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Effects of land use and management on aggregate stability and hydraulic conductivity of soils within River Njoro Watershed in Kenya

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Abstract

There has been tremendous changes in land use and management in the River Njoro Watershed during the last three decades. Formerly large scale farms have been converted into smallholder farms and plantation forests have gradually been lost. These changes in land use and management have brought in different approaches that have triggered soil erosion and other forms of land degradation. The objective of this study was to trace the changes in land use and determine their effects on aggregate stability and hydraulic conductivity. A semi detailed soil survey of the watershed was undertaken following a three-tier approach comprising image interpretation, field surveys and laboratory analysis. The measured variables in the soil were analysed using ANOVA and correlation analysis. The major land uses were found to be forestland, agricultural land, grassland, and wetland. A strong soil type – landscape relationship was observed within the watershed. Soils of slopes were moderately to severely eroded, shallow and less developed whereas those on summits, pen plains, uplands, plateaus and valleys were deep and well developed. Aggregate stability was the highest in forestland and decreased in the order of grassland, agricultural land and wetland respectively. The mean weight diameter under the various land use conditions was 0.68, 0.64, 0.58, and 0.41 respectively. Hydraulic conductivity was the highest in forestland and decreased in the order of agricultural land, grassland and wetland respectively. There was significant negative correlation between hydraulic conductivity and the bulk density and clay content of the soils. Reduced aggregate stability and lowered hydraulic conductivity is likely to be responsible for some of the severe soil erosion and other forms of land degradation observed in the River Njoro Watershed.

Key Words: Land use, Land management, Land degradation, Aggregate stability

1 Introduction

Sparse population, forestry and large-scale conservative agriculture characterized the River Njoro Watershed in the 1940s. Large-scale farmers growing mainly wheat and keeping dairy cattle occupied most of the land. After independence in early 1960s, there was increased settlement of the people who had been displaced during the independence war. Therefore land subdivision, intensive cultivation and urbanization ensued and the hitherto large-scale farms were converted into small-scale farms and plantation forests were gradually lost (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 (Government of Kenya, 2001). This high population growth rate and the accompanying land fragmentation have strained exploitation of land resources (Mathooko, 2001) resulting in massive soil erosion of up to 8.6 kg of soil per hectare (Onyando et al., 2004) and other forms of land degradation. This massive soil loss was probably due to reduced aggregate stability expressed in terms of the mean weight diameter (MWD) ratio and hydraulic conductivity (K_{sat}).

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Soil is a dynamic and living entity used to produce goods and services of value to humans but not necessarily with perpetual ability to withstand the degradative process unless appropriately managed. As soon as land is newly put into production as in the case with River Njoro Watershed, the soil degradative processes are set in motion triggering deterioration of soil structure and disruption of carbon cycles and depletion of soil nutrient reserves. One goal of soil science is to apply pedological information to understand, predict and solve practical soil use problems.

The following questions are asked by users of soil resource information:

- What soil properties are changing with time and space?
- What are the most suitable approaches for characterizing, monitoring, predicting and managing soil changes?
- What tools or soil assessment manuals can be provided to make suitable predictions about sustainable soil use?

These three inquiries can easily be solved, by applying approaches that use pedological frame work to spatially integrate and display soil characteristics of landscapes. This information will help to develop strategies to manage both spatial and temporal soil changes.

In Kenya as in many other countries, the spatial distribution of soils has traditionally been given in soil survey maps. However such maps cannot offer the finer detail required in precision watershed management programmes. However these details can be provided by on-site intensive sampling that quantifies soil properties in the transition from one mapping unit to another to account for the variability within mapping units (Gaston et al., 2001).

Several authors have studied the spatial distribution of soil properties like particle size, organic matter, and pH and soil microbial activity at different scales ranging from a few meters (Gajem et al., 1981) to several kilometres (Ovalles and Collins, 1988). Several authors have studied the spatial distribution of soil properties Moreover aggregate stability has been studied extensively since the early 19^{th} century (Yoder, 1936). This sustained interest shows that aggregate stability plays a central role in the behaviour of soils and secondly that this role is not clearly understood. However opportunities arising from spatial dependence of soil properties can be exploited to explain the role of aggregate stability in the behaviour of soils.

It is evident now that spatial variability of soil properties are scale dependent especially those related to water transport in the soils (Iqbal et al., 2005). Indeed within the last two decades technologies have been developed to help land users better manage land resources utilising spatially varying prescription intensities based on localised plant growth requirements or deficiencies (Stafford, 1997; Cassel and Nielsen, 2000). From the foregoing literature review many studies on spatial variability of soil properties have concentrated on the properties of agriculturally managed soils.

The comprehensive relationship between the soil use changes and soil properties is not known. Soil management practices associated with various soil uses may modify the soil behaviour for example through additions or withdrawal of OM and compaction thereby profoundly altering aggregate stability and hydraulic conductivity. An assessment of the soil properties, their spatial variability and response to changes in soil use and management is therefore needed for a sustainable watershed management strategy. The objective of this study was therefore to trace the changes in soil use and determine their effects on aggregate stability and hydraulic conductivity and undertake a semi detailed soil survey of the watershed following a three-tier approach comprising image interpretation, field surveys and laboratory analysis.

2 Materials and methods

2.1 *Study area location and extent*

The River Njoro catchment 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 catchments covers about 225 km^2 (22,500 ha) and is located about 200 km North West of Nairobi in Nakuru District. The catchments lie between altitudes 1,720 m above sea level (asl) and 3,000 m asl. The river has its source from Mau escarpment and drains into Lake Nakuru (Fig. 1).

2.1.1 Altitude and physiographic units

The River Njoro Watershed cuts across six physiographic units namely: mountains, hills, plateaus, uplands, plains and valleys. It lies between altitudes 1,720 m and 3,000 m above sea level (Fig. 2), with slopes in the range of less than 2% to more than 30% (Fig. 3).

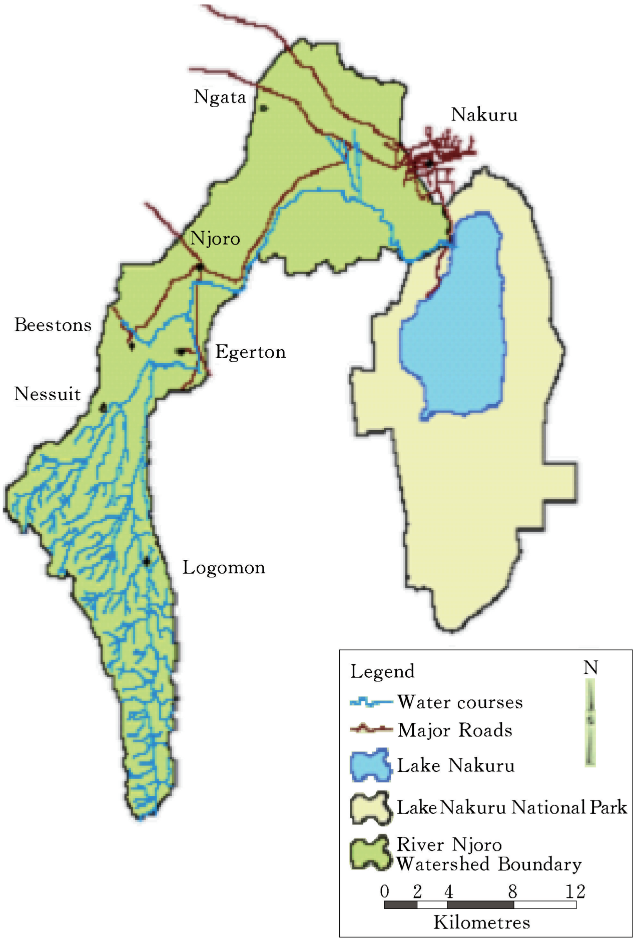

Fig. 1 Study area

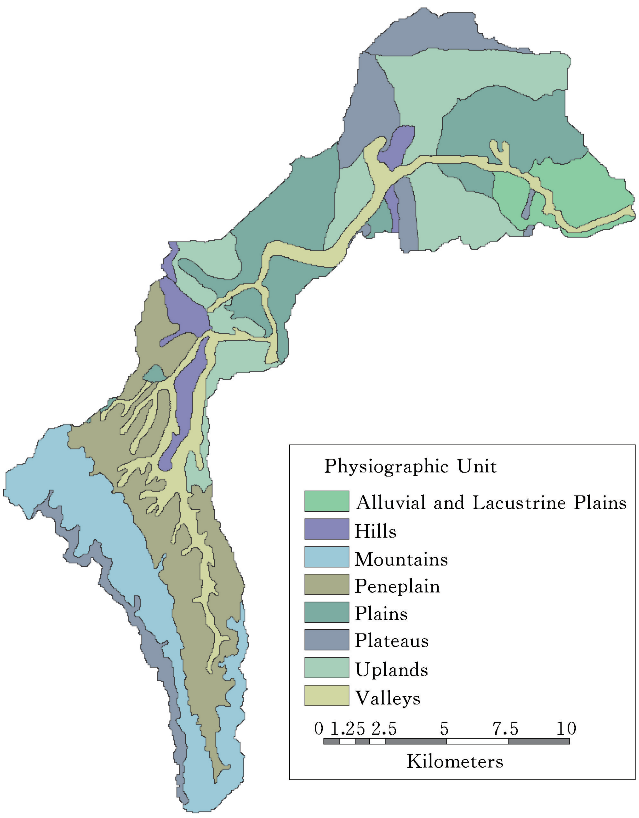

Fig. 2 Physiographic units

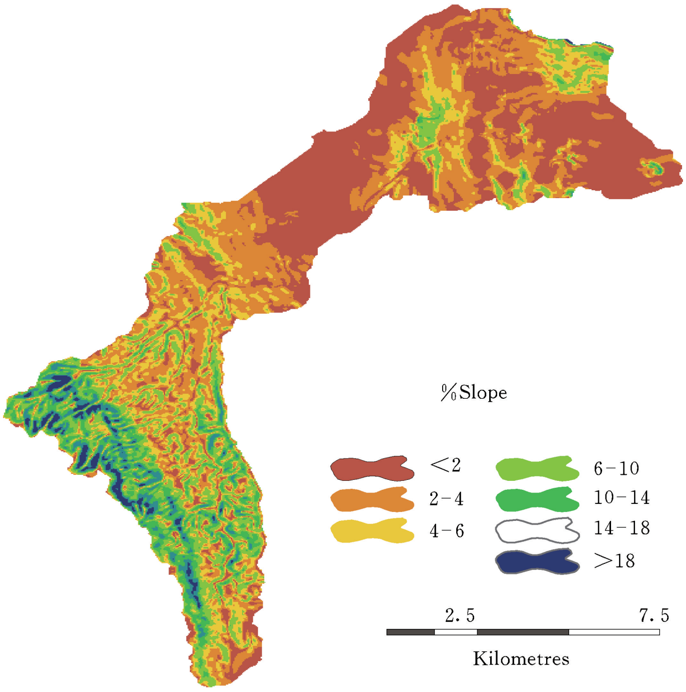

Fig. 3 Slope Map

2.1.2 Climate

The catchment area covers agro-climatic zones (ACZ) Ⅰ–Ⅳ (Sombroeck, 1982) 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 1,700 mm in agro-climatic zone I while potential evaporation ranges from 1,200 mm in ACZ I to 1,500 mm in ACZ Ⅳ. Mean annual temperatures range from 10℃ in ACZ Ⅰ to 18℃ in ACZ Ⅳ (Fig. 4).

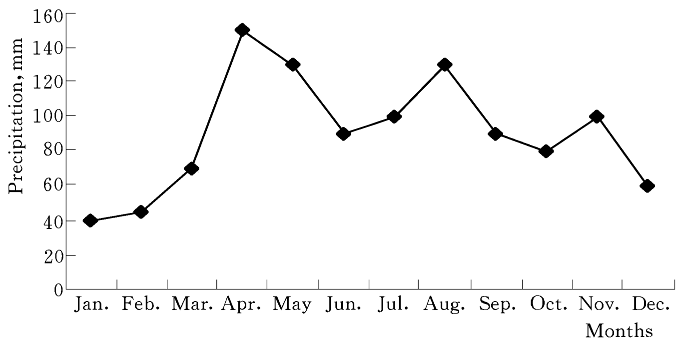

Fig. 4 Long term monthly precipitation in Njoro area

2.1.3 Geology, soils and drainage

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, 1982). The soils of the watershed have been developed on the 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.

2.2 *Methods*

The existing Exploratory Soil Map of Kenya (E1 Report) at a scale of 1 : 1,000,000 (12) was studied and the major soil units 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 sited 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. The other topsoil samples were taken for determination of Aggregate stability by measuring the mean weight diameter(MWD), texture and organic carbon. All sample points and profile pits in this study area were georeferrenced.

2.2.1 Laboratory procedures

The soil samples were air dried, crushed, mixed thoroughly and passed through a 2 mm sieve. The < 2mm fraction and the undisturbed core samples were characterised by standard analytical procedures described by Okalebo et al(2002).

2.2.2 Data analysis

Measured variables in the soil were soil texture, hydraulic conductivity and organic matter(OM). Data sets were analysed using the ANOVA and correlation statistical methods(Sall et al., 2003).

3 Results and discussions

3.1 *Landscape, soils and soil Use*

Six physiographic units namely mountains, plateaus, uplands, valleys, plains, and hills were identified and mapped as shown in Fig. 2. A strong soil-landscape relationship was found to exist within the watershed. Particular soils were found in particular landscape positions as shown in Fig. 5.

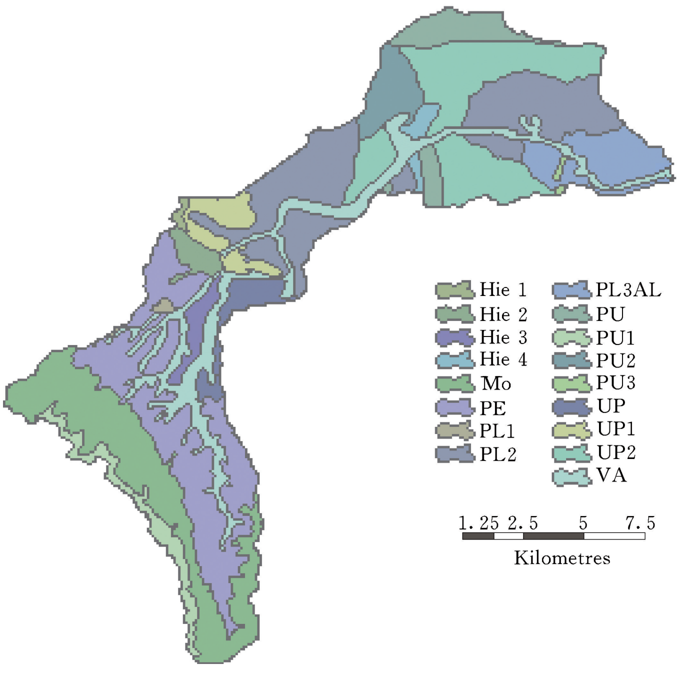

Fig. 5 Soil Map of River Njoro Watershed

For example Gleysols occurred in the valleys(VA), Acrisols were found in the mountains(Mo) and Fluvisols occurred in the plains(PL1 and PL2). However, the dominant soils occurred in more than one landscape position. For example, Andosols were found in the hills, plateaus and uplands(Hie 1-4, PU, PU 1-3, UP, UP 1-2) while Phaozems were found in the uplands and plains(UP and PL). Soils of the slopes were found to be moderately to severely eroded, shallow and less developed whereas those on summits, peneplains, uplands, plateaus and valleys were deep and well developed(Fig. 2, Fig. 5). Therefore it appeared that apart from the pedologic influences, the geomorphologic processes of erosion and deposition was actively influencing the development and properties of soils in this watershed. The major land uses were: Agricultural land, Forestland, Grassland and Wetland. Agricultural land was found close to Grassland while Wetland and Forestland occurred in close proximity. Forestland and Wetland were confined to the mountain region but Agricultural land and Grassland were found in almost all physiographic units(Fig. 2). Baldyga(2005) found out that the predominantly small-scale farmers cleared the forest for agriculture, then after some years abandoned it to fallow and eventually used the fields for grazing. Sometimes the farmers changed the land use from Grassland to Agricultural land. Similarly Wetland sections were being alienated for agriculture but reverted to wetland after some years. Likewise it was observed that Forestland and Wetlands were mainly restricted to soil types that occurred in these physiographic units. The soils found in mountain areas, commonly under forest, were mainly Acrisols, and parts of the plains occupied by wetlands and characterized by poor soil drainage, were dominated by Planosols.

3.2 *Land use and aggregate stability (MWD)*

The influence of Land use on aggregate stability showed that soils under Forestland had higher aggregate stability than the soils of nearby areas, which were under other land uses. The mean aggregate stability given in terms of MWD ratio for Forestland, Agricultural land, Grassland and Wetlands were 0.68, 0.58, 0.64 and 0.41 respectively (Fig. 6).

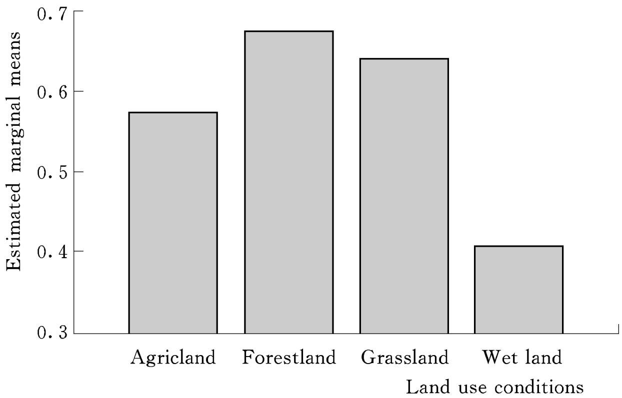

Fig. 6 Aggregate stability under different land use conditions

The ANOVA revealed a significant difference in the mean aggregate stability amongst the four land use conditions ($F=21.7$, $p<0.0001$). The poor structure associated with poorly drained soils may have contributed to the lowest MWD ratio in the wetlands. Tillage might have resulted to the decreasing aggregate stability in the Agricultural land.

3.3 *Hydraulic conductivity (K_{sat}), organic matter (OM) and land use*

The ANOVA revealed no significant difference in the mean hydraulic conductivity (K_{sat}) amongst the four land use conditions ($F=2.32$, $p=0.107$), but there was a significant difference in the in the mean organic matter content amongst the four land use conditions ($F=21.6$, $p<0.0001$). In general organic matter content was high in all the four land use conditions with the Forestland having the highest (4.60%). This was probably due the high amounts of litter and the tree canopy that reduced the rate of organic matter oxidation. Wetlands had the lowest amount (3.48%) may be due to the fact that these areas are permanently saturated with water and hence low decomposition rates. A multiple comparison of the mean Organic matter content in the Forestland, Grassland and Agricultural land revealed that the difference amongst these three land use conditions was not significant. Grasslands however had a higher amount (4.40%) than Agricultural land, which had 4.19% (Table 1).

Table 1 Mean values of some soil physical properties

Soil use	MWD	OM	K_{sat}	Clay
	Ratio	%	Cm h^{-1}	%
Agricland	0.58	4.19	77	27
Grassland	0.64	4.40	69	32
Forestland	0.68	4.60	104	23
Wetland	0.41	3.48	63	30

This difference may have been due to the fact that physical disturbance caused by tillage exposed organic matter to oxidation and hence lowering its content. There was a positive correlation between organic matter and aggregate stability (Fig. 7)

Whereas the land use conditions did not have a significant influence on the K_{sat}. it was observed that a strong

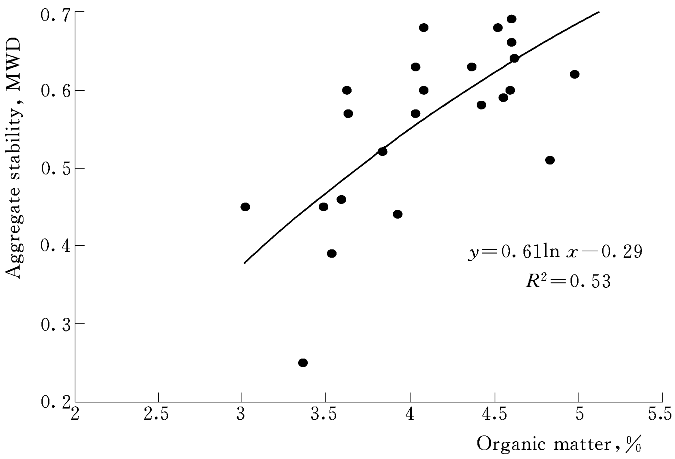

Fig. 7 Relationships between aggregate stability and organic matter

correlation existed between the K_{sat} and the clay content in the (Fig. 8).

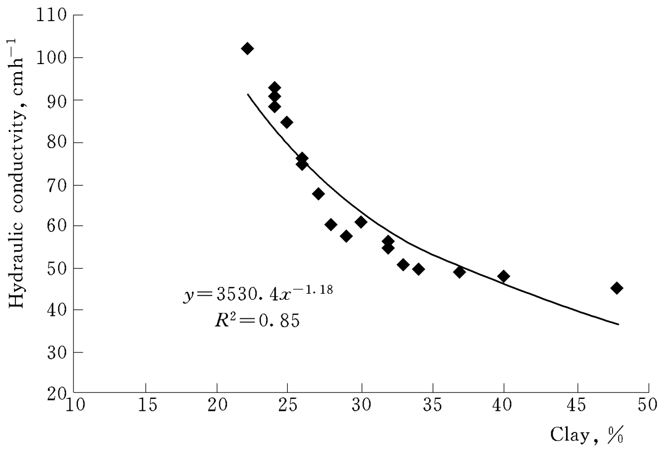

Fig. 8 Relationships between clay and hydraulic conductivity

4 Conclusion

This study shows that land use practices influence aggregate stability but not hydraulic conductivity of the soil. Aggregate stability was found to be highest in the Forestland and lowest in the Wetlands. It is most likely that the organic matter content of the soil had a major influence in increasing the aggregate stability of the soils in the various land use conditions studied. The land management practices that encourage addition of organic matter to the soil are thus important in reducing land degradation due to soil erosion. This is because high aggregate stability of a soil results in high resistance to soil erosion.

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