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RESEARCH ARTICLE

LAND DEGRADATION ASSESSMENT USING THE LADA LOCAL TOOLS AND METHODS IN LESOTHO: ASSESSMENT OF SOIL PHYSICAL PROPERTIES

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ABSTRACT

The combat against land degradation in Lesotho has been in existence since the arrival of the missionaries but failed due to lack of scientific evidence on the cause, extent and severity of the degraded watersheds to help plan sustainable management strategies to mitigate land degradation. Field investigation was conducted using LADA Soil Assessment Methodologies to assess the physical properties of the Bolahla- Mphosong catchment to provide a first-hand scientific data on the state and causes of land degradation for decision support making at the different levels of economic planning. The field assessment indicated that the soil quality status of the catchment was moderate but high bulk density and high slope gradients were the main causes of land degradation in the Bolahla-Mphosong catchment. Sustainable management practice such as Conservation Agriculture (CA), organic mulching, contour ridging and stripe cropping, avoiding overgrazing and farming on marginal lands should be encouraged among the land users to help mitigate land degradation in the catchment.

INTRODUCTION

Land is a finite resource yet mostly neglected and mismanaged either knowingly or unknowingly. The most prominent outcome of this mismanagement of land and water resources in Lesotho is the unprecedented state of land degradation and soil erosion in both croplands and rangelands. The net effects of land degradation and soil erosion are structural damage of the soil surface and the decline in the productivity of land based natural resources. In recent times, the impacts of climate change on land degradation is causing serious global environmental problems often threatening food systems, water resources and biodiversity and adversely affecting the physical and chemical properties, productive, physiological, cultural and ecological functions of land resources (Wessels et al. 2007; Webb *et al.,* 2017). Land degradation results in a reduction in soil structural characteristics including pore geometry and continuity, thus aggravating a soil's weakness to crusting, compaction, reduced water infiltration, increased surface runoff, wind and water erosion, greater soil temperature fluctuations, and an increased susceptibility for desertification (Lal, 2015).

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There are also changes in the physical properties of the soil such as soil depth, texture, structure and bulk density when the soil is translocated due to tillage and water erosion (Kosmas *et al.,* 2001; de Alba *et al.,* 2004; Karuma *et al.,* 2014). In Lesotho, the situation of soil degradation is demonstrated through the loss of biological productivity and soil depth resulting from over-exploitation and mismanagement of the natural resource base such as water, land, plants or animals (UNCCD, 2004).

Soil resilience is the resistive or recovery capacity of the soil from natural or anthropogenic perturbation (Tenywa *et al.,* 2013) while soil exhaustion is the decline or inability of the soil to resist or recover from anthropogenic or natural perturbation. Land degradation results in a reduction in soil structural characteristics including pore geometry and continuity, thus aggravating a soil's weakness to crusting, compaction, reduced water infiltration, increased surface runoff, wind and water erosion, greater soil temperature fluctuations, and an increased susceptibility for desertification (Lal, 2015). According to Verdoodt (2012), soil structure is the main soil property that affects the physical, chemical and biological degradative processes, causing a decline in soil quality. Soil degradation adversely affects soil quality through the reduction in soil biota, organic matter, nutrients, infiltration rate, low soil aggregate stability and water holding capacity, thereby reducing the soil's productivity (Dlamini *et al.,* 2014; Vagen *et al.,* 2015). There are changes in the physical and chemical properties of the soil such as soil texture, organic matter content, chemical deposition, nutrient concentration and bulk density when the soil is translocated due to tillage and water erosion (Kosmas *et al.,* 2001; de Alba *et al.,* 2004). Variation within field in parameters such as soil pH, organic matter content, soil depth, available soil water, nutrients, electrical conductivity and cation exchange capacity affect yield and crop quality (Kosmas *et al.,* 2001; Vagen *et al.,* 2015). Globally, improper agriculture practices result in the oelease of soil organic carbon which is estimated at 1.6 Gt C yr^{-1} into the atmosphere, thereby causing a decrease in soil organic carbon and biomass carbon contents through soil biological degradation (Lal and Follett, 2009 Winowiecki *et al.,* 2016). Despite several research investigations on some specific aspects of land degradation in Lesotho such as reservoir sedimentation and soil erosion at Roma Valley and Maliele Catchment by Chakela (1981), the effect of traditional land transactions on soil erosion and land degradation in four lowlands locations by Leduka (1998) and other multidisciplinary research programmes such as the Livestock production and range management, Land rehabilitation programme, integrated catchment management programme, etc., land degradation in Lesotho is still spiraling out of control due to lack of current information on the causes, extent and severity of land degradation. This study seeks to assess the soil physical properties of the Mphosong-Bolahla Catchment to provide scientific evidence for decision support making at different levels of economic planning.

MATERIALS AND METHODS

Site Description and Characterization of the Study Area

Site Description: The study area is the Mphosong-Bolahla catchment in the foothills of the Leribe district (Fig. 1) located between 1800 m to 2300 m above sea level. The overall catchment was divided into three sub-catchments of Bolahla (18.0 ha), Senyokotho (10.4 ha) and Mphosong (14.2 ha) for a total area of approximately 42.6 ha in size. The average annual rainfall in this area is 500mm to 800mm. The annual average temperature ranges from 32°C to -2°C. The topography of rugged terrain is characterized by steep slopes of the mountain valley with the catchment being covered with natural vegetation, including indigenous shrubs and grasses with few exotic forests. The major soil types common across all three sub-catchments are a combination of single soil series or associations' major soil series: Popa (Lithic Hapludolls), Matsana (Typic Hapludolls), Ralebese (Typic Hapludolls). However, Machache (Typic argioudolls) soil series is observed in the Bolahla sub-catchment only. Matšaba (Typic Argiudolls) and Ralebese soil series are dominant in the croplands while popa series occupies the main the rangelands across the three sub-catchments. The land uses are categorized in rangelands, croplands, settlements and forest made of few patches of exotic woodlots stocked with *pinus radiate and eucalyptus* while the natural thickets are found within the water courses and the north-facing slope maily stocked with *Olea africana and Licosidia* species. The land tenure system is largely communal especially the rangelands where the administration is done by the chiefs and local counselors. The cropland is semi-private while under cultivation with majority having their own land.

Characterization of the Study Area: The study site was characterized using Lada Local methodology (FAO, 2016) with the participatory of the Bolahla- Mphosong communities and the resource people from the local technical sector which was made up of all the main stakeholders, NGO's and other pertinent projects in the area concerned with the environment to provide an overview of the study site in relation to the land use systems, level and types of degradation and the sustainable land management (SLM) practices in the area. Before the characterisation of the catchment begun, secondary data about the catchment was obtained from maps and satellite images, policies, socio-economic and technical information of the catchment in order to study the timelines and trends of the changes that had occurred in the catchment for the past ten years. A general meeting was organised with the local authorities to inform them about the objectives and activities of the assessment and secure their support and help in selecting the main stakeholders, identify relevant projects and NGO's in the catchment area and finally help conduct a reconnaissance walk before undertaking the focus group discussion (FGD). Tools such as FGD, wealth ranking, institutional mapping and study area mapping were used to characterise the study area.

Focus Group Discussion (FGD): After the reconnaissance walk, FGDs were conducted in each of the sub-catchments with twenty (20) community elders (key informant) on average who have knowledge about the history, land use systems and the community territory to provide a detailed information on the causes and impacts of soil degradation using questionnaires (Photo 1). The participants were disaggregated by gender as follows: 5 of men, 10 of women, 5 of youth. The discussions were guided by an open ended question. The FGDs were organised to provide a decadal experience of the study area to inform the team about the history, range of land users, individual and communal management regimes, the types, magnitude and trends of degradation of the study area.

Wealth Ranking: After the FGD, an individual interview for wealth ranking was conducted in the catchment to ascertain the relative "wealth status" of the people in the community. This was done to determine the views and behaviour of the people in relation to the land resource they use directly and the natural resources in the community. Wealth was measured by the number of animals, farm equipment, type of house, farm size, vehicle that one possesses. First of all, the community was grouped into households by identifying the community members with a set of key indicators for the main wealth groups such as "better off", "medium" or "poor". Indicators like farm size, household size, type of house, number of livestock, outside farm employment, financial assest, educational level, etc. were arranged in order of importance relative to the study area and assessed.

Rapid land tenure analysis and Institutional Mapping: Land tenure affect how people access and manage their natural resources. Land tenure and institutional mapping (NGO's, informal groups of land and water users, private sector investors, etc.) was conducted by groups of land users in relation to tenure and access right on land resources, formal and informal land rules and governance and land policies. Issues like land ownership, tenancy or leasehold agreement and right of access to females to own lands were assessed to investigate the effect of land tenure on LD. Afterwards, an institutional map was drawn to show the roles and influence of the stakeholders in the community on LD or SLM.

Study Area Mapping: After the institutional mapping, a map of the study site was sketched by the team with the help of four (4 key) informants. The map was sketched based on the information from the reconnaissance walk and FGDs and also with the help of an existing topographic map and satellite images (google earth), to show the boundaries of the study site, types of settlements, land use systems, topography of the area, natural resources, area affected by degradation and the SLM practices undertaken. It also provided a secondary information of the location, types, degree and severity of degradation, and the history of the land use and land cover to help the team understand the current state of the area. It also helped the team to choose an appropriate direction to draw the transect diagram for a detail soil assessment. After the map of the entire catchment was drawn, the assessment team divided the catchment into three sub-catchments due to the size of the catchment and also to help assess the area accurately to obtain credible results. The sub-catchments were Bolahla, Ha Senyokotho and Mphosong sub-catchment.

Transect Diagram: A transect diagram was drawn across the study area based on the information from the sketched map, FGD and the reconnaissance walk. The transect diagram provided precise locations and directions for soil sampling and assessment of the study area, indicating the various land use types, degradation conditions and the SLM practices in the area. The team, together with the local informants and land users located the transect route using GPS and factors such as land use, soil, natural vegetation, types of degradation and the problems and opportunities perceived by the local informants was considered when drawing the transect diagram. The team recorded on the field form their observations, the length and width of the area, the start and end point of the transect, the GPS coordinates, altitudes (m) and the land use types across the transect. After the transect was drawn, the team embarked on a detailed soil assessment along the transect line.

Soil Assessment Using LADA Local Methodology: The LADA Local Methodology for soil assessment (FAO, 2016) was used to make a variety of soil assessments using specific tools of assessment (McGarry, 2006; Sheperd, 2000) either by visual methods or standard measurement of specific properties based on the land use types in the catchment. The experimental design was an RCBD design with 3 replications. The criteria for blocking was land use systems

Visual Assessment of Soil Quality

Soil Depth: Soil depth was measured using a soil auger (Photo 2) to drill the soil until it hits the bedrock and then, a tape measure was inserted into the auger hole to measure the soil depth and recorded on the assessment sheet.

Soil Texture: Soil texture was assessed using the finger texturing method, where the soil sample was put in the hand and water was added to the sample in a drop wise manner while the soil was been worked in the hand until a sticky consistency was attained. Then, the soil was rolled into a ball shape and into various shapes, and the texture was determined using the LADA Manual for soil quality assessment (FAO, 2016).

Soil Structure: Soil structure assessment was divided into 2 parts. First assessing the presence of pans in the soil (i.e. platy and massive pans, continuous pans, horizontal layers); and secondly describing of aggregate size distribution (size and shape of the soil units), using the drop shatter method.

Assessing Tillage and other soil pans: An intact soil of depth 30cm and 25cm of length was excavated using a spade and examined for the presence, thickness and degree of development of any pans in the soil (platy and massive, continuous, horizontal layers, “trampling” or “swards’ by animal on the soil surface) using the hand and then, the observations were scored on the field score sheet based on the presence, thickness and degree of development of pans using Shepherd (2000) method.

Aggregate size distribution (drop-shatter method): Aggregate size distribution was assessed using the Drop shatter method. An intact soil of depth 30cm and 25cm of length was excavated using a spade and dropped three (3) times from a uniform height onto a plastic sheet on the ground. The individual aggregates were sorted into groups of equal sizes and recorded as good, moderate or poor condition of soil aggregates using Shepherd (2000) method (FOA, 2016).

Soil Crusts: The soil surface was examined for the presence of soil crust (biological and physicochemical crusts) on the selected site and its coverage and thickness was measured using a ruler. The observations on the biological, chemical and physical crusts were measured and recorded based on their presence, coverage and thickness and then scored as good, moderate or poor condition (FOA, 2016).

Soil Colour: Soil colour was assessed using the Munsell Colour Chart. A lump of soil from the layer of interest was taken and moistened with water and then, cross matched with the appropriate chroma/hue chips on the Munsell colour chart to determine the soil colour.

Soil Life (Earthworms and Other Soil Biota) Soil life was assessed by taking an intact soil of 0.2 m cube using a spade and dismantled using the hand to observe the presence (number and size) of earthworm. The number of earthworm found was multiplied by 25 to convert to per **meter square** basis of spade depth and scored as plentiful, moderate, few or no earthworms (FAO, 2016).

Roots: An intact “block” of soil with a depth of 0.3 or 0.4 m and a width of 0.25 m was excavated from the site under investigation and the root system emanating from the intact soil was examined. The soil was dismantled afterwards to examine the roots inside. The observations made were based on the number and concentration of roots on the surface layer and the root growth conditions (stunted, L- shape, etc.) and then, scored on the field sheet as good, moderate or poor condition of root using Shepherd (2000) method (FAO, 2016).

Measurement of Soil Physical Properties: Soil Measurement assessment was made up of an assessment of four soil properties which were scored and evaluated on the basis of its soil quality status. The experimental design was an RCBD design with 3 replications. The criteria for blocking was land use systems

Slaking and Dispersion: This was done using the Immersion Method (Field *et al.,* 1997). Soil aggregate from the layer of interest was taken, air dried and totally submerged into a clear petri dish containing water (river). After the soil aggregate had totally immersed in the water, the aggregate was observed and visually judged on their degree of dispersion using a scale of 0 – 4 every 10 minutes for two hours and then scored (FAO, 2016) as follows: no dispersion (4), slight dispersion (3), moderate dispersion (2), strong dispersion (1) or complete dispersion (0).

Water Infiltration: This method was measured in two scenarios: firstly, the infiltrometer was inserted to a depth of 5 mm into the soil surface to facilitate three dimensional flow and secondly, the infiltrometer pushed to a considerable depth into the soil to enable a one dimensional flow of the water. The infiltrometer was inserted a few millimeters into the soil at a levelled and undisturbed area, to get a seal between the ring and the soil surface. Then, the soil surface in the ring was prewetted using 50 ml of water. After 20 minutes, an additional 50ml (0.4l) of water was poured into the ring and the time taken for the water to disappear was recorded.

Afterwards, the recorded time both one-D and 3-D flow were converted and score the time according to the permeability class (i.e. fast, medium and very slow rate) (FAO, 2016).

Bulk Density and Slope gradient: Soil bulk density and Slope gradient were measured using the penetrometer and abney level respectively. Soil compaction was measured by pushing the tip of the penetrometer into the soil so the groove marked on the tip was even with the level of the soil, then the level of compaction was measured on the penetrometer scale by the distance moved by the ring.

Soil Aggregate Stability: Soil aggregate stability was determined using the wet sieving method. Soil samples were sieved to 8-12mm size. 70g of the samples (Sample mass) were weighed and soaked in water for 5 minutes on 2 mm sieve and washed for 2 minutes to get aggregates > 2mm. Then 250µm to 2mm aggregates were also washed for 2 minutes using 250µm and 2mm sieve respectively. The sieved aggregates were then dried in the oven at 105°c for 24 hours and the dried aggregates were removed and weighed. The dried aggregates were weighed and aggregates stability was calculated as follows:

- % stability in 2mm fraction = (net weight of soil) / (Sample Mass - weight of stones)
- % stability in 250µm fraction = (net weight of soil) / (Sample Mass g - weight of stones)
- Where net weight of soil = total weight of soil – weight of stones.
- % Total Stability in > 250µm fraction = % stability in 2mm +% stability in 250µm fraction
- After calculating, the values of the % total stability in >250µm fraction are scored on the basis of texture as very low, low, medium or high.

Soil Quality Assessment: The soil quality assessment was calculated by adding up the VS-Fast score (Field score card) of each of the indicators of both soil measurement parameters and soil visual assessment parameters except soil depth, texture and colour, and integrating the total score into soil quality (soil health) status (i.e. < 7= Poor , 7-14 = Moderate and 15-22= Good).

Statistical analysis: The means of the soil visual assessment except for soil colour, depth and texture, and soil quality assessment results were analysed using Microsoft Excel 2013 and the field score card respectively.

RESULTS AND DISCUSSION

Soil Physical Properties and Aggregate Stability: To assess soil degradation, a range of soil physical properties (structure, texture, colour, compaction, soil depth, slaking and dispersion, permeability (infiltration), crust, tillage pan, soil type, slope, earthworms, roots and aggregates stability) were measured across all three sub-catchments stratified by the degree of degradation (degraded or undegraded) for the major land use types (Rangelands, croplands and forest lands). Major soil types common across all three sub-catchments were a combination of single soil series or associations' major soil series: Popa (Lithic Hapludolls), Matsana (Typic Hapludolls), Ralebese (Typic Hapludolls). However, Machache (Typic argioudolls) soil series was observed in the Bolahla sub-catchment only. Matšaba (Typic Argiudolls) and Ralebese soil series were dominant in the croplands while popa series occupied on the main the rangelands across the three sub-catchments.

Assessment of Soil Properties in Rangelands: Table 1 outlines the result of soil physical analysis on degraded (Table 1 (a)) and undegraded (Table 1 (b)) rangelands. The slope of the rangeland landscapes across the Mphosong Bolahla catchment ranged from 13 – 27 percent. The mean slope in the Bolahla sub-catchment was 17 percent across degraded and undegraded landscapes compared to 23 (Senyokotho) and 23.5 (Mphosong) percent respectively. Comparatively average soil depth across the Mphosong-Bolahla catchment ranged from 40 – 96 cm varying widely between degraded slopes (40 cm) and undegraded slopes (94 cm) in the Bolahla sub-catchments. Analysis of soil erosion estimates in the Mphosong-Bolahla catchment shows that 186087.32 tonnes/ha of soil is lost from the rangelands. However, rangelands in Senyokotho sub-catchment experienced the greatest soil loss (115395.73 tonnes/ha) followed by Bolahla sub-catchment (61490.3 tonnes/ha) and the least amount of soil loss experienced at Mphosong sub-catchment (9201.29 tonnes/ha). In comparison, the analysis shows less variation in soil depth in the other sub-catchment e.g. Senyokotho (40-55 cm) and Mphosong (76-96 cm) (Table 1 (a) (b)). Analysis of compaction shows that the measures of soil bulk density ranged from 1.32 to 2.64 kg cm^{-3} across the whole catchment. The degree of compaction was slightly higher (2.42 g cm^{-3}) in the degraded rangelands compared to 1.88 g cm^{-3} ungraded rangelands. The aggregate size distribution of the soil across the Mphosong-Bolahla catchment ranged from moderate to good regardless of sub-catchment and was characterized overall by high ranging from 50.33 to 56.96 percent with the mean skewed slightly in favour of degraded (mean = 54.59 %) compared to undegraded (50.53%) landscapes. Overall, the soils were slightly dispersed regardless of the state of rangelands. The texture of the soils across the Mphosong-Bolahla catchment were Loam, Gravelly Loam and Sandy Loam. The rangeland soils across the Mphosong-Bolahla catchment area did not have tillage pans but had generally slightly dispersed soil aggregate, no earthworm, fast permeability (K_{sat}), good root growth conditions and poor soil crust which means there were no biological crust but physical crust and a high aggregate stability of 56.96 percent. The soils have poor crust, no tillage pans and no earthworms, slightly dispersed soil aggregate and good root growth conditions (no root restrictions) The soil have poor good root growth conditions with no root restrictions, fast permeability (K_{sat}) and slightly dispersed soil aggregate upon submergence.

Assessment of Soil Properties in the Croplands: Table 2 outlines the result of soil physical analysis on degraded (Table 2 (a)) and undegraded (Table 2 (b)) croplands. The slope of the cropland landscapes across the Mphosong Bolahla catchment ranged from 5 – 14 percent. The analysis revealed a clear stratification of degraded landscapes by slope gradient where degradation of croplands was associated with higher slope gradients in the watershed (mean = 13 % ranging from 11 – 14 percent). The non-degrade cropland strata, on the other hand, was located on landscape positions with low slope gradient (mean = 5.67 with a narrow range from 5-6 percent). Similarly, soil depth measurements were directly related to the slope gradients where the soils on the degraded landscape positions were shallow (mean depth = 41.67 cm with a wider range from 25-75 cm) compared to the undegraded landscape positions where the soils were comparatively deeper (mean depth = 80.67 cm with a narrower range from 71-100 cm). Analysis of compaction shows that the measures of soil bulk density followed similar trends ranging from 1.68 to 2.61 g cm^{-3} across the whole catchment. The degree of compaction was significantly higher (mean = 2.59 g cm^{-3}) in the degraded croplands compared to undegraded croplands (mean = 1.75 g cm^{-3} with a range from 1.68 – 1.90 g cm^{-3}). The aggregate size distribution of the soil across the Mphosong-Bolahla catchment was rated moderate for all sub-catchments. However, aggregate stability was also stratified along state of land degradation with significantly higher aggregate stability measurement in degraded croplands (mean = 43.24% and range: 39.92-49.80%) compared to undegraded croplands (mean = 22.40% and range: 12.69 -32.63%). Overall, the soils were slightly dispersed regardless of the state of rangelands.

Table. 1 (a). Assessment of Physical Soil Properties in Degraded Rangeland of the Mphosong-Bolahla Watershed

Watershed	Depth (cm)	Slope (%)	Bulk Density (g cm^{-3})	Aggregate Size Distribution	Crust	Tillage Pan	Earthworm	Roots	Texture	Slacking /Dispersion	Permeability (k_{sat})	Aggregate Stability (%)
Bolahla	94	13	2.64	Moderate	Mod	Good	None	Good	Loam and SD. Loam	Slightly dispersed	Fast	51.13
Senyokotho	55	25	2.62	moderate	Mod	Good	None	Good	Loam	Slightly dispersed	Fast	50.14 High
Mphosong	96	20	2.00	Poor	Mod	Good	None	Good	Loam and G. Loam	Slightly dispersed	Fast	50.33 High

Table. 1(b). Assessment of Physical Soil Properties in Undegraded Rangeland of the Mphosong-Bolahla Watershed

Watershed	Depth (cm)	Slope (%)	Bulk Density (g cm^{-3})	Aggregate Size Distribution	Crust	Tillage Pan	Earthworm	Roots	Texture	Slacking /Dispersion	Permeability (k_{sat})	Aggregate Stability (%)
Bolahla	40	21	1.75	Good	Mod	Good	None	Good	Loam and SL. Loam	Slightly dispersed	Fast	56.96 High
Senyokotho	40	21	2.58	Good	Mod	Good	None	Good	Loam	None dispersed	Fast	55.19 High
Mphosong	76	27	1.32	moderate	Poor	Good	None	Good	Loam and SD. Loam	Slightly dispersed	Moderate	52.51 High

Mod – Moderate; SD- Sandy; G-Gravelly; SL-Silt

Table. 2 (a). Assessment of Physical Soil Properties in Degraded Cropland of the Mphosong-Bolahla Watershed

Watershed	Depth (cm)	Slope (%)	Bulk Density (kg cm^{-3})	Aggregate Size Distribution	Crust	Tillage Pan	Earth worm	Roots	Texture	Slacking /Dispersion	Permeability (k_{sat})	Aggregate Stability (%)
Bolahla	25	14	2.61	Moderate	Poor	Mod	None	Mod	Loam and CL. Loam	Slightly dispersed	Fast	40 Medium
Senyokotho	75	11	2.58	Moderate	Poor	Mod	None	Good	Loam	Slightly dispersed	Fast	49.80 High
Mphosong	25	14	2.58	Moderate	Poor	Mod	None	Mod	G. Loam	Slightly dispersed	Fast	39.92 Medium

Table. 2(b). Assessment of Physical Soil Properties in Undegraded Croplands of the Mphosong-Bolahla Watershed

Watershed	Depth (cm)	Slope (%)	Bulk Density (kg cm^{-3})	Aggregate Size Distribution	Crust	Tillage Pan	Earth worm	Roots	Texture	Slacking /Dispersion	Permeability (k_{sat})	Aggregate Stability (%)
Bolahla	71	6	1.68	Moderate	Poor	Good	None	Good	CL. Loam and G. loam	Slightly dispersed	Fast	21.89 Low
Senyokotho	100	5	1.90	Moderate	Poor	Good	None	Good	CL. Loam	Slightly dispersed	Fast	12.69 Very Low
Mphosong	71	6	1.68	Moderate	Poor	Good	None	Good	CL. Loam and G. Loam	Slightly dispersed	Fast	32.63 Low

Mod – Moderate; SD- Sandy; G-Gravelly; SL-Silt; CL-Clay

Table. 3. Assessment of Physical Soil Properties in Degraded Forests of the Mphosong-Bolahla Watershed

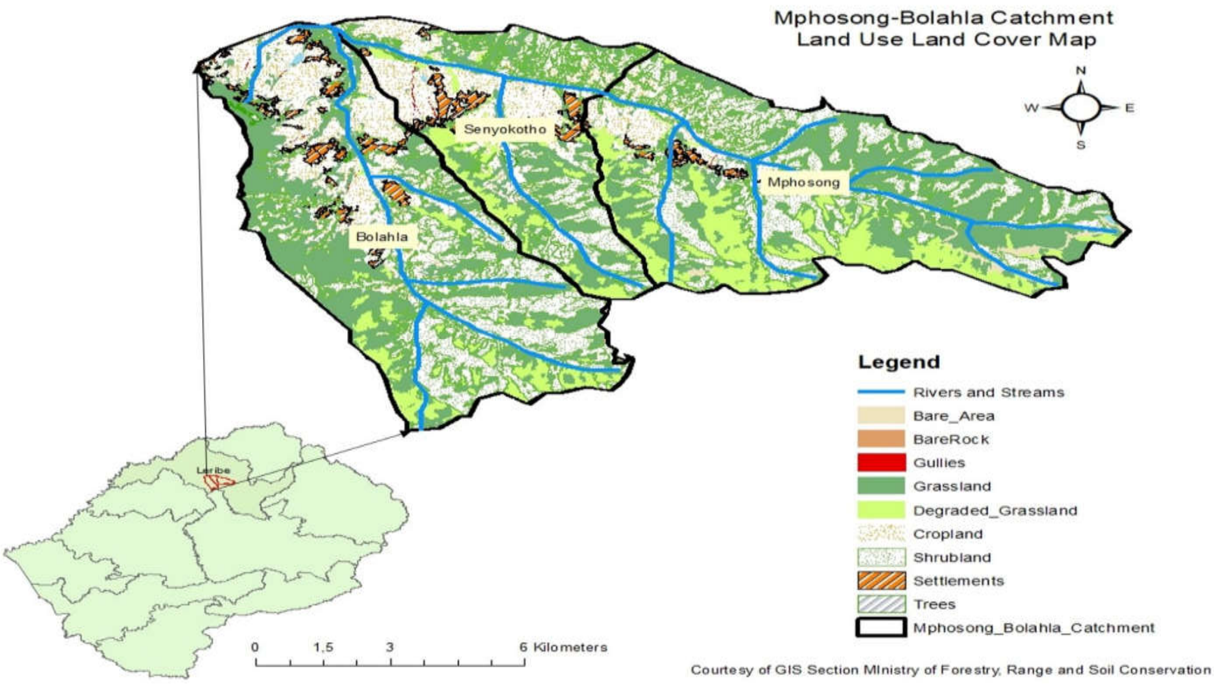
Watershed	Depth (cm)	Slope (%)	Bulk Density (kg cm^{-3})	Aggregate Size Distribution	Crust	Tillage Pan	Earthworm	Roots	Texture	Slacking /Dispersion	Permeability (k_{sat})	Aggregate Stability (%)
Bolahla	29	15	2.64	Moderate	Mod	Good	None	Good	Loam	No Dispersion	Moderate	53.69 High
Senyokotho	77	13	2.61	Moderate	Mod	Good	None	Good	Loam	No Dispersion	Moderate	40.49 High
Mod – Moderate;												

Table 4. Soil Quality Assessment in Different Land Use Types

Land Use Type											
Indicator Type		Degraded Rangeland		Undegraded Rangeland		Degraded Cropland		Undegraded Cropland		Degraded Forest land	
		Value	Score	Value	Score	Value	Score	Value	Score	Value	Score
Soil Indicator	Aggregate Size Distribution	Mod	1	Mod	1	Mod	1	Mod	1	Mod	1
	Crust	Mod	1	Poor	0	Poor	0	Poor	0	Mod	1
	Tillage Pan	Good	2	Good	2	Mod	1	Good	2	Good	2
	Root	Good	2	Good	2	Good	2	Good	2	Good	2
	Permeability (K_{sat})	Fast	2	Fast	2	Fast	2	Fast	2	Fast	2
	Earthworm	No	0	No	0	No	0	No	0	No	0
	Slaking and Dispersion	SD	3	SD	3	SD	3	SD	3	ND	4
	Organic Carbon (%)	Poor	0	Mod	1	Poor	0	Poor	0	Mod	1
	EC (mS)	Good	2	Good	2	Good	2	Good	2	Good	2
	TOTAL	Mod	13	Good	15	Mod	11	Mod	12	Mod	13
	Mod – Moderate, SD – slightly dispersed, ND – No dispersion										

Box 1. Sample Questions for Focus Group Discussion.

QUESTIONS	RESPONSE
What are the main changes experienced in the area over the last 10 years?	
What are the causes of these changes?	
What interventions are being done to remediate these changes?	
What are the advantages and disadvantages of these interventions?	



Box 1. Sample Questions for Focus Group Discussion

Photo 1. A picture showing the Focus Group Discussion at Bolahla village

Photo. 2. Drilling a hole through the soil to measure soil depth

Photo 3. Aggregate size being sorted into equal sizes

Photo 4. Picture showing physical crust been measured

The texture of the soils across the Mphosong-Bolahla catchment were Loam, Gravelly Loam and clayey Loam. The cropland soils across the Mphosong-Bolahla catchment area had moderate tillage pan slightly dispersed soils overall. The soils did not have any indications of earthworms but the permeability (K_{sat}) was rated as fast with moderately to good root growth conditions and poor soil crust which means there were no biological crust but physical crust. Thus although the lands are ploughed frequently, the presence of cover crops and residues resulted in the dilation of the soil pores and thereby increasing infiltration and reducing runoff.

Degraded Forest: Table 3 outlines the result of soil physical analysis on degraded forest ecosystems in the catchment

Photo 5. Picture showing slaking and dispersion

(Table 3) except for Mphosong which had no forest because the tree population was not a representative of a forest land use type. The slope on the forested landscapes across the Bolahla Senyokotho catchment ranged from 6 – 15 percent. Comparatively average soil depth across the Bolahla-Senyokotho catchment ranged from 29 – 71 with a mean depth of 59 cm. The texture of the soil across the Bolahla-Senyokotho catchment was Loam. Analysis of compaction shows that the measures of soil bulk density ranged from 2.61 to 2.64 g cm^{-3} with a mean of 2.63 g cm^{-3} across the whole catchment. The aggregate size distribution of the soil across the Bolahla-Senyokotho catchment ranged from 32.63 – 53.69 percent regardless of sub-catchment with a mean of 42.27 percent. The study revealed good tillage pan with slightly dispersed soil exhibiting poor to moderate crusting, fast to moderate permeability (K_{sat}), good root growth conditions and the crusting means there were no biological crust but physical crust.

The forest is a reserved field which is created within degraded rangelands to control the level of degradation. Trees like *eucalyptus rubida* are incorporated into the degraded rangelands. There is no dispersion of soil aggregate, moderate aggregate size distribution, moderate soil crust, no earthworm, moderate permeability (K_{sat}), good root growth conditions, no tillage pans and a high aggregate stability of 53.69%. Other findings such as microbial growth within the forest soils prevented the normal flow of the infiltrated water but only allowed a preferential flow. According to Nabiollahi *et al.* (2018), slope gradient greater than 10% causes greater soil loss rate through erosion and also, land use affects the rate of soil loss. Taye *et al.* (2013) reported that rangelands record higher seasonal runoff coefficient (RCs) and seasonal soil loss rate (SLs) than croplands. High bulk and slope create the greatest impact in the soil degradation process (Varela *et al.,* 2001). Soils with bulk density greater than 1.6 g/cm^3 tends to restrict root growth, influences runoff, affects the ability of the soil to shrink and to conduct water unsaturated condition (Dec *et al.,*2008; Cerda *et al.,* 2017) . High soil organic matter content reduces erosion, and bulk density, enhances water infiltration rate, porosity, water-stable aggregation, water retention capacity and responds better to natural recovery mechanisn (freeze-thaw and wet-dry cycle) (Blanco-Canqui and lal, 2010) . Arthur *et al.* (2012) observed that an increase in soil organic matter content can decrease soil resistance to compaction, due to the reduction in bulk density. Bulk density is affected by the amount of organic matter in soils, texture, porosity and constituent minerals. According to Chaudhari *et al.* 2013, sandy soil has a higher effect on bulk density than clayey soil. They also observed high degree positive correlation of bulk density with sandy soils (r = 0.9094) and significantly negative correlation of bulk density with clayey soils (r = - 0.6332) and Silty soils (r = - 0.7343).

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Soil Quality Assessment: The soil quality assessment of Bolahla-Mphosong catchment shows the quality status of the undegraded rangeland was good while the degraded rangeland was moderate. However, the soil quality status of both undegraded and degraded croplands were moderate (Table 4).

Conclusion and Recommendation

The field assessment showed that the soil health status for the physicochemical properties of both degraded and undegraded land use types was moderate for all the three sub-catchments and the entire catchment but high bulk density and high slope gradient were the principal causes of land degradation in the catchment. The types and level of degradations found among the various land use types are the main factors to consider in approaching good soil rehabilitation and conservation practices. High bulk density and slope gradient are the main causes of the degradation process at Bolahla-Mphosong Catchment. High bulk and slope create the greatest impact in the soil degradation process (Varela *et al.,* 2001). Gray (2016) reported that slope gradient and length are essential components in determining soil loss. Steep slopes affect soil erosion through its morphological characteristics (Tefera *et al.,* 2002; Shen *et al.,* 2016).

To help understand and combat land degradation at Bolahla-Mphosong watershed; first of all, the study should be repeated at different times to ascertain a firm conclusion on the status of the physical properties of the soils and help improve them. Also, measures such as plausible land use methods (conservation agriculture practice), organic mulching, use of cover crops, afforestation, stripe cropping or contour ridging, avoid overgrazing and the use of marginal for arable production. Several theories have been developed that should be considered when addressing combating and restoration activities of land degradation in Lesotho (UNCCD, 2004: FAO, 2016). These include a comprehensive National plan for combating drought and desertification, develop an early warning mechanisms to enhance preparedness, create anti-desertification mechanisms to be integrated within the plan and promote public cognisance of desertification control and drought effect management. Also, the role of science and policy and the understanding of the historic perspectives between the stake holders and the policy makers will help combat land degradation. For restoration to be successful, it should be within the constraints of the socio-political and biophysical worlds (Patten, 2006)

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