). The soils are developed on ashes and other pyroclastic rocks of recent volcanoes. They are well drained, deep to very deep, dark brown, friable and smeary, sandy clay to clay, with acid humic topsoil. The soils are classified as Humic Andosols.

The uplands are undulating with slopes of between 5% – 8%. The soils are developed on volcanic ashes and other pyroclastic rocks of recent volcanoes (mapping unit UP). They are well drained, deep to very deep, dark reddish brown, friable and smeary, silty clay to clay, with humic topsoil. The soils are classified as Mollic Andosols.

The plains are flat to very gently undulating in relief with slopes of between 0 – 2%. Two types of plains are distinguished namely volcanic plains and lacustrine plains. Soils of the volcanic plains are developed on volcanic ashes and other pyroclastic rocks of recent volcanoes (soil mapping unit PL1). The soils of this unit are well drained, deep to very deep, dark reddish brown to dark brown, friable, slightly gravelly loam to clay loam, with humic topsoil. The soils are classified as Mollic Andosols. Soils on sediments mainly from volcanic ash (soil mapping unit PL2), the lacustrine plains developed on sediments derived from volcanic and other sources (soil mapping unit PL3). The soils of unit PL3AL are imperfectly drained to poorly drained, very deep, dark greyish brown to dark brown, firm to very firm, slightly to moderately calcareous, slightly to moderately saline, moderately to strongly sodic, silty loam to clay loam; in many places with humic topsoil. The soils are Sub recent lake edges of the Central Rift valley. The soils are classified as Stagnic Solonetz, salic phase.

Soils of mapping unit VA (Valleys) are well drained to imperfectly drained, moderately deep to deep, strong brown to dark brown, friable to firm, sandy clay loam to clay; in places mottled, slightly smeary and brittle. The soils are classified as Ando-Haplic Phaeozems and Gleyic Cambisols.

3.2 *Land degradation*

In the catchments, physical, chemical and biological land degradation takes place in the different physiographic units at varying degrees. Several land degradation processes take place in the catchments including erosion, compaction, sealing and crusting, water logging, sedimentation/siltation, nutrient depletion, acidification, salinization, sodification, water pollution, organic matter decline and vegetation depletion. Soil erosion, nutrient depletion and vegetation depletion are by far the most important degradation processes in the catchments.

3.2.1 Physical degradation

(a)Erosion susceptibility

Erosion susceptibility in the Middle River Njoro Watershed (Fig. 5 and Table 2) indicates erosion susceptibility in the various soil mapping units. Mountains and major scarps (unit Mo), hills and minor scarps (units Hie1 and Hie2), plateau (unit PL) and the uplands (unit UP) show high to very high susceptibility to erosion. The main contributing factors are slope steepness and length. In the field, it was observed that once the natural vegetation is cleared in these areas, the topsoil is exposed to the erosive forces leading to decapitation of the topsoil and in some cases exposing the underlying weathering rock. Grass, stone and gravel pedestals were observed on eroded bare soils. This indicates that once the protective vegetation cover is lost, these areas are very prone to erosion. Once erosion has started, slope steepness and length determine the rate at which it accelerates.

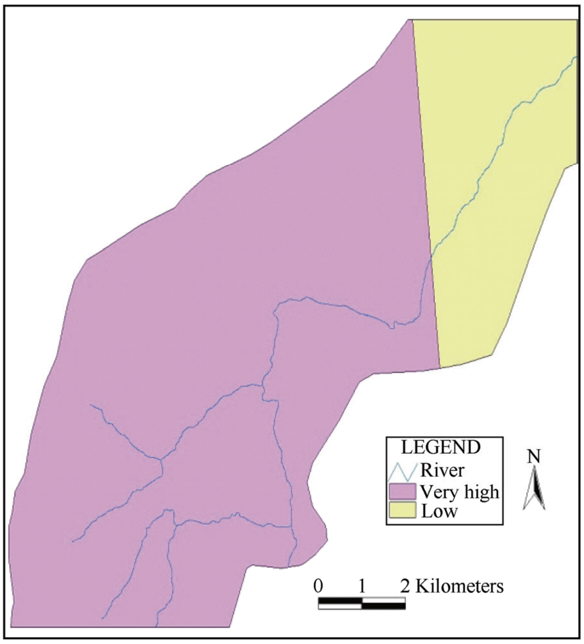

Fig. 5 Erosion susceptibility

Table 2 Erosion susceptibility and hazard in the Middle River Njoro Watershed

Mapping unit	Area (ha)	ACZ	Mean alt. (m)	Mean slope (%)	Erosion susceptibility	Major land use /cover/ management/ conservation measures	Erosion hazard
MO	152	III	2,308	>30	Very high	Small scale and large farming	Moderate
Hie1	1,524	I	2,308	>16	Very high	Forestry, wetlands, deforestation	Moderate
Hie2	244	II	2,308	>16	High	Small scale farming	Moderate
PU	221	I	1,814	5–8	Very high	Small scale farming; grassland	Moderate to severe
UP	3,544	II– III	1,814	5–8	Very high	Small scale farming; grassland; wetlands	Slight–moderate
PL1	1,463	III	1,717	0–2	High	Small and large scale farming, grassland	Non–Slight
PL2	78	III	1,717	0–2	Low–moderate	Forestry and grassland; wildlife	Slight
PL3	1,333	III	1,717	0–2	Low	Small and large scale agriculture; grassland	Non–slight

Therefore, areas with high to very high susceptibility to erosion such as the Mau Escarpment should be left under natural or planted vegetation cover to act as water catchment areas while combinations of soil conservation measures should be intensified in the cultivated areas of the uplands and plateau. Slope is a major contributor to susceptibility to erosion especially in units with slopes greater than 5%. Rill erosion was observed along footpaths, moderate splash erosion was observed in maize fields but no erosion features were observed in pastureland and in places with woodlots. Gravel pedestals on bare soil also indicated the high vulnerability of these soils to erosion. The absence of erosion features in pastureland and in woodlot emphasizes the importance of vegetation cover in the control of soil erosion.

Soils of the volcanic plains (mapping unit PL1) and lacustrine plains (mapping unit PL3 and PL3AL), developed on recent volcanic deposits show low susceptibility to erosion as a result of the flat to very gently undulating relief of these physiographic units with slopes of 0 – 2%.

A good soil cover should be maintained in all soil mapping units as all soils are prone to erosion no matter the relief on which they occur once they are left bare.

(b)Erosion hazard

The results (Fig.6 and Table 2) show that though the mountains and hills indicate very high inherent susceptibility to erosion, they have moderate erosion hazard mainly due to the presence of forests rocks, stones and boulders.

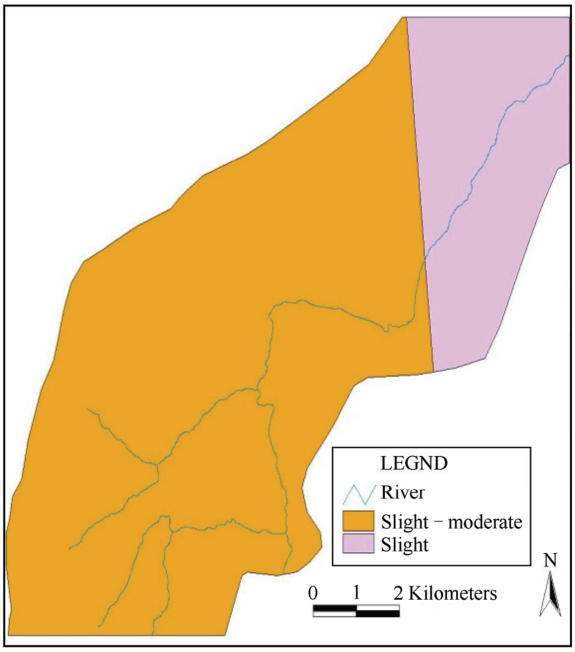

Fig. 6 Erosion hazard

A study by De Meester (1987) found that there was almost no erosion in the Mt Kenya forest area and adjacent tea zone although there are very steep slopes due to the effective soil cover by forests and the tea crop. On the other hand stones protect soils from rain splash but may also encourage turbulence in runoff and thereby encourage rilling on bare soil surface. Stones were found to be effective if they covered more than 30% of the soil surface. Stone and gravel layers on the soil surface reduce erosion by increasing infiltration rates and reducing rain splash and overland flow (Epstein et al., 1966; Thomas and Barber, 1981).

The plateaus show moderate to severe erosion hazard depending on the predominant land use and conservation practices. Soil erosion hazard is generally slight to moderate in the uplands as the main land use consists of strip cropping with pastures. Woodlots in some fields reduces the soil erosion hazard.

The volcanic and lacustrine plains have aslight erosion hazard. Lewis et al. (1983) found that fields in perennial cash crops generally had the lowest soil losses while those under food crops produced the highest soil losses. This was attributed to farmers practicing greater conservation measures such as terracing on steep slopes and mulching in fields having cash crops.

Conservation and good crop husbandry practices are the most effective mitigation measures for soil erosion. Ongwenyi (1978) observed that in cultivated areas, if crop management and agricultural practices including soil and water conservation are improved by half through cropping systems and management, as well as by supporting practices such as contour cultivation and planting as opposed to down/upslope operations, then the soil losses for the individual crops would be reduced nearly by half. Studies by Owino et al. (2006) of the Middle River Njoro Watershed showed that narrow grass strips were capable of reducing sediment loss by 54% within 18 months of establishment. If mulching, terracing or both further support these contour operations, soil erosion can be reduced to its bare minimum. The soil can therefore be managed sustainably by cultivation and planting through proper husbandry and agronomic practices, construction of structures that prevent the soils from being eroded to lower areas and retaining natural vegetation on most vulnerable or susceptible areas.

(c) Surface sealing, crusting and compaction

Surface sealing and crusting is a common phenomenon in bare and intensively cultivated soils. The processes have adverse effects on permeability, infiltration rates and seed germination. They are a major cause of high run off and erosion. Some soil characteristics render soils liable to sealing and crusting. These properties include texture (high silt: clay ratio), low organic matter content, high bulk density and the presence of finely divided calcium carbonate and other soluble salts on the soil surface. Soil erodibility is therefore a good indicator of soils which are likely to experience this problem if left bare and are exposed to impacts of raindrops.

According to Mainuri and Owino (2013), the catchment's mean values of aggregate stability as expressed by mean weight diameter (MWD) were found to be in a decreasing order of forest (0.68), grassland (0.64), agriculture (0.58), and wetland (0.41). Forest soils were 1.7 times more stable than wetlands soils possibly due to poor structure. The study further indicated that grazing of livestock packed down the topsoil leading to lower hydraulic conductivity (69 cm hr^{-1}) than cultivated (77 cm hr^{-1}) and forested land (104 cm hr^{-1}). Continuous cultivation and grazing destroy topsoil structure and enhances deterioration of other soil physical characteristics such as porosity and moisture holding capacity. Cultivation enhances oxidation of organic matter thus ultimately making the soils susceptible to sealing and crusting.

The soils should be protected from the impacts of raindrops by maintenance of soil surface cover with pastures and growing crops that give the soil surface a good cover. Incorporation of manure and fertilizers is important as it results in healthy plants with leaves that give larger coverage of the soil surface. Use of manure improves the structural stability of the topsoil and therefore reduces vulnerability to sealing and crusting. Strip cropping/farming and crop rotation are also important management practices as they are effective in controlling soil losses from individual farms.

(d) Siltation/Sedimentation

The high total dissolved solids (TDS) in the upper part of the river indicates increased soil erosion processes possibly due to the deforestation and agricultural activities on the upper parts of the catchment and as the river flows downstream the middle parts have lesser sediments due to decreased agricultural activities (Table 3). The increasing TDS on the lower part indicates increased water polluting activities from Njoro town and the adjacent canning factory.

Table 3 **Quality of water from River Njoro (April, 2008)**

Location	TDS (mg L^{-1})	Temp. (˚C)	Altitude asl. (m)
Upper	130	19.9	2,308
Middle	90	19.3	1,814
Lower	100	19.5	1,777

3.2.2 Chemical degradation

The factors causing soil chemical degradation could be natural or human induced (anthropogenic) and include process such as leaching. Leaching is influenced by climate, soil drainage, soil texture, clay mineralogy and the slope angle (FAO, 1979).

(a) Soil fertility decline

Soil fertility declineis mainly gradual and almost inconspicuous. The soils were moderately acid (pH 5.0 – 5.9) to strongly acidic (pH 4.5 – 4.9) and slightly alkaline (pH 7.0 – 7.4) in some caseswith adequate to moderate organic matter and low nitrogen (N) levels (Table 4). The other nutrients were adequately supplied.

Table 4 **Influence of land use on the soilsin the River Njoro watershed**

Land use	CEC ($cmol\ kg^{-1}$)	Clay (%)	OC (%)	N (%)	P (ppm)	Ksat ($cm\ hr^{-1}$)	Na (%)	MWD
Cultivated land	16.6	27	2.1	0.12	22	77	0.83	0.58
Pastureland	15.6	32	2.5	0.13	46	69	0.64	0.64
Forest	9.9	23	2.7	0.13	47	104	0.53	0.68

Decline in fertility as indicated by OC, N and P are mainly as a result of continuous cultivation and erosion. Continuous cultivation over a long period without adequate application of organic and inorganic fertilizers has been documented to cause a decline in yields. Qureshi (1987) reported a decline in maize yield of up to 34% on a Nitisols. Farmers in the catchments reported similar unquantified decline in yields. Qureshi (1987) showed that continuous cropping over the years without any replenishment decreased the contents of available K, Ca, Mg, Mn and P, total N and OC, though there was not much change in soil pH. Application of manure alone did not maintain the content of available K, Ca, Mg, Mn OC and total N. Incorporation of maize crop residue increased available K, Ca, Mg, P, OC and total N to varying extents.

Soil erosion affects chemical properties of a soil mainly through the loss of soil organic matter, minerals and the exposure of the subsoil with low fertility and high acidity. The nutrients that are most affected due to loss of topsoil caused by erosion include: P, OC, Ca, N, Mn and Na, with a decrease in soil pH thus making the soils acidic (Gachene et al., 1997).

4 Conclusions

- TheMountains and major scarps (unit Mo), hills and minor scarps (units Hie1 and Hie2), plateau (unit PL) and the uplands (unit UP) showed high to very high susceptibility to erosion once natural vegetation was cleared for cultivation.
- Infiltration, runoff and soil loss were largely linked to watershed land use, management conditions, slope steepness and length.
- Land under forested cover (indigenous and plantation forest) registered high infiltration, low runoff and low soil loss.
- The areas of the catchments that had land use characterized by loss of land cover and disturbed soil surface conditions experienced high runoff, low infiltration and high soil loss.
- Conservation and good crop husbandry practices are recommended as the most effective mitigation measures for land degradation in the watershed.
- A good soil cover should be maintained in all soil mapping units as all soils are prone to erosion once left bare no matter the land form on which they occur.
- Continuous cultivation over a long period without adequate application of organic and inorganic fertilizers is discouraged.

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References

Aboud, A. A. (1992). *Population pressures, environmental degradation and farmers' adaptive strategies in Nakuru District of Kenya* (Ph.D. Thesis). University of Illinois, U.S.A.

Anyango, M. O., Ng'ang'a, N. M., & Olayo, J. A. (2000). *Sweet potato processing for improved vitamin A intake: Gender implications and potential for sustainable technology adoption in Siaya District, Kenya.* African Potato Association, Conference Proceedings, Vol. 5, pp. 491-495.

Chemelil, M. C. (1995). *The Effects of Human-induced Watershed Changes on Stream flows* (Ph.D. Thesis). Loughborough University of Technology.

De Meester, T. & Legger, D. (eds) (1988). *Soils of the Chuka – South Area, Kenya*. Department of Soil Science and Geology, Agricultural University, Wageningen, The Netherlands.

Epstein, E., Grant, W. J., & Struchtemeyer, R. A. (1966). Effects of stones on runoff, erosion, and soil moisture. *Soil Science Society of America Journal*, *30*(5), 638-640.

FAO. (1977). *Guidelines for soil profile description*. FAO, Rome

FAO. (1979). *A provisional methodology for soil degradation assessment.*

FAO/UNESCO. (1997). *Soil Map of the World.Revised Legend with corrections and updates*. Technical Paper 20, ISRIC, Wageningen.

Gachene, C. K., Mbuvi, J. P., Jarvis, N. J., & Linner, H. (1997). Soil erosion effects on soil properties in a highland area of central Kenya. Joint contribution from the Dep. of Soil Science, Uni. of Nairobi, Kenya and Dept. of Soil Sciences, Swedish Univ. of Agric. Sciences, Uppasala, Sweden. *Soil Science Society of America Journal*, *61*(2), 559-564.

GoK. (2001). *Statistical Abstract*. Nairobi: Kenya Central Bureau of Statistics,Ministry of Planning and National Development.

Hinga, G., Muchena,F. N., & Njihia, C. M. (1980). *Physical and Chemical Methods of Soil Analysis*. National Agric. Res. Labs, Nairobi, Kenya.

Karanja, A., China, S. S., & Kundu, P.M. (1986). The Influence of land use change on the Njoro River Catchment between 1975 and 1985. In D. B. Tomas, E. K. Biamah, A. M. Kilewe, L. Lundgren, & B. O. Mochoge (Eds.), *Soil and water conservation in Kenya*.

Kenya Soil Survey Staff. (1987). Manual for soil survey and land evaluation.Vol. 1. Miscellaneous paper no. M24, Kenya Soil Survey, Nairobi.

Lewis, L. A., Kamau, G., & Cheruiyot, R. C. (1983). Land degradation monitoring programme of the National Environment and Human Settlement Secretariat, Clark University, I.D Program, Worcester.

Mainuri, Z. G. & Owino, J. O. (2013). Effects of land use and management on aggregate stability and hydraulic conductivity of soils within River Njoro Watershed in Kenya. *International Soil and Water Conservation Research, 1*(2), 80-87.

Mathooko, J. M. (2001). Disturbance of a Kenya Rift Valley stream by the daily activities of local people and their livestock. *Hydrobiologia*, *458*(1-3), 131-139.

Ongwenyi, G. S. O. (1978). *Erosion and sediment transport in the upper Tana catchment with special reference to the Thiba Basin* (Ph.D. Thesis). University of Nairobi.

Owino, J. O., Owido, S. F. O., & Chemelil, M. C. (2006). Soil loss in runoff from a clay loam soil protected by narrow grass strips. *J. World Assoc. Soil Water Conserv.*, J1-1, 1-14.

Qureshi, J. N. (1987). *The cumulative effects of N-P fertilizers, manure and crop residues on maize grain yields, leaf nutrient contents and some soil chemical properties at Kabete*. National Maize Agronomy Workshop, Nairobi, February 17-19th, 1987, p. 12.

Sombroek, W. G., Braun, H. M. H., & Van der Pouw, B. J. A. (1982). *Exploratory soil map and agro-climatic map of Kenya. Exploratory Soil Report No. E1*. Kenya Soil Survey, Nairobi.

Thomas, D. N., & Barber, R. G. (1981). *The control of soil and water losses in semi-arid areas. Some problems and possibilities.* Paper presented at the International Workshop on Strategies for developing the resources of the arid and semi-arid areas of Kenya.

UNEP. (1993). *Report of the United Nations Conference on Environment and Development*. Rio de Janeiro, June 3-14th, 1992. Vol. 1, Chapter 10, UN, New York.

Weeda, A. (1987). *Rating of Land Qualities in Kenya 3rd Approximation*. Internal Communication No. IC 29. Kenya Soil Survey, Nairobi.

Ziegler, A. D., & Giambelluca, T. W. (1997). Importance of rural roads as source areas for runoff in mountainous areas of northern Thailand. *Journal of hydrology*, *196*(1-4), 204-229.

Ziegler, A. D., Sutherland, R. A., & Giambelluca, T. W. (2000). Runoff generation and sediment production on unpaved roads, footpaths and agricultural land surfaces in northern Thailand. *Earth Surface Processes and Landforms*, *25*(5), 519-534.