Chapter 2

Isotopic Signatures ($\delta^{13}C$ and $\delta^{15}N$) and Characteristics of Two Wetland Soils in Lesotho, Southern Africa

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Additional information is available at the end of the chapter

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Abstract

There is sparse data on comparative analysis of soil indicators and isotopic signatures to monitor the health of wetland ecosystems in Lesotho. This study used (i) soil indicators (i.e. soil organic carbon (SOC), soil organic carbon density, and silt:clay ratio) and (ii) isotopic signatures ($\delta^{13}C$ and $\delta^{15}N$) to monitor environmental change aquatic ecosystems of Lesotho. Transects of 2000 m were chosen in two agro-ecological zones (AEZ) (Lowlands and Mountains) of Lesotho and sub-divided into upper (US), middle (MS) and toe slopes (TS). Soil samplings were made horizon-wise (1.20 m deep) in triplicates, labeled and shipped to the laboratory in plastic bags. Aquatic vegetation samples were randomly collected along these transects for stable isotopes. All samples analyzed using standard procedures. Results showed that wetlands located in the Lowlands (Ha-Matela) AEZ were much more degraded and heavily impacted. This indicated by low silt/clay ratios, low SOC contents and SOC density and less negative $\delta^{13}C$ compared to that of Mountains AEZ (Butha Buthe). Thus, these indicators can be used to predict degradation of wetlands. However, the severity of degradation, can be easily predicted the $\delta^{13}C$ values and $\delta^{13}N$ served as a robust indicator of wetland eutrophication. These results showed that soil indicators used as well as stable isotopes signatures used (i.e. $\delta^{13}C$ and $\delta^{13}N$) may be used as monitoring tools for wetland management and restoration.

Keywords: Lesotho, organic carbon, stable isotopes, South Africa, wetlands soils

1. Introduction

The kingdom of Lesotho is a small landlocked country in South Africa with a population of about 1.8 million [1] and occupies a total land area of 30,350 km^2 [2] and has four distinct agro-ecological zones (AEZ) based on the geology and climate (**Table 1**) [3] and has 10 districts (**Figure 1**).

Wetlands are among the Earth's most productive ecosystems. The significance of wetlands lie in their roles in the hydrological cycle, for flood and biomass production, as refuge for wildlife, biogeochemical functions, as nutrient and pollution filters for water quality improvement among others [4]. Globally, large percentage of these lands have been lost due to drainage and land clearance as consequence of agricultural, urban and industrial development activities [5–8]. According to Barbier et al., [9], the features of wetlands system can be grouped into *components, attributes* and *functions*. The *components* are the biotic and non-biotic features such as soil, water, plants and animals, while the *attributes* relate to the variability and diversity of these components e.g. diversity of species. However, the interactions between the components are expressions of the *functions* of the system such as nutrient cycling, water flow/exchange dynamics between the atmosphere (rainfall), the surface water and the shallow groundwater system. However, influence of agricultural land-use activity and hydrological modifications (affecting a biotic factor) are said to affects the attributes and functions of wetlands ecosystem [12–15].

Agriculture and wetlands has not had a very harmonious relationship in the past and agricultural activities have been affecting ground and surface water quality adversely from both point and non-point sources [10–12]. In Lesotho, wetlands are called *mekhuabo,* which apart from serving as refuge for wildlife, are primarily utilize to sustain agricultural activities at the local communities. These ecosystems support more than 300,000 households through agriculture and livestock watering. The wetlands ranged from several square meters to several square kilometers and occur in all the AEZs [13–15]. They can be categorized under three broad categories: palustrine, lacustrine and riverine [13, 16]. The palustrine wetlands are the dominant type and these include mires (bogs and fens), most of which are found at high altitude, at valley heads and at the upper reaches of rivers [8–12]. The lacustrine on the other hand occupies land area of ≥0.41 ha and comprises of artificial impoundments for water supply and soil conservation works (e.g. Katse and Mohale dams). The riverine wetlands are found along the river systems and these are generally small and often localized. In the recent years, there have been threats to wetlands across all the four AEZs [3, 22]. Threats to wetlands in Lesotho are attributable to over grazing, livestock watering; weed infestation, agricultural runoff and eutrophication, land reclamation for agricultural uses, and sedimentation of wetland beds [16, 23].

Agro-ecological zones	Area (km^2)	Altitude (m)	Topography	Mean annual rainfall (mm)	Mean annual temperature (°C)
Lowland	5200	<1800	Flat to gentle	600–900	−11 to 38
Senqu river valley	2753	1000–2000	Steep sloping	450–600	−5 to 36
Foot-hills	4588	1800–2000	Steep rolling	900–1000	−8 to 30
Mountains	18,047	2000–3484	Very steep bare rock and gentle rolling valleys	1000–1300	−8 to 30

§Source: State of the Environment in Lesotho [9, 10].

Table 1. Agro-ecological characteristics of Lesotho§.

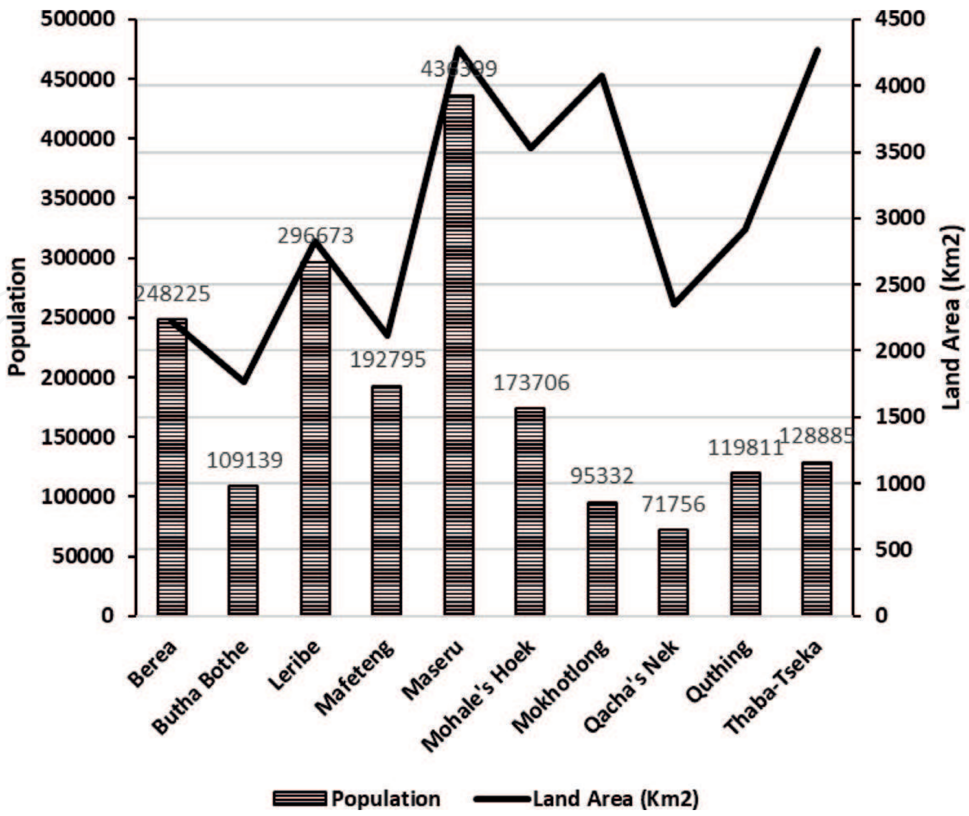

Figure 1. Population and land area in 10 districts of Lesotho.

Current indicators of wetland monitoring often examine nutrient loadings such as soil and water total phosphorus (TP) and total nitrogen (TN) concentrations, species composition, biomass and primary production. These indicators often show the changes that have taken place on the impacted systems [24–26], but these have the shortcoming of identifying early ecosystems disturbance. However, the need for early and timely identification of systems of ecosystems disturbance is critical these days [27, 28]. Stable isotopes of carbon and nitrogen in organic matter offers an alternative means to detect early signs of environmental changes in aquatic ecosystems [29–32]. The ratios of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ (defined as $\delta^{13}C$ and $\delta^{15}N$) has been used to provide insight into the sources, sinks and cycling of carbon and nitrogen in aquatic ecosystems as these biota interact with its physical and chemical environments [33–36]. This study aimed at comparing the characteristics of wetland soils in the Lowland and Mountains AEZ in terms of soil characteristics, and compare the isotopic signatures ($\delta^{13}C$ and $\delta^{15}N$) in these wetlands thereby understand the responses and mechanisms controlling the isotope variation in these wetlands. The ultimate goal is to identify causes of mismanagement and suggests plausible management options for a sustained and continuous use of these fragile lands for ecosystems services and agriculture.

2. Methods

The study was conducted on two wetlands located separately in two AEZs of Lesotho namely the Mountains (Butha-Buthe) and the Lowlands (Ha-Matela) (**Figure 2**). Butha-Buthe:

The wetland in Butha-Buthe is a palustrine wetland [13] and it is situated in the Mountain AEZ. It is located at an altitude/elevation of between 3181 and 3202 m above sea level (asl) and at points Latitude 28° 53.821/Longitude 28° 47.993 E. The site falls within the Afroalpine Grassland zone characterized by grasses-*Festuca caprina, Merxmuellera disticha* and *Pentaschistis oreodoxa;* shrubs and woody plants—*Chrysocoma ciliate, Erica dominans* and *Euryops evansii;* and other flowering plants—*Kniphofia caulescens, Helichrysum trilineatum, Dierama robustum, Zaluzianskaya ovate* and *Dianthus basuticus var. grandiflorus* [13]. Ha Matela: Ha Matela wetland is a Riverine wetland situated in the Foothills AEZ at an elevation of 1820 m above sea level, at points; Latitude: −29°38.3333/Longitude: 27°76.6667. It is characterized as the Afromontane Grassland zone. Dominant grasses includes: *Themeda triandra, Festuca caprina, Merxmuellera macowanii* and *Eragrostis curvula;* trees and shrubs: *Salix mucronata, Rhus erosa, Rhus pyroides, Leucosidea sericea, Myrsine Africana, Rhoicissus tridentate, Buddleja loricata* and *Chrysocoma ciliate* and flowering plants: *Gladiolus (several species), Kniphofia (several species), Helichrysum (many species), Agapanthus campanulatus subsp. Patens, Dierama robustum, Euphorbia clavarioides* and *Aloe polyphyll*. The geology of Lesotho is called formation [37] with sedimentary and volcanic clastics. Wetlands in these two agro-ecological zones: the Mountains and Lowlands (**Table 1**) were characterized as low, medium or high impacted wetlands based on local (i) land-use characteristics and (ii) intensity of anthropogenic pressures such as mining, smelting and discharge of industrial pollutant into the wetlands [38]. According to [38], the low impacted wetlands has little (i.e. <5%) or no agricultural activity within 150 m of the wetland boundary. Secondly, wetlands that were classified as highly impacted had agricultural activities; within 10 m of wetland boundary (i.e. < 33% of the wetland area is impacted). The medium impacted wetlands had agricultural activities between 5 and 32% of the wetland boundary. Wetlands in the Lowlands AEZ (i.e. Ha-Matela) were classified as being highly impacted, while that in the Mountains (i.e. Butha Buthe) had little impacts after [38]. About 2000 m transects were chosen and divided into upper (US), middle (MS) and toe slope (TS). Profile pits (1.20 m) were dug

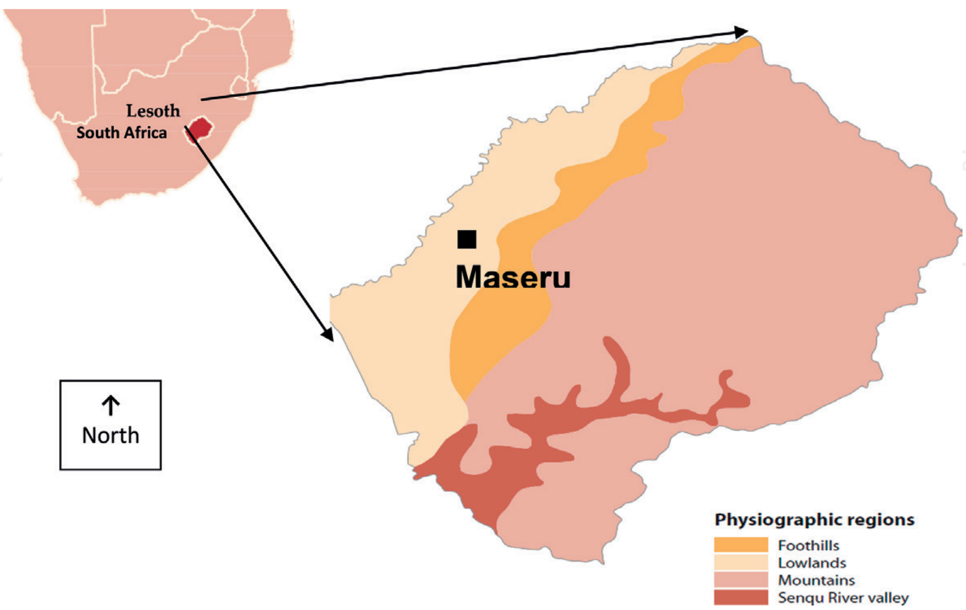

Figure 2. The location of Lesotho within South Africa and its four agro-ecological zones.

to reveal the natural soil horizons. Samplings were made in triplicates using the natural soil horizons. Soil samples were placed inside labeled plastic bags and shipped to the laboratory. Soils collected were analyzed after the standard methods:pH water (1:2 soil-water ratio) and pH-KCl (1:1 soil-water ratio), particle size analysis [39], total N [40] and available P (Bray-1-P) [41], the organic carbon (OC) [42], and the SOC pool [43] and the equation:

$$\text{C-pool} = d \times BD \times organic\ \ carbon \quad (1)$$

where C-pool (kgC m^{-2}), d: soil layer thickness (m), BD: bulk density (kg m^{-3}), organic carbon (g g^{-1}). The base cations (Ca, Mg, Na and K) were by extracting soils with 1 N NH_4OAc (pH 7) and these were determined atomic absorption spectrophotometer (Perkin Elmer, 2007 AAS model WinLab) and flame photometers. Plant samples for isotopic signatures (i.e. $\delta^{13}C$ and $\delta^{15}N$) in these wetlands were randomly collected in duplicates from the US, MS and TS sections of the toposequence/topography across years (2008–2010). These were labeled, air-dried, and shipped to the Soil and Water Management and Crop Nutrition Laboratory, of the International Atomic Energy Agency (IAEA), Seibersdorf, Austria. The results are reported in standard δ notation as $\delta^{13}C$, $\delta^{15}N$, %C and %N values in reference to the international standards Vienna Pee Dee Belemnite (V-PDB) and air N_2 respectively. Analytical precision was ±2‰ for both $\delta^{13}C$ and $\delta^{15}N$ based on repeated analyses of laboratory standards. All data collected were subjected to analysis of variance (ANOVA) using the general linear model procedure (PROC GLM) of Statistical Analysis Systems (SAS) [44]. Means were separated using Duncan multiple range test (DMRT) at 5%.

3. Results and discussion

Generally, most of the wetlands across all agro-ecological zones of Lesotho are either used for livestock watering, grazing and agriculture and drinking water. In a related study on comparative assessments of wetlands in West and Southern Africa, it was found that most of the rural population used the wetlands largely for grazing and watering (**Figure 3**). It is evident from this result that approximately, 21% respectively of the population considered wetlands being important for irrigation and livestock grazing and watering. Similar observations were made by researchers from Southern Africa [45, 46], Taznania [47] and Kenya [45]. These authors found that wetlands constituted an important area of the livelihoods of the rural people. Hence, one of the major constraints to the sustainable use of wetlands in Lesotho and Africa in general is the lack of information on the diverse benefits that can be obtained from wetlands if properly managed. Hence, this information is needed by the government planners, natural resource managers and local communities.

A close observation of the soil physico-chemical properties of these wetlands is shown in **Table 2**. Results showed that the particle size distribution (i.e. texture) of the wetland soils at Butha Buthe was dominated by sand size texture compared to that at Ha-Matela. At the latter site, the particle size distribution had almost equal proportions of sand, silt and clay sized particles (**Table 2**). Both wetland soils generally had acidic soil pH (i.e. 4.69–5.44),

Transects	Position	Sand (%)	Clay (%)	Silt (%)	pHw	pHKCl	AVP (mg kg^{-1})	SOM (%)	Ca (cmol kg^{-1})	K (cmol kg^{-1})	Na (cmol kg^{-1})	CEC (cmol kg^{-1})
	Butha Buthe (Mountains AEZ)											
1	US	67.16	12.04	20.81	5.44	4.69	1.40	4.49	17.51	0.05	3.17	5.23
1	MS	63.99	10.17	25.81	5.26	4.60	2.71	5.25	15.00	1.49	5.38	2.07
1	TS	62.95	7.32	29.53	5.33	4.66	2.23	4.58	15.31	0.05	2.89	0.05
2	US	66.65	5.42	27.93	5.00	4.47	3.29	8.38	10.44	0.04	4.57	4.82
2	MS	78.21	5.08	16.71	4.69	4.31	2.42	8.00	11.28	0.04	2.35	5.97
2	TS	70.84	7.40	21.72	4.95	4.49	3.04	7.74	17.06	0.05	4.69	4.92
	Ha-Matela (Lowlands AEZ)											
1	US	24.66	33.33	42.83	5.42	4.46	4.11	4.54	0.63	0.49	0.09	0.18
1	MS	40.78	23.28	36.00	5.02	4.39	3.21	3.74	0.28	0.34	0.09	0.17
1	TS	34.12	36.81	30.58	5.12	4.37	2.83	3.35	0.38	0.47	0.10	0.17
2	US	38.37	36.97	25.33	5.69	4.72	3.30	2.94	1.28	0.37	1.15	0.17
2	MS	39.23	33.91	27.08	5.06	4.56	2.56	4.32	1.03	0.41	0.53	0.17
2	TS	44.97	29.30	26.56	5.25	4.64	3.13	3.90	1.06	0.38	0.25	0.17

US, upper slope; MS, mid-slope; TS, toe slope; AVP, available P; SOM, soil organic matter; CEC, cation exchange capacity; pHw, pH in water.

Table 2. Physical and chemical properties of wetlands in Butha Buthe and Ha-Matela, Lesotho.

low available P ranging between 1.40 and 3.29 mg kg^{-1} (Butha Buthe) and between 2.94 and 4.54 mg kg^{-1} (Ha-Matela). Some researchers had associated phosphorus mineralization in wetland soils was associated negatively with acidic soil pH and coarser soil texture [49–51]. The soil organic matter across both wetland types was relatively high. Higher exchangeable Ca (10.44–17.51 cmol kg^{-1}) was noted in Butha Buthe wetlands as opposed to very low contents observed in the Ha-Matela soils (i.e. 0.28 cmol kg^{-1}). Wetland soils in Butha Buthe had higher bulk density (BD) (i.e. 1.24–1.55 g cm^3) compared to Ha-Matela wetlands (i.e. 1.32–1.38 g cm^3). The higher BD in the former compared to the latter might be attributed to higher sand contents (**Figure 4**). The ratio of silt and clay—called silt:clay ratio—is an index of soil age and the ease of erodibility [52]. Lower ratio of between 0.43 and 1.99 (Ha-Matela) compared to 1.10 and 9.89 (Butha Buthe) is an indication that wetland soils in the former site are older and would be easily eroded compared to the latter (**Figure 5**). This was in agreement with the findings of some researchers that lower silt/clay ratio is an indication of high degree of erosion [52, 53]. Higher SOC contents were observed in the Butha Buthe wetlands

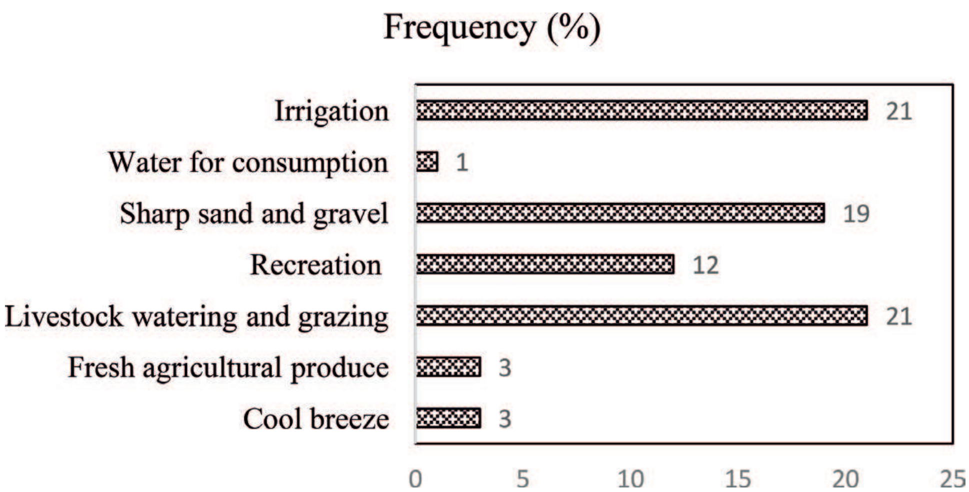

Figure 3. Utilization of wetlands in the Lowlands AEZ of Lesotho.

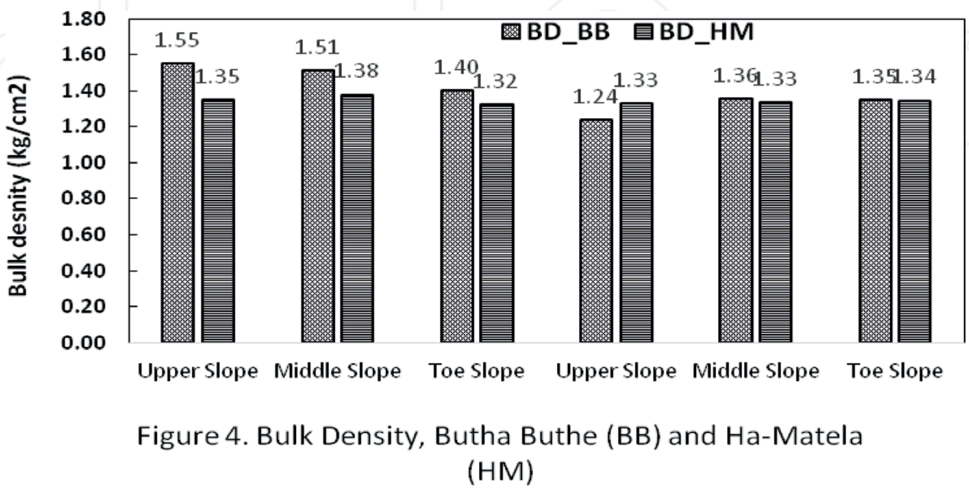

Figure 4. Bulk density, Butha Buthe (BB) and Ha-Matela (HM).

compared to the Ha-Matela wetlands (**Figure 6**). The high SOC is related to the balance of input from net primary production and microbial decomposition and the decomposition rates in wetlands are generally low due to low availability of oxygen and low temperatures [54].

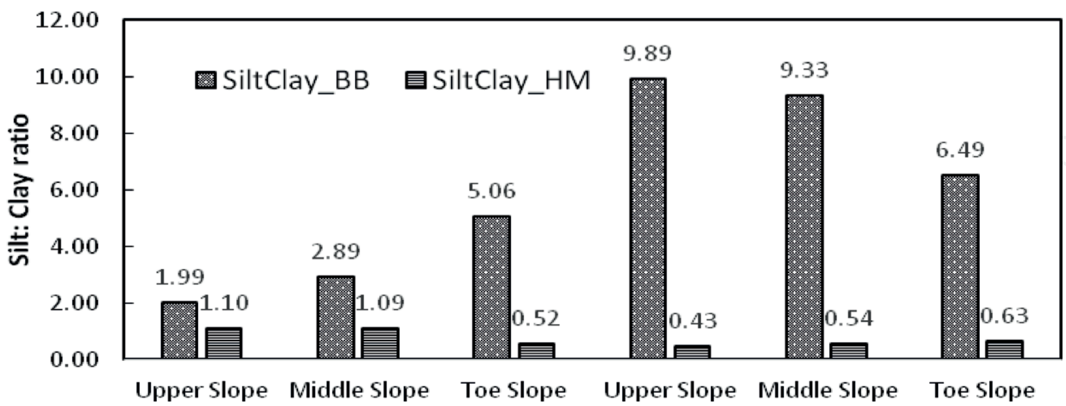

Figure 5. Silt clay ratio, Butha Buthe (BB) and Ha-Matela (HM).

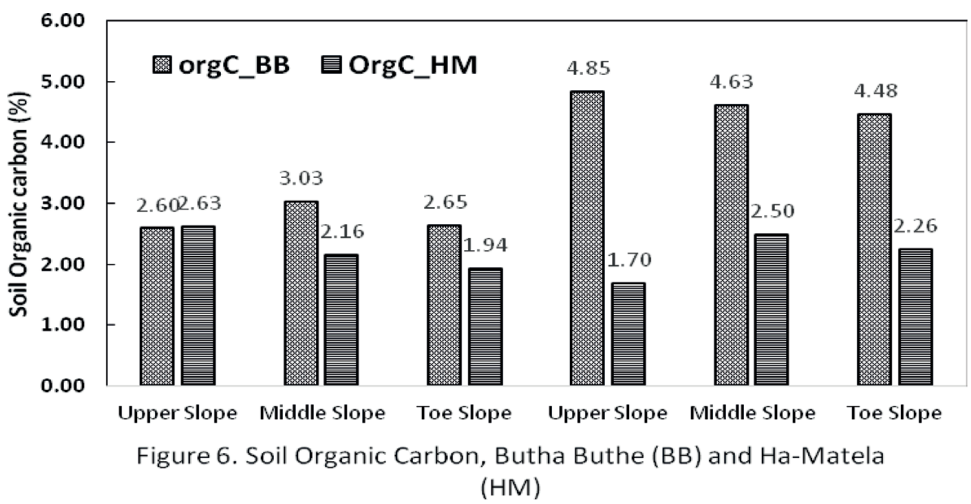

Figure 6. Soil organic carbon, Butha Buthe (BB) and Ha-Matela (HM).

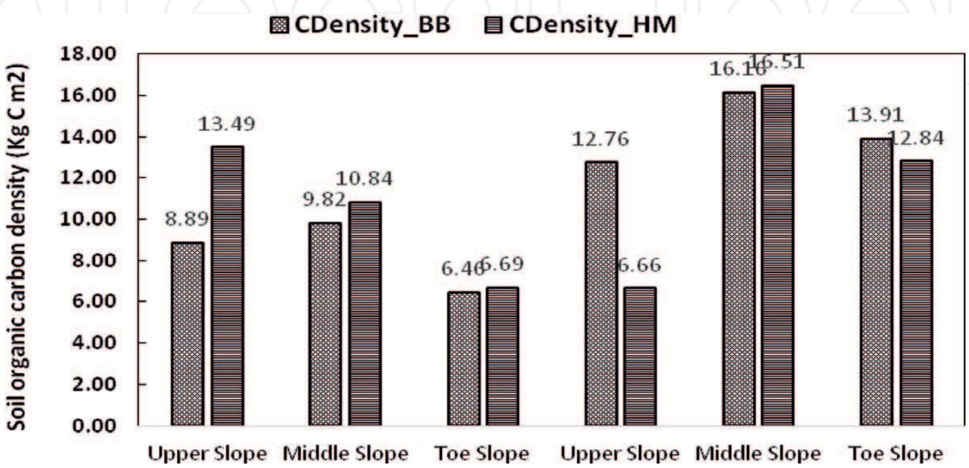

Figure 7. Soil organic carbon density, Butha Buthe (BB) and Ha-Matela (HM).

Thus, one of the reasons for higher SOC in Butha Buthe wetlands is due to high altitude (i.e. 2000–3483 m) and low temperature (i.e. ≤8°C) in winter periods. Furthermore, the SOC density was observed in the Butha-Buthe wetlands (6.69–16.51 kgC m^{-2}) compared to that in the Ha-Matela (6.46–13.91 kgC m^{-2}) (**Figure 7**). These results showed that wetland soils in the former site are much more stable and would not be easily eroded. Serval authors had attributed higher soil organic carbon density to several factors and these includes type of land use and soil management practices and these can significantly influence soil organic SOC dynamics and C flux from the soil [22, 55–59]. The vegetation isotopic $\delta^{13}C$ and $\delta^{15}N$ across the

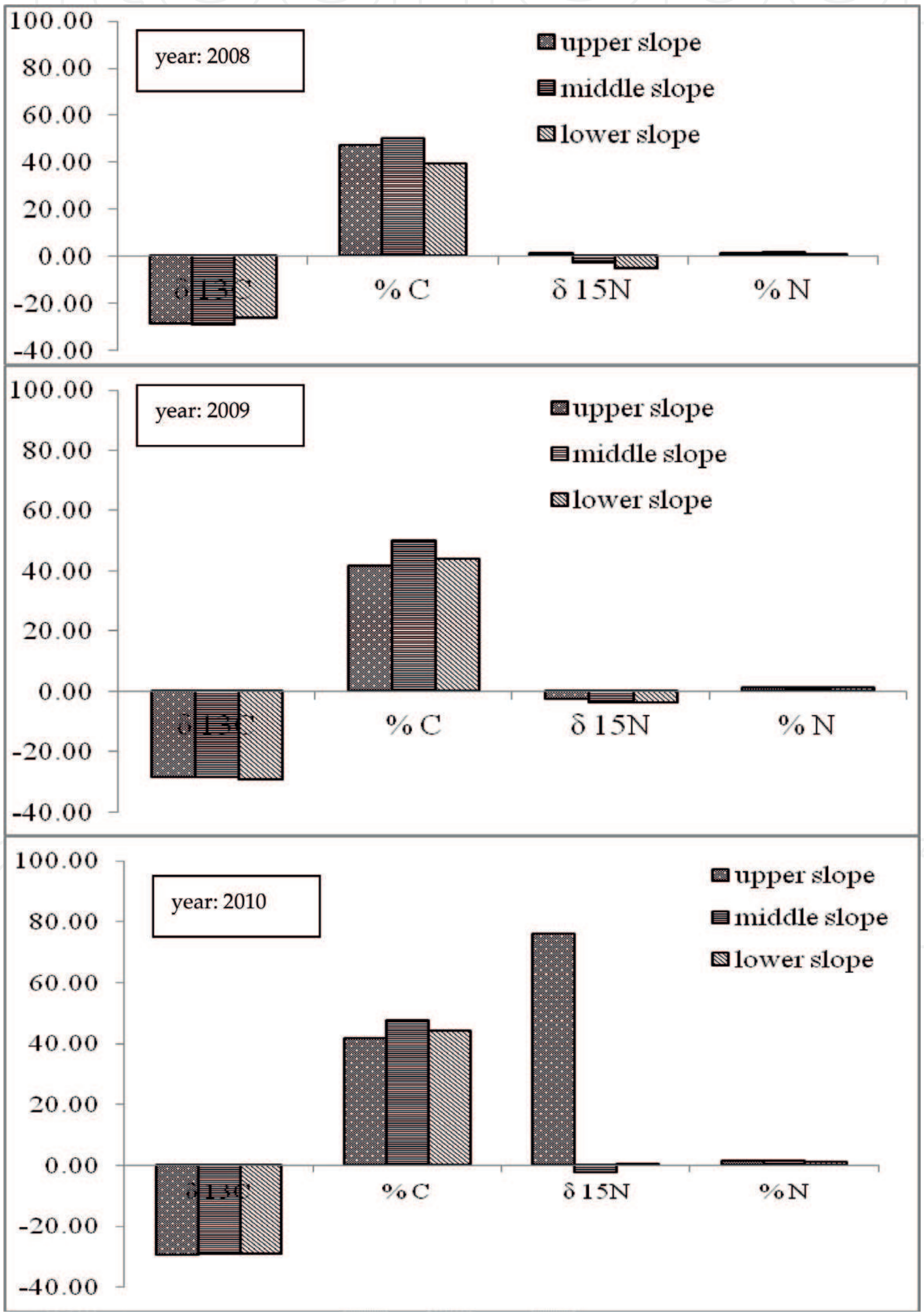

Figure 8. Isotopic $\delta^{13}C$, %C, $\delta^{15}N$ and % N of vegetation, Butha Buthe.

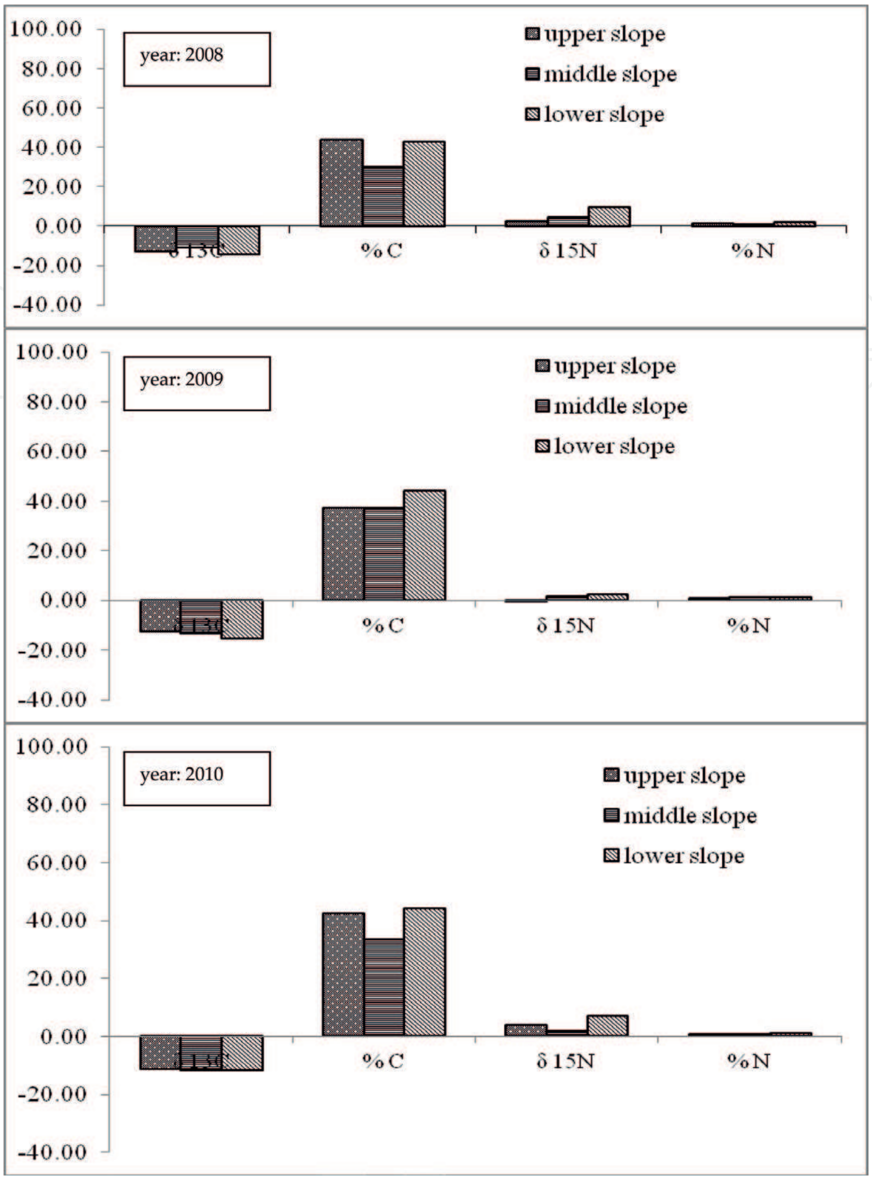

Figure 9. Isotopic δ^{13}C, %C, δ^{15}N and % N of vegetation, Ha-Matela.

two wetlands and years (2008–2010) are shown in **Figures 8** and **9**. The less negative values of Isotopic δ^{13}C (Ha-Matela), compared to Butha Buthe is an indication of degradation [29, 36, 60]. High δ^{15}N in Butha Buthe is ascribed to nutrient enrichment as a result of anthropogenic activity (i.e. livestock grazing [61].

4. Conclusions

Human influences have led to disturbances in the wetland ecosystems in Lesotho. The study showed that despite the fact that soil characteristics can be used to assess changes in the ecosystems, environmental isotopes of C and N in aquatic plants responded positively to nutrient increase due to δ^{13}C values in plants. Results showed wetlands located in the Lowlands (Ha-Matela) AEZ are much more degraded and heavily impacted as indicated by low base cations (K, Ca, Mg and Na), lower silt/clay ratios as well as lower SOC contents and SOC density, higher bulk density and less negative $\delta^{13}C$ compared to that of Mountains AEZ (Butha Buthe). However, the severity of degradation, can be shown by the $\delta^{13}C$ values as these values are sensitive indicators of nutrient stress and $\delta^{13}N$ served as a robust indicator of wetland eutrophication. These results showed that soil indicators used as well as stable isotopes signatures used (i.e. $\delta^{13}C$ and $\delta^{13}N$) may be used as monitoring tools for wetland management and restoration.

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Conflict of interest

No conflict of interests.

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