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Bridging the Gaps between the Increasing Knowledge and Degrading Land Resource Quality in Mosiro: Analysis of Productivity Decline and Multi-Hierarchal Stakeholders Platform for Redress

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Abstract
Knowledge on the state of land resources has significantly increased in Kenya, and yet land productivity is on downward trends. Therefore, soil quality trends, cluster-specific soil related constraints and multi-hierarchal interventions were examined in Mosiro Irrigation Scheme with an objective of bridging the gaps between the increasing scientific outputs and deteriorating state of land resources. Soil quality trends were studied as a measure of the decline in soil productivity through comparative analysis of soil information collected in 2002 and 2012. Characterization and delineation of the area into clusters were done to assess the suitability of soils for the envisaged crops. Based on the results of the 2002 and 2012 studies, the identified soil-related constraints to crop production included high salinity, high sodicity, presence of surface crusting/sealing/compaction, low soil workability, poor soil structure, adverse silt/clay ratio, high soil pH, low organic matter content, low availability of micro-nutrients, heavy metal toxicity, and nutrient imbalances. Since hardly any recommendations given in the past have been implemented, the magnitude of these problems increased, resulting into significant reduction in productivity index from 56% in the year 2002 to 8% in the year 2012. Five clusters were identified with varied potentials for different crops. Most of the five clusters were found to be non-suitable to marginally suitable for the envisaged crops. The results of this study demonstrate how the identified constraints vary in magnitude in different clusters and their limitations to different crops. To address these problems, multi-hierarchal stakeholder platform was recommended to combat the increasing rate of soil quality decline through adoption and implementation of the appropriate interventions.
Keywords: Soil quality index, land degradation and interventions

1. Introduction

Innovation has increased the accessibility of information on the status of land resources including soils, water and climate in relation to the requirements of alternative land uses. Scientific breakthroughs have increased the prospective stocks of data and information on the quality and productivity of land resource base as well as the ecosystem functions that sustain them. Recent development in land resource survey and evaluation focuses on the assessment, monitoring and prediction of the environment and land resources under diverse management systems at landscape scale, using remote sensing, geographical information system, ecological modeling and multi-objective decision support system to understand the spatial variability of the degree of land degradation as well as temporal dynamics and their relations with human activities as a basis of prioritizing areas requiring interventions. However, most of these stocks of data exist in websites, book shelves, office cabins, computer programmes and scientific publications (Muya et al., 2013). In Kenya, biophysical land resources information has been generated at various scales for the analysis of land resources potentials through soils and agro-ecosystem based investigation and mapping (Muya et al., 2014). This has been mainly for enriching the national biophysical databases for multi-purpose land use planning (Rachilo et al., 1998). The biophysical databases developed has been useful in providing information about soils, land and environment and their interrelationships with agricultural production for the whole country for general projects identification and planning (Rachilo et al., 1998). Despite all these efforts, land degradation and increased rate of soil productivity decline continue to be a threat to sustainable agricultural development. Muya et al. (2010) observed that the sharp drop in agricultural production by over 80% in Kalacha Irrigation Scheme was a clear indication of the absence of appropriate stakeholders' platforms and extension mechanisms required to facilitate the access and utility of the research outputs on land resources management. In Mosiro Irrigation Scheme, the information on land resource base and the state of land degradation existed in exploratory soil map (Sombroek et al., 1984), technical proposal (TAHAL Consulting Engineers LTD, 2001) and detailed soil and land evaluation reports (Waruru and Muya, 2002). Waruru and Muya (2002) gave a strong recommendation that the identified soil-related constraints be eliminated to ensure sustainable irrigation development, and gave emphasis on the need for technological redress, specifically on high salinity, high sodicity, and presence of surface crusting/sealing/compaction, flood water hazard and poor soil structure. Since hardly any of these recommendations were implemented, the magnitude of these problems increased over years in the area as is reported by Muya et al. (2014). The problem is caused by the lack of the required linkages between research workers and land users, ranging from policy makers to extension workers, input suppliers to farmers themselves (Oduor, 2011). Against this background, this research attempted to bridge the gaps between the increasing knowledge on land resource base and deteriorating soil quality through analysis of the trends in soil productivity in Mosiro irrigation scheme. Participatory identification of intervention strategies and their adoption through multi-level stakeholders' platforms are also discussed.

2. Materials and methods

2.1. Description of the study area

Mosiro Irrigation Scheme is situated South-West of Nairobi in Narok County, about 12 km South of Mosiro trading centre, and about 82 km from Ntulele. The intersection of the grid line 36^{o} 04' E and 1^{o} 28' S marks approximately the centre of the scheme, at an elevation of approximately 1265 m above the sea level.

The proposed Mosiro Irrigation Scheme is the major irrigation development in Narok County, Kenya. Therefore, sustainable land management envisaged for the area should integrate land use policy, technologies and agricultural activities in such as way as to enhance economic performance of the area, while maintaining the quality and environmental functions of land resource base (Dumanski, 1997). Land use policy dimension is critical in the area because of the challenges associated with high fragility of the land resource base which is undergoing a paradigm shift from livestock based economy to market oriented irrigated agriculture. This requires land use planning which normally comes into play where major land use change is envisaged for improved agricultural and rural development. Land use planning, based on biophysical and socio-economic data collected from the project area will assist in zoning of the area, indicating ecologically sensitive regions which should never be irrigated, locations with opportunities and potentials for agricultural development; and zones with potential conflicts over use of water and land due challenging land utilization requirements. Currently, most land users are using the land without zonation and a firm, statutory regulations on the use of each zone according its biophysical, environmental and socio-economic requirements, thereby resulting into unsustainable production and development.

The concept of zonation was utilized in characterizing the project area, where the soils were delineated and grouped into different biophysical domains called clusters. The Clusters are zones at micro-level, which have been arrived at by considering the proposed irrigation scheme as an extension of the surrounding landscapes in a broader geographical scale. In this case, the project area is broadly divided into three zones, based on physiographic parameters, namely: Upper level catchments, middle level catchments and lowlands (Figure 1). The upper level catchment consists of uplands, low level plateaus and rolling landscapes (U-L-R), the symbols being a part of soil mapping codes at a national scale in Kenya. The middle level uplands consist of relatively low level plateau (L-Pd1) and the lowlands consist of alluvial flood plains and bottomlands (AL2-LS-B4).

2.2 Analysis of the previous works

The information contained in the report written by TAHAL Consulting Engineers LTD (2001) was examined with a view understanding the layout of the proposed irrigation structures in relation to the types and spatial distribution of soils, capacities of engineering works with respect to the existing cropping patterns, as well as the physical and structural suitability of soils for the proposed layout of the engineering works.

Detailed analysis of the previous works relevant to the project area was carried out with a view of studying the trends in soil quality and productivity in relation to land degradation. Detailed soil survey and mapping carried out by Waruru et al. (2002), were examined in terms of their mandate, major findings and recommendations given for the proposed irrigation development. The soils quality indicators applied in evaluating the agricultural and irrigation potentials for various crops were also studied as well as the criteria for land suitability assessment.

2.3 Participatory soil investigation and mapping

Prior to soil investigation and mapping, the extension staff was sensitized on the methodologies to be applied in characterization and clustering of the scheme. PowerPoint presentation was done at District Agricultural Office and the issues emerging from the meeting were incorporated into the soil survey activities carried in the field. One of the major issues was the need to demonstrate the soil quality indicators used for clustering the production systems to the Field Extension Staff for on-ward dissemination to Irrigation Water User Association (IWUA) and farmers during the implementation of the management strategies identified for all the clusters.

In the field, the zonation of the land facets was done through site evaluation, based on slope, relief features and surface conditions. Each zone identified was studied through more detailed characterization of soils in terms of colour, depth, structure, consistence, surface sealing and crusting, and the reaction to HCL as a basis of identifying different clusters, with a view of establishing the specific location and geographical distribution of the critical problem areas with stakeholders as well as the soil profiles representing the clusters; defining the farm units occurring in different clusters; identifying the location and spatial extent of the area requiring urgent environmental conservation.

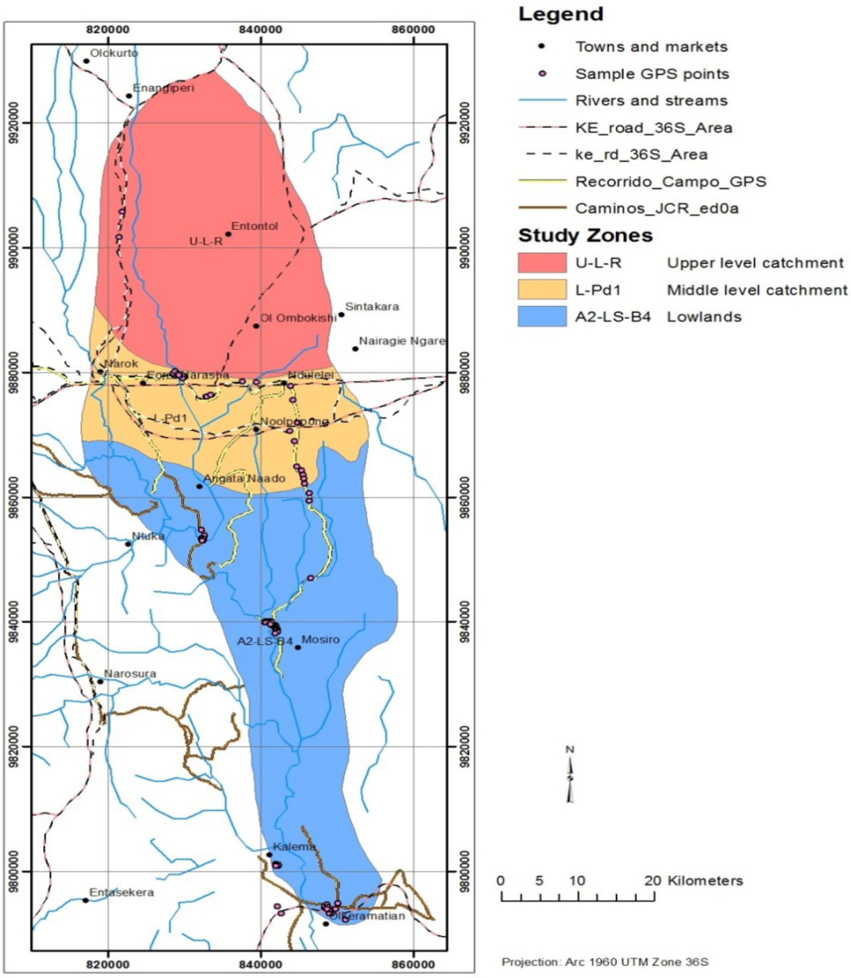

Figure 1. The broad geographical zonation of the project area

3 Results and discussions

3.1 Analysis of the results presented by TAHAL Consulting Engineers LTD (2001)

The technical proposal written by TAHAL Consulting Engineers LTD (2001) recommended that a detailed soil survey and mapping be carried in the area earmarked for Mosiro irrigation development. The Consulting Engineers indicated that the results of soil survey would be the basis of formulating a suitable agricultural development plan/cropping pattern as well as determining the related engineering activities. Agricultural development plan recommended was to be based on the crops that were not only favoured by the soils and environmental conditions, but also socially acceptable for human and animal consumption. Integrated soil-water-plant system for enhanced food security and environmental sustainability was envisaged in the plan, based on systematic survey and land evaluation processes. The study also recommended further detailed soil investigation and cropping systems to come up with intensity on the basis of which to calculate the irrigation water supply requirements. To plan, design and operate the proposed water supply and distribution system, participatory determination of soil physical and hydraulic properties was recommended to be the basis of providing the extension services on appropriate irrigation scheduling. According to FAO (1986), this should include selection of the crops and cropping patterns; seasonal and monthly water supply requirements; scheduling of the irrigation water supply over the growing season.

3.2 Results of the past studies with respect to soil quality

The main finding from the past study (10 years previously) was that the soils were adequately supplied with major plant nutrients except nitrogen, which was found to be relatively low (Table 1). However, the physical and hydraulic properties of soils had values which were lower than environmental thresholds, thereby placing the area at risk of environmental degradation. The study also predicted an increased decline of soil quality due to the generally fragile soils with high susceptibility to erosion, which was attributed to intensive and indiscriminate bush clearing and charcoal burning. These activities resulted into the depletion of organic matter. According to Abbott and Good (1989), the soil productivity is sustained by faunal activities which depends on organic matter content. For the soil productivity to be sustained the following recommendations were made, based on the detailed soil study carried out in the year 2002: reduction of pressures on land through keeping optimal number of animal and controlled grazing; construction of diversion ditches, based on judicial assessment of soil aggregate stability and its capacity to sustain the engineering structures; application of organic inputs into the farm land to enhance soil organic carbon and nutrient availability; deep ploughing and application of plant residues to improve soil structure; mixing top and sub-soils of highly stratified soils; surface mulching to reduce the temperature and water evaporation, and adopting irrigation methods and scheduling, based on the calculated crop water supply requirements, field water retention capacity and hydrological balance/budget. It was also suggested that irrigation water with relatively low quality must be accompanied by enhanced soil quality through good agricultural practices. This is because the irrigation water was found to have high sodium adsorption ratio (SAR) of 16.5, (being higher than environmental threshold of 10) and medium salinity (0.27 mS/cm). Chloride and sulphate levels were found to be higher than normal, with values of 16.9 and 48.5 me/litre respectively. This water was found to be suitable for irrigation but only when irrigating highly permeable soils and plants with high salt tolerance levels. The soils of the research area, having low permeability, required quick adoption and implementation of the recommended practices to improve soil structure and hydraulic properties so as to enhance the salt leaching rates. In this case, the improved soil quality will be indicated by decreased soil compaction and sealing, increased infiltration and hydraulic conductivity (Sharma et al., 2004).

Table 1: Soil conditions of Mosiro Irrigation Scheme in the year 2002

Soil quality indicators	**Mean values**	**Critical limits**
Soil organic matter	3.32%	2.0%
Nitrogen	0.14%	0.2%
Phosphorous	91.6 ppm	20 ppm
Potassium	3.6 me%	0.80 me%
Soil pH	6.3	5.5
Exchangeable sodium percentage	1.6	6.0
Bulk density	1.2	1.0
Infiltration rate	0.5 cm/hr	2.5
Hydraulic conductivity	0.1 cm/hr	2.0

Source: Waruru and Muya (2002)

Table 2: Evidence of severe land degradation and soil quality decline

Year	**Mean**	**Organic matter content %**	**P ppm**	**pH**	**Bulk density (g/cc)**	**ESP**	**K**	**N**	**PI%**
		3.32	91.6	6.74	1.20	13.4	3.64	0.12	56
2002	Std Deviation	0.844	38.956	0.40	0.082	2.88	0.503	0.032	
2013	Mean	1.62	25.78	7.46	1.29	13.4	0.76	0.07	8
	Std Deviation	0.839	11.539	0.84	0.145	0.11	0.114	0.004	0.039
	% Change	83.3	83.3	75.0	41.7	100	83.3	83.3	83.3
	Significance	0.13	0.07	0.00	0.101	0.00	0.00	0.08	0.075

3.4 Causes of land degradation and soil quality decline

Land degradation processes can be explained in terms pressure-state-response relationships in the project area. The state of land resource base, measured by the change in productivity index between the year 2002 and 2013 is a consequence of increased rate of land degradation. The increased rate of land degradation processes is as a result of the negative interactions between pressures put onto these resources through natural and man-made forces and responses in terms of various land use and management attributes including, grazing, charcoal burning and crop farming without applying appropriate technologies (Figure 2). Limited access to the research results in areas of agronomic and irrigation technologies as well as non-response to recommendations based on soil survey and mapping have contributed to the degraded state of land resource base that needs urgent redress (Waruru and Muya, 2002). Since the vision of the Government of Kenya is to transform agriculture sector into a profitable entity, agricultural research and extension are the key components of economic recovery and wealth creation through application of science, technologies and innovations (KARI, 2009).

Despite the increasing land degradation caused by unfavourable alterations in ecological processes, most pastoralists still continue with grazing even on severely degraded ecosystems since agricultural production through irrigation has not reached the level that meets all the human needs. Analysis of land suitability for various land use types and irrigation as well as prescription of the appropriate inputs and technologies for sustainable agricultural production is the first step. This forms an important component of the precision agriculture recommended by the Mid-Term Review Mission (LOG ASSOCIATE, 2011) that involves integrated information and production based farming systems, designed to increase site and cluster specific production efficiencies through combination of agricultural inputs and appropriate irrigation technologies. The timely adoption of the recommended technologies and practices that match with the increasing rate of land degradation processes will, not only arrest the situation, but also enhance soil health and its capacity to function in sustaining agricultural production and the required ecosystem functions such as recycling nutrients and stabilizing soil structure.

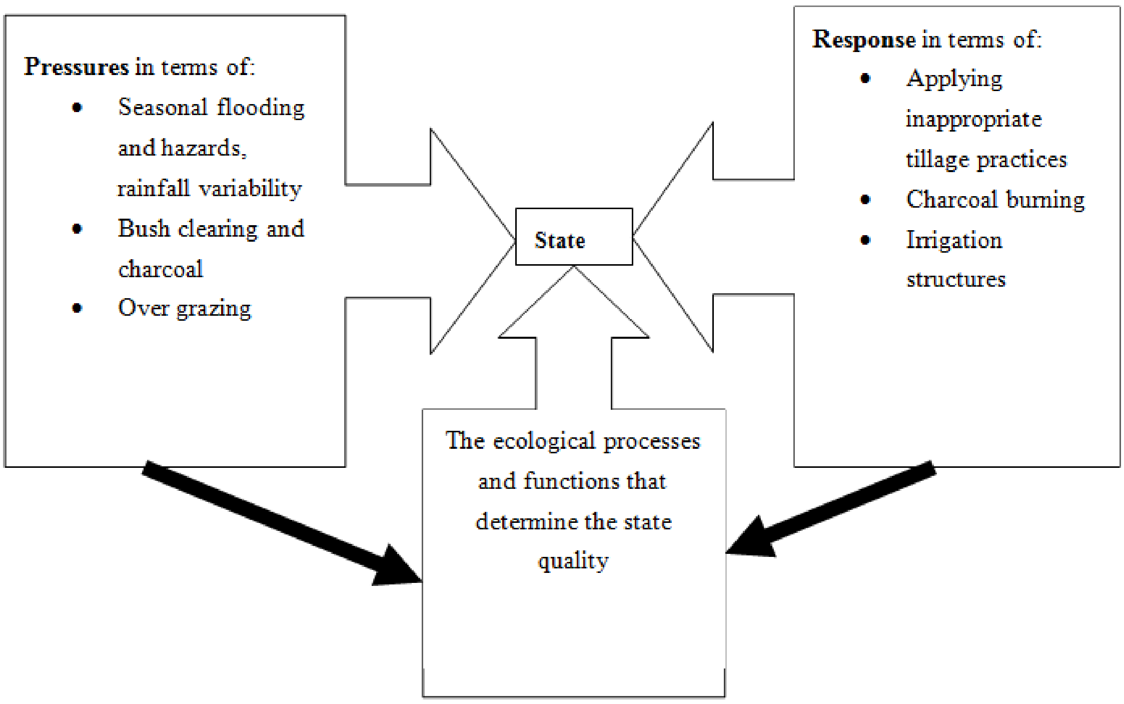

Figure 2: Pressure-state-response relationships

Table 3: Chemical soil quality attributes of the top-soils for all the five clusters

Indicators	**Clusters**				
	C1	**C2**	**C3**	**C4**	**C5**
Soil pH	6.38	7.0	6.66	8.3	6.8
Total nitrogen%	0.18	0.09	0.16	0.07	0.16
Organic carbon%	1.71	0.92	1.58	0.69	1.55
Phosphorous ppm	15	5	10	6	70
Potassium me%	2.05	2.28	2.11	2.1	2.60
Calcium me%	8.6	10.8	8.3	11.6	13.5
Magnesium me%	3.95	3.45	3.55	1.67	3.89
Manganese me%	0.71	0.94	0.88	0.06	0.40
Copper ppm	0.53	0.60	0.68	0.41	0.88
Iron ppm	65.4	23.8	28.9	11.5	39.6
Zinc ppm	7.06	4.56	7.77	0.40	12.8
Sodium me%	0.67	0.68	0.58	0.23	0.78
Electric conductivity mS/cm		1.10	1.00	1.30	0.74

3.6 Multi-hierarchal stakeholder platform for implementing technological packages

The first step in implementing the recommended practices is to bring all the relevant stakeholders on board and apply a multi-level stakeholder approach to sustainable management of different clusters (Hans Hurni, 1997). The second hierarchal level is to study the information required for the implementation of the recommended practices, including the critical problem areas. The third level is to identify the relevant actors and interest groups to define a clear pathway to sustainable development through implementation of the recommended practices. The fourth hierarchal level is communication and outreach. For Mosiro Irrigation Scheme, the major actors are the Ministry of Agriculture and Livestock (MOAL), Kenya Agricultural Research Institute (KARI), and Irrigation Water User Association (IWUA). To all these actors, the identified constraints determined at different levels and times must be presented as well the intervention strategies. From the previous studies, the identified constraints included high salinity, high sodicity, presence of surface crusting/sealing/compaction, low soil workability, poor internal drainage, flood water hazard, poor soil structure, adverse silt/clay ratio, high soil pH, low organic matter content, low availability of micro-nutrients, heavy metal toxicity, nutrient imbalances and undesirable climatic conditions. Since hardly any recommendations given in the past have been implemented, the magnitude of these problems has increased over years. These problems impact differently on different crops, and they vary in magnitude in different clusters. As is shown in Table 4, cluster 1 (C1) was found to be highly suitable for sorghum, while for maize, beans, ground nuts, tomatoes and onions, it was rated as moderately suitable. Cluster 2 (C2) was found to be moderately suitable for sorghum, marginally suitable for maize and ground nuts; and non-suitable for beans, tomatoes and onions. Cluster 3 (C3) and 4 (C4) was found to be non-suitable to marginally suitable for all the envisaged crops. . However, for the formulation of the technological packages, each cluster should be examined individually and the limitations of soils in each of them should be matched with individual crops, so as to define accurately, the soil-cluster-crop specific interventions to be recommended for trials and validation by the extension staff (Table 5).

Table 4: Irrigation suitability for different clusters

Clusters/crop	C1	C2	C3	C4	C5
Maize	S2	S3	S3	NS	S2
Bean	S2	NS	S3	NS	S2
Sorghum	S1	S2	S3	NS	S1
Ground nut	S2	S3	S3	NS	S2
Tomato	S2	NS	S3	NS	S2
Onion	S2	NS	S3	NS	S2

Key: S1-highly suitable; S2-Modrately suitable; S3-Marginally suitable; NS-Non suitable

Table 5: Limitations of different clusters to different crops

Clusters/Crop	C1	C2	C3	C4	C5
Maize	3, 5, 7, 9	4, 6, 7, 9	2, 4, 7, 9	1, 2, 3, 4, 5, 6, 7, 9	2, 5, 8, 9
Beans	3, 5, 7	1, 6, 7	7	1, 2, 3, 4, 6, 7	7, 8
Sorghum	3,5, 8	6, 7	10	1, 2, 3, 4, 6, 7	8
Ground nut	3, 4, 5	1	10	1, 2, 3, 4, 6, 7	8
Tomato	3, 4, 5, 7	1, 6, 7	7	1, 2, 3, 4, 6, 7	8
Onion	3, 4, 5, 7	1, 2, 6, 7	7	1, 2, 3, 4, 6, 7	8

Key: 1-Sodicity; 2-Salinity; 3-Surface sealing/crusting; 4-Workability; 5-external drainage flood hazards; 6-depth/water availability; 7-Nutient availability; 8-soil texture/structure; 9-climate regime; 10-No serious limitations

Based on the results of land evaluation and judicious analysis of soil-crop-environmental interactions, the following cropping patterns were suggested: Maize (180 ha), from May to September; followed by beans (180 ha) from October to February; Onion (120 ha), from March to August; followed by ground nut (120 ha) from November to March. The total acreage covered by the suggested cropping patterns is 300 ha with an intensity of 200%.

3.7 Critical problem issues, key actors and challenges

The proposed Mosiro Irrigation Scheme is the major irrigation development in Narok County, Kenya. Therefore, sustainable land management should be envisaged in formulating the technological packages intended to enhance horticultural production and economic performance of the area. According Dumanski (1997), sustainable land management requires integration of technologies, policies and agricultural activities in such a way as to enhance economic performance while restoring and maintaining the quality and environmental functions of land resource base. Table 7 shows the critical problem areas in each cluster, intervention options and key actor categories to be brought on board. A sensitization stakeholder workshop is strongly recommended to highlight the priority areas for interventions, implementation framework and the way forward on the required technical and financial inputs to ensure sustainable management of the proposed production systems for improved soil quality, horticultural production and water use efficiency. The cluster map (Figure 3) provided will facilitate the implementation processes by providing the geographical location and information on the degree and extent of the identified soil-related constraints to agricultural production. Each actor category must understand that the solutions found for addressing the problem in each cluster are socially and environmentally feasible, economically viable and ecologically sound at the local scale, and at the same time, having well defined and measurable attributes that will assist in monitoring the biophysical and economic sustainability of the production systems proposed for each cluster. Biophysical sustainability of each of the clusters identified will be realized if the sufficiencies of the soil quality attributes that define the clusters do not deteriorate under the proposed irrigation development (Hans Hurni, 1997). Maintaining soil quality at a desirable level is challenging in the project area, which is a fragile land resource base, undergoing a paradigm shift from livestock based economy to market oriented irrigated agriculture. In this area, there is an urgent need to adopt appropriate soil and plant management practices that reduce land degradation and maintain soil quality that enhances agricultural production for improved income and livelihood. The rate of adoption of the envisaged intervention should be reasonably high to cope with the consequences of increased land degradation. Aspects of erosion as one of the cause of the declining trends in soil quality are some of the most important parameters to be examined for controlled land degradation. The key actors in different zones or clusters will adopt and promote technologies which are relevant to the respective zones or clusters, depending on the types and degree of land degradation expressed in form of soil erosion. Because of the increased land degradation, Mosiro Irrigation Scheme is bound to have low soil quality and health due to decline in soil structure, increased compaction, hence increased erosion, which is reflected in heavy sheetwash and increased siltation of the river water (Table 6).

Table 6: Erosion aspects in different areas

Physiographic units	Effective rain (mm)	Run-off potential (mm)	Sediment yield index %
Upper level catchments, mainly uplands	30	111	75
Intensively cultivated and rolling middle level catchments	120	21	25
Steep valley sides next to Ewaso Ngiro River	35	123	29
Lowlands	20	130	65

Table 7: Soil-related constraints and proposed intervention strategies

Critical problem issues	Implications	Cluster where dominant	Options for interventions	Stakeholders or actors to take leading roles
Severe land degradation and vulnerability to seasonal flooding	Decline in biological activity and productivity	C4	Water harvesting for flood control and establishment of appropriate fodder grass/tree species to consume flood water and reduce overland flows into the scheme	Kenya Agricultural Research Institute (KARI), Ministry of Agriculture (MOAL) and Irrigation Water User Association (IWUA)
	Physical degradation through run-off , silt/sediment transport and degrading banks of drainage channels	C3 and C4	Construction of conservation structures including rechanneling the diversion ditch to natural water way or stable soil mapping units; conservation tillage	Irrigation Engineers and IWUA
	Chemical degradation	All the clusters	Soil amendment packages	KARI, MOAL
Poor internal drainage	Impeded water uptake and artificial moisture stress	C1	Appropriate tillage and irrigation methods	KARI, MOAL
Stratified soils	Unstable soil profiles, excessive drainage and low moisture holding capacity	C5	Deep ploughing to mix soil layers and application of farmyard manure	KARI, MOAL
Shallow and gravelly soils, in places extremely compact with low nutrient availability	Limited water and nutrient availability	C2 and C3	Integrated water and fertility management	KARI, MOAL

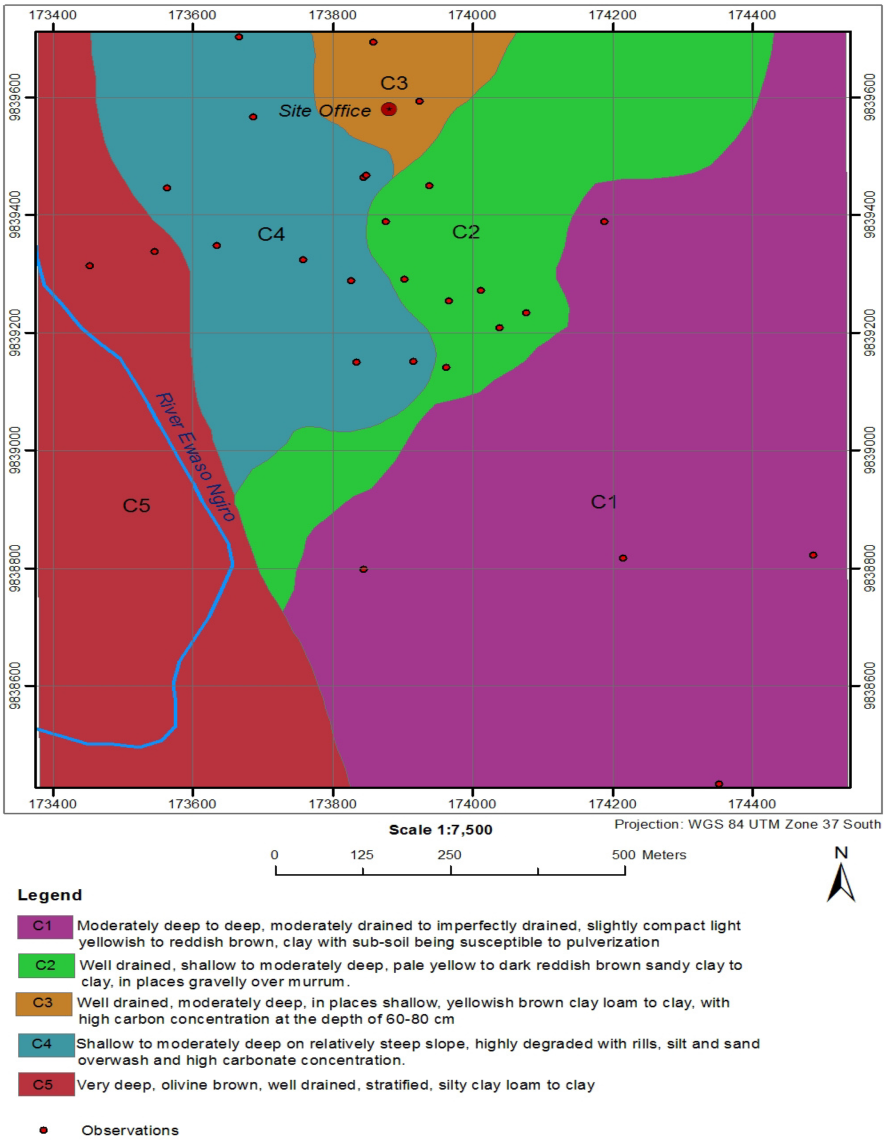

Figure 3: Delineated clusters as a basis of formulating intervention packages

4 Conclusions and recommendations

Based on the results of previous studies and analysis of the physical soil quality indicators, fiver clusters and their soil suitability classification were arrived at. All the five clusters except cluster one (C1) were found to be non-suitable to marginally suitable for most of the envisaged crops. The identified soil-related constraints to crop production included high salinity, high sodicity, presence of surface crusting/sealing/compaction, low soil workability, poor soil structure, adverse silt/clay ratio, high soil pH, low organic matter content, low availability of micro-nutrients, heavy metal toxicity, nutrient imbalances and undesirable climatic conditions. Since hardly any recommendations given in the past have been implemented, the magnitude of these problems was found to have increased, resulting into significant reduction in productivity index from 56% in the year 2002 to 8% in the year 2013. The identified constraint and problems are expected to impact differently on different crops, and vary in magnitude in different clusters. These include: severe land degradation and vulnerability to seasonal flooding; poor internal drainage; stratified soils, with excessive drainage and low water holding capacity; and shallow, gravelly soils, in places extremely compact with low nutrient availability. Elimination of these constraints to achieve full biophysical production potential is possible through the implementation of the recommended activities including: organizing stakeholders' workshops to disseminate the main research findings; communication and outreach bring key actors on board; identifying and promoting appropriate soil and water conservation methods including water harnessing, interception and storage of run-off water; identifying integrated organic, inorganic and plant-based approaches for sustained fodder and crop production; developing and promoting precision agriculture for improved water use efficiency and nutrient recycling.

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