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RESEARCH ARTICLE

ASSESSMENT OF THE SOIL CHEMICAL PROPERTIES USING THE LADA METHODOLOGIES IN LESOTHO: THE CASE OF MPHOSONG-BOLAHLA WATERSHED IN THE FOOTHILLS OF THE LERIBE DISTRICT

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ABSTRACT

Land degradation in Lesotho is destroying the limited natural resources on which the Basothos' depend for survival. Soil chemical property assessment was conducted at the Bolahla-Mphosong Catchemnt using LADA Mehtodologies to estimate the extent of soil nutrients depletion and the level of degradation in the catchment. The study indicated that the level of degradation in the catchment was from slightly to very highly degraded soils and there was severe Phosphorus with Nitrogen depletion whiles organic carbon and organic matter content were poor in the soil due to low pH. Sustainable management practise such as Conservation Agriculture (CA), organic mulching, liming, contour ridging and stripe cropping, avoid overgrazing and avoid farming on marginal lands should be encouraged among the land user to help mitigate land degradation in the catchment. Also, the study should be repeated to ascertain concrete evidence on the soil properties to help undertake decision support projects.

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INTRODUCTION

Evidence of land degradation is visually noticeable across the landscape in all parts of Lesotho in both cultivated and rangelands since the 1800s when the development of gullies was reported by the early missionaries (Couzens, 2003). Soil erosion and land degradation on arable lands is driven by water and wind causing a unified impact deteriorating soil fertility, sediment deposition on and outside farm lands, erratic stream flow regimes and lowering of water tables. Currently, the state of agricultural land in Lesotho is described as critical due to the country's prominent soil erosion problems (Chakela, 2014) and land degradation is generally recognized and acknowledged as a major threat depriving the Basotho people of their agriculture based livelihoods. Lesotho, with a population of two million, has Seventy (70) percent of the population of lives below the poverty line (CIA World Factbook, 2018) with approximately 85 percent of the population deriving their livelihood from arable agriculture and livestock systems heavily reliant on the rangelands for fodder resulting in overgrazing and degradation of the rangelands (Chakela, 2014). However, land degradation on arable lands is aggravated by the susceptibility of the country to drought, unsustainable farming practices in both arable lands for crop production and rangelands for livestock production on steep slopes and desertification conditions which has resulted in a substantial loss of vegetation cover, nutrients mining and loss of agricultural lands (FAO, 2017). Land degradation in Lesotho is estimated at an annual loss of 0.25 percent of arable lands to soil erosion (FAO, 2017) and is widely known that productive arable lands have declined from 12.25 percent in the 1970's to currently 8.97 percent of the total land area due to soil erosion. The soils have low reserves of nutrients such as nitrogen, phosphorus and zinc, and an annually estimated nutrient depletion rate that range from 47 to 88 kilogram of NPK per hectare (Henao and Baanante, 2017). The rate at which agricultural lands are being lost is increasing and is currently 30-35 times the historical rate while soil erosion is reported to cause a worldwide loss of potential productivity which is estimated to be about 20 million tons of grains per annum (UNEP, 1999). In view of the land degradation processes in Lesotho due to human interference on the natural ecosystems, it then becomes pertinent to assess the soil chemical properties to estimate the degree of degradation and nutrients depletion.

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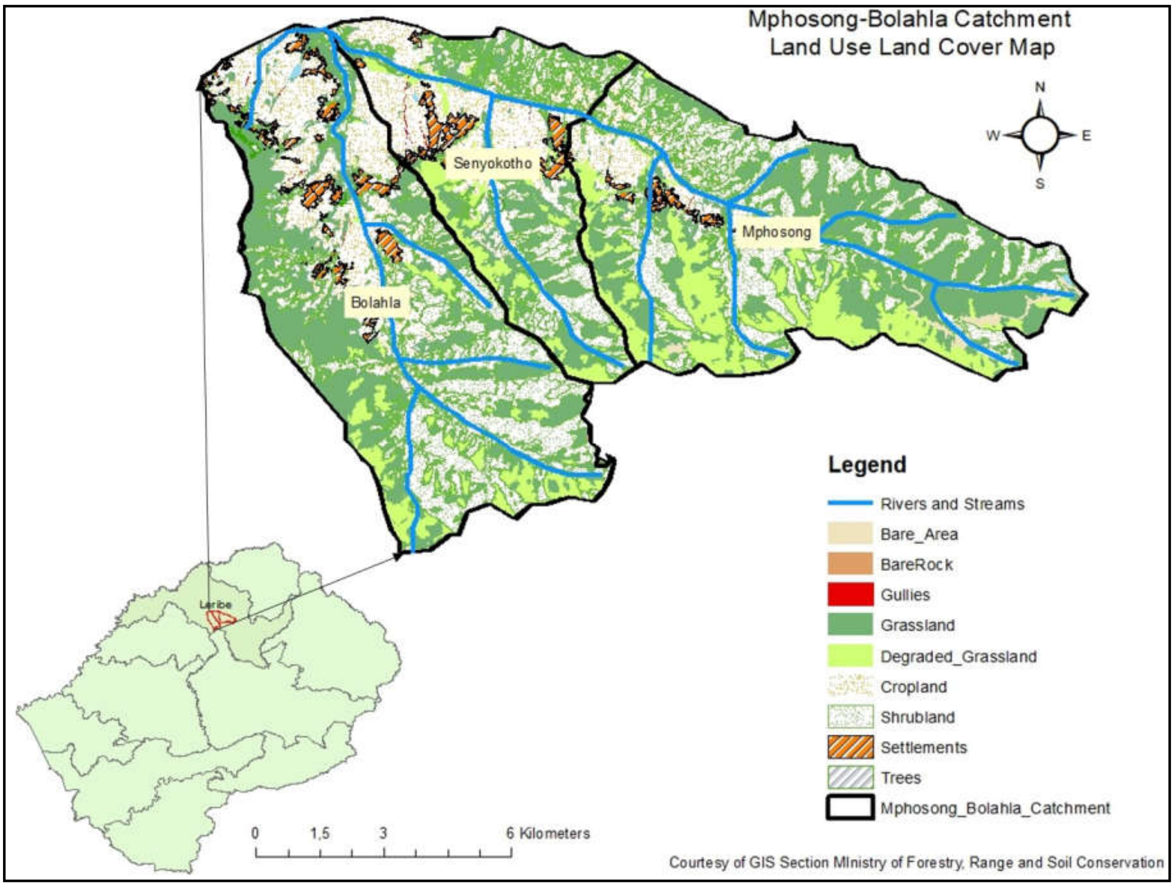
MATERIALS AND METHODS

Site Description and Characterization of the Study Area

Site Description: The study area is located in the Mphosong-Bolahla catchment in the foothills of the Leribe district (Fig. 1).



The location is in the foothills between 1800 m to 2300 m above sea level. The average annual rainfall in this area is 500mm to 800mm. The annual average temperature ranges from 32^{o}C to -2^{o}C. The topography of rugged terrain is characterized by mountain locks 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 of 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 by 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 land tenure is communal although croplands are semi-private while under cultivation. The majority of people own land although the spate of landlessness is increasing especially among the youth.

Characterization of the Study Area: The study site was characterized using Lada Local methodology (FAO, 2016), which was conducted using a participatory process with the Bolahla- Mphosong community and the resource people from the local technical sector. 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.

Sampling Strategy and Procedure: A purposive 1000 m long transect was drawn across the landscape going through key land use systems. Sampling stations were setup along the transect. At each sampling station, representative points were randomly picked and soil tests conducted. Three replicate observations were made at each sampling station. The experimental design was an RCBD design with 3 replications. The criteria for blocking was land use systems. In this study, the soil was sampled randomly at a depth of 0 – 20 cm, 20-40cm and 40-60 cm along the transect line.

Laboratory Analysis: The samples were taken using an auger from a depth of 0-20cm, 20- 40cm and 40-60cm, bagged in a sampling bag and sent to the laboratory for analysis. The samples were air dried at room temperature for 72 hours, crushed and sieved to pass a 2mm sieve for the normal routine and 0.5mm sieve for soil organic carbon determination in laboratory. Soil pH and salinity measurements were determined using pH meter and EC meter in soil suspension in water at 1:2 soil-water ratio respectively.

Organic matter and Total nitrogen determination were conducted using dry combustion method (CN 628 analyser) (Dumas Method). Two (2) grams of the sample was weighed into a metal foil while standard samples of phenylanine was made with known content of nitrogen to serve as quality control measurement and both samples and standard samples were put into the auto sampler of the analyser. The combustion, temperature, oxygen dosing and carrier gas pressure parameters for analyser were set to run the analysis and the total carbon (TC) and nitrogen (TN) were recalculated based on dry matter content DM (%) using the equation below:

$T (C,N)_{105}oc= (T(C,N)/DM) \times 100\%$

Available Phosphorus was determined using Bray and Kurtz No.1 extract in a spectrophotometric analysis (Bray and Kurtz, 1945).

Statistical analysis: The laboratory results were analysed using Microsoft Excel 2013 to calculate the means.

RESULTS AND DISCUSSION

Soil Chemical Properties: Based on VS- Fast and VSA methodologies described in the LADA-Local manual, three land use types (rangelands, forest and croplands) were assessed along the transect line (FAO, 2016). Soil chemical properties: pH (H_2O), organic carbon (%) and electrical conductivity (dS/cm) for the three sub-catchment (Bolahla, Senyokotho and Mphosong) are presented (Table 1). There was no forest at Mphosong because the tree population was not a representative of a forest land use type.

Soil Organic Carbon: Soil organic carbon (OC) was consistently higher in the undegraded landscapes regardless of land use system (Table 2). The organic matter content for the entire catchment ranges from poor (1.05%) to moderate (2.57%). The results indicates that low organic matter content is the main cause of the degradation process at Bolahla-Mphosong Catchment. Low soil organic carbon (SOC) content affect soil erosion through its morphological characteristics such structure and aggregation which in turn affects soil hydraulic properties (Tefera *et al.,* 2002; Murphy, 2015; Minasny and Mcbratney, 2015). Soil organic carbon is highly correlated with soil organic matter which influences positively or negatively affect the physical, chemical and biological properties of soils (Deng and Dixon, 2002; Murphy, 2015). Several Scientists have shown the importance of soil organic carbon in soil vulnerability to degradation (Auerswald *et al.,* 2003; Tejada and Gonzalez 2007, 2008; Lehmann and Kleber, 2015), emphasising how an increase in soil organic carbon content decreases soil loss. However, the effect of SOC on soil properties and soil loss depends on the amount of SOC present in the soil (Tejada and Gonzalez 2006, 2007). Also, low soil pH (5.4 or lower) results in the unavailability of essential nutrients (such as Phosphorus, Calcium, Magnesium and molybdenum), Aluminium toxicity, reduction in vegetation, loss of soil structure due to the loss of fine clay fractions and finally leads to soil degradation. (Slattery *et al.,* 2001; Roques *et al.,* 2013).

Soil pH: Soil pH measurements were acidic across all land use types but the degraded rangelands were moderate to strongly acidic while the undegraded rangelands were moderately acidic. However, the undegraded croplands were strongly acidic and the degraded croplands were moderate to strongly acidic (Table 1).

Soil Electrical Conductivity: Soil electrical conductivity measurements were consistently lower in the undegraded cropland landscapes compared to the degraded croplands (Table 1). However, in the rangeland soils higher Ec measurements were observed in the undegraded landscapes of the land use type with exception of the Mphosong sub-catchment. Studies conducted by Colorado Bureau of Reclamation showed that rangelands contributes 47% salt to the Colorado River (Reclamation, 2005). Excessive application of inorganic fertilizer increases the salinity of arable lands resulting in the reduction of soil fertility (Savci, 2012).

Soil Nutrient Measurement: Soil nutrients (P and N) were consistently higher in the undegraded landscapes regardless of land use system and sub-catchments (Table 2) which is consistent with predicted impacts of soil erosion and land degradation on soil properties. Soil resilience is the resistive or recovery capacity of the soil from natural or anthropogenic perturbation (Biswas, 2016; 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 causes a decline in soil structure which is followed by a reduction in soil organic carbon content and then, loss of soil fertility (Pilgrim *et al*., 2010). The soil chemical scores (Table 3). for the degree of degradation for the entire Mphosong-Bolahla catchment showed that the degraded forest and degraded rangelands with respect to N content, available P and EC were moderately degraded soils, very highly degraded soils and none to slightly degraded soils respectively.

The undegraded rangelands with respect to N content, available P and EC were none to slightly degraded soils, very highly degraded soils and none to slightly degraded soils respectively. The degraded croplands with respect to N content, Available P and EC were moderately degraded soils, very highly degraded soils and none to slightly degraded soils respectively. The undegraded croplands with respect to N content, available P and EC were none to slightly degraded soils, very highly degraded soils and none to slightly degraded soils respectively. Chemical analysis shows that the soils are very low in available P and N content with somewhat low pH levels which indicates that there is severe soil nutrients depletion as a result of their degree of soil degradation across the entire catchment.

Table 1. pH, OC and EC measurements across three sub-catchments

Sub-Catchment	Rangelands		Croplands		Forestland
	Degraded	Undegraded	Degraded	Undegraded	Degraded
Soil Organic Carbon (%)					
Bolahla	1.84	2.05	1.37	1.72	2.07
Senyokotho	1.58	1.95	0.50	1.55	2.11
Mphosong	1.39	3.7	0.24	1.45	-
Soil pH					
Bolahla	5.44	5.97	5.77	5.10	6.02
Senyokotho	5.93	5.96	5.02	5.36	5.22
Mphosong	5.30	5.6	5.81	5.12	-
Electrical Conductivity (dS cm^{-1})					
Bolahla	0.1	0.25	0.11	0.06	0.45
Senyokotho	0.1	0.14	0.12	0.04	0.10
Mphosong	0.13	0.08	0.17	0.07	-

Table 2. Soil P and N measurements across three sub-catchments

Sub-Catchment	Rangelands		Croplands		Forestland
	Degraded	Undegraded	Degraded	Undegraded	Degraded
Soil P Measurement (mg kg^{-1})					
Bolahla	0.21	0.66	0.29	0.86	0.65
Senyokotho	0.28	1.18	0.68	2.02	0.42
Mphosong	0.11	0.23	0.69	0.60	-
Soil N Measurement (%)					
Bolahla	0.09	0.15	0.14	0.18	0.07
Senyokotho	0.13	0.15	0.12	0.12	0.16
Mphosong	0.10	0.25	0.04	0.12	-

Table 3. Assessment of soil degradation using chemical indicator parameters

Soil Indicators	Degree of Degradation (%)			
	1	2	3	4
Content of N (Multiple decrease), %	0.13	0.10-0.13	0.08-0.80	<0.08
P Concentration (mg kg^{-1})	>8	7-8	6-7	<6
Salinization (mmol (cm^{-1} yr^{-1})	<2	2-3	3-5	>5

Source: Senjobi et al. (2012). Where 1= none to Slightly degraded soils; 2= Moderately degraded soils, 3= Highly degraded soils, 4= Very highly degraded soils.

Soil organic matter (SOM) influences P sorption in soils but the rate of sorption depends on specific soil properties such as pH, degree of P saturation (DPS) and P sorption capacity (PSC), and it is mostly related to land use (Debicka *et al*., 2015). In other studies (Slattery *et al*., 2001; Ying *et al.,* 2016), low soil pH (5.4 or lower) results in the unavailability of essential nutrients such as Phosphorus, Calcium, Magnesium, Nitrate and molybdenum. Also, the quantity and nature of soil organic matter have a very significant influence on the availability of P and N but SOM has greater influence on Nitrogen (N) availability than Phosphorus (Broadbent, 2017). Shen *et al.* (2003) reported that nitrate accumulation occurs more rapidly in soils having a pH $\geq$ 6.5 and pH is an excellent indicator of soil nitrification capabilities while the growth and activity of the soil organic matter decomposing organisms varies according to pH (Slattery *et al.*, 2001: Ying *et al.,* 2016). Chemical analysis in this case shows that pH levels are acid to slightly acidic. Furthermore, Senjobi (2012) reported that depletion of soil nutrients by land use leads to soil degradation.

Conclusion and Recommendations

The Chemical analysis indicated that 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. Soil nutrients vary and changes from one land use type to another. Soil nutrients depletion and the level of soil degradation in all the three sub-catchments were slightly, moderate, high and very high based on the nature of the land use types (degraded/undegraded). To help understand and combat soil degradation and minimise soil nutrients depletion in the study area, the study should be repeated in other seasons to ascertain a firm conclusion on the status of the chemical properties of the soils and help improve them. Seasonality affects soil organic matter (SOM) distribution and nutrient flow with decreased respiration during the growing season and increased respiration in the non-growing season as a result of climate change which influences all the degradation threats, and hence soil properties (Suseela and Dukes, 2013; Siles *et al.,* 2016). Also, measures such as plausible land use methods (conservation agriculture practice), liming to reduce the soil acidity, organic mulching, use of cover crops, afforestation, stripe cropping or contour ridging, avoiding overgrazing and the use of marginal lands for arable production. Several strategies have been proposed to combat soil erosion and land degradation with the view to restore soil productivity in Lesotho (UNCCD, 2004; FAO, 2016). These include a comprehensive development of a National plan for combating drought and desertification, developing 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 circumstances of the farmers (Patten, 2006)

With the submission of this manuscript, I would like to undertake that

- The Submitted manuscript should contain the original and authentic results, data and ideas, which are not published elsewhere.
- The Authors should not submit the same manuscript, in same language simultaneously to more than one journal.
- The author of this paper has read and approved the final version submitted.
- Any direct or indirect financial interest or conflicts that exist or may be perceived to exist have been disclosed in the cover letter.

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