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Wetlands in *Khalong-la-Lithunya* catchment in Lesotho: Soil organic carbon contents, vegetation isotopic signatures and hydrochemistry

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ABSTRACT

There is sparse information on the characteristics of the wetlands in the *Khalong-la-Lithunya* catchment (KLC), Lesotho in terms of physico-chemical properties, soil organic pools and vegetation isotopic signatures and hydrochemistry of surface waters after five years of rehabilitation. At the KLC two transects of length 250 m–700 m were chosen and soil observations made at intervals of 50 m and at these points, piezometers were installed in duplicates and water samples were collected from Jan to Dec for four years (2009–2012). Soil samples were collected in duplicate from excavated mini-pits (0.50 m). Vegetation samples were collected monthly (Jan, Apr and Aug) of 2010 from these transects (upper slope, middle and toe-slopes) on which δ^{15}N isotope was applied. Samples (soil, water and plant) collected were properly labelled and transported to the laboratory. Samples were analysed after standard method. Results showed that soil organic carbon varied significantly across mini-pits, and transects. These ranged from 15.50 g kg^{-1} with a mean of 28.61 g kg^{-1} (Transect-1) to between 34.60 and 53.50 g kg^{-1} with a mean of 43.24 g kg^{-1} (Transect-2). Majority (or 78%) of the pedons in Transect-1 are strongly weathered, while in Transect-2, majority of the pedons (i.e. 73%) were classified as non- or weakly weathered using soil organic matter: silt + clay ratio. Results of the cluster analysis showed that clusters 1, 2, 3 and 4 were related to the water holding capacity, the soil weatherability, the soil ability to store carbon (carbon mitigation) and the soil's acidity. Results of the δ^{13}C data for both transects varied slightly with slope positions though not significantly different ($p < 0.05$) but higher negative values of the vegetation −28.13 to −28.90‰ were observed. The results of the δ^{15}N ranged from −2.52‰ to −2.93‰ with a mean of −2.81‰. Results of the hydrochemistry from the installed piezometers showed that across years and months the following variables (pH, EC, Ca, Mg, Na, K & NO_3-N) were within the normal range stipulated by the WHO (2004), while the phosphate concentrations were beyond the limits of the USEPA/NOAA (1988). It was concluded that more research is needed to identify sources and forms of phosphates in this wetland.

1. Introduction

The kingdom of Lesotho has a total land area of 30,588 km^2 and is divided into four agro-ecological zones (AEZs): the Lowland, Senqu River valley, Foot-Hills and Mountains. The relative area covered by each AEZ is presented in Table 1. Most soils have low organic carbon contents coupled with low available P and acidic pH (≤ 3.5). The highest population pressure is in the Lowland AEZ, where the arable land is concentrated. In addition to the high population pressure, there is the problem of serious soil erosion and land degradation as a result of steep slopes, low soil organic carbon and sparse vegetation.

Lesotho has witnessed considerable internal migration in recent years and this pattern of migration has in large part, been from the rural to urban areas and from the Mountains AEZ to the Lowland AEZ. This internal migration is influenced by factors such as unemployment and increasing population pressure on agricultural lands in the rural areas. Despite having only one-quarter of the total land area, the Lowlands, Foot-Hills and Senqu River Valley AEZ holds more than three-quarters of the total population. Lesotho is replete with wetlands of varying sizes and at different levels of degradation.

Wetlands are important reservoirs of carbon, representing about 15% of the terrestrial biosphere carbon pools (Bolin et al., 2000; Gitay et al., 2001). Bolin et al. (2000) observed that when boreal forests and some tropical forested wetlands are included as wetlands, the amount of carbon reservoirs will be approximately about 37% of the total terrestrial carbon pool. The capability of a wetland to store carbon is related to the hydrology, geomorphology, and local climate condition (Patterson, 1999; Sahagian and Melack, 1998). It is estimated that wetland ecosystems have a total C stock of approximately 20–25% of the total stock in terrestrial soils (Zhang et al., 2008) and considered to play an important role in global C cycling. It is reported that the global C cycling directly affects the concentration of atmospheric CO_2, with potential implications for global climate change (IPCC, 2000; Lal, 2004). Native and restored

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Table 1
Agro-ecological characteristics of Lesotho.
Source: Olaleye (2012).

Agro-ecological zones	Altitude (m) above sea level	Topography	Mean annual rainfall (mm)	Mean annual Temperature (°C)
Lowland	<1800	Flat to gentle	600–900	−11 to 38
Senqu river valley	1000–2000	Steep sloping	450–600	−5 to 36
Foot-hills	1800–2000	Steep rolling	900–1000	−8 to 30
Mountains	2000–3484	Very steep bare rock and gentle rolling valleys	1000–1300	−8 to 30

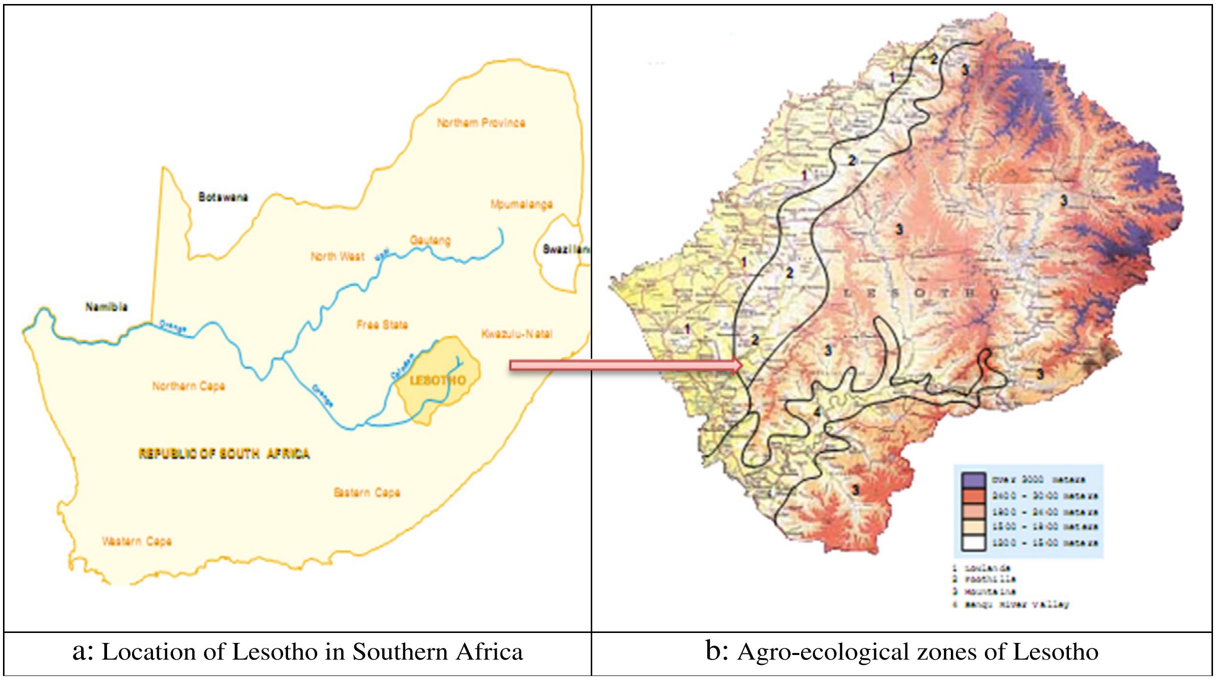
wetlands are generally a sink for atmospheric CO_2, and therefore make an important contribution to global C sequestration (Furukawa et al., 2005; Inubushi et al., 2003; Roulet, 2000). Some authors estimated that the global C stock down to one metre depth in wetlands is approximately 225 Pg (1 Pg $= 10^{15}$ g) (IPCC, 2000). Armentano and Menges (1986) reported that this value compares favourably with the estimated range (180–249 Pg).

Stable isotopes are increasingly being used to detect and understand causes of environmental change. They have been used both to monitor ecosystem change and to make specific connections between ecology, land use, and geochemistry (Fry, 2006). In aquatic ecosystems, carbon (C) and nitrogen (N) isotopic signatures of organic matter (OM) have been used to detect changes in plant and microbial processes related to anthropogenic disturbance gradients. Studies employing natural abundance carbon (C) and nitrogen (N) isotopes have provided important insights into plant ecophysiology, organic matter cycling, and biogeochemical processes (Ewe et al., 2007; Troxler, 2007; Troxler and Richards, 2009) in wetland ecosystems. All these information may provide insight into their degradation and maintenance. Physiologically mediated variations in C isotopic composition in wetland plants can result from a number of sources, including the photosynthetic pathway, the nature of the primary inorganic C source (atmospheric vs. dissolved), the available carbon form and subsequent mode of assimilation (CO_2, HCO_3), and the limits on diffusion imposed by plant life form or conditions of the aquatic environment (Troxler and Richards, 2009). Similarly, variations in N isotopic composition can reflect differences in N source and processing (Dai et al., 2005; Mitsch and Gosselink, 2007). There is sparse data on the morphology and physio-chemical characteristics of wetlands in *Khalong-la-Lithunya* catchment, soil organic carbon pools and the vegetation isotopic signatures and surface water chemistry in the wetlands of Lesotho. Hence, investigations were conducted between 2009 and 2012 on the soil characteristics, hydrochemistry of the surface waters and vegetation isotopic signatures in order to assess the extent to which conservation and rehabilitation practices have allowed the wetlands to return to its former status.

2. Materials and methods

2.1. Site description

The study was conducted in a Lacustrine wetlands located in the *Khalong-la-Lithunya* catchment (KLC) in the Mountains AEZ of Lesotho in Butha-Buthe district. The KLC is located at points latitude 28° 53 S, 28° 47 E at an altitude between 3100 and 3200 m above sea level (asl) (Fig. 1a and b). The catchment of this wetland forms a part of sub-catchments of a main quaternary catchment draining into Motete River. The reference site has a total area of 3280 ha while the restoration catchment size is approximately 1332 ha (or 40.61%) (Department of Environment, 2009). Restoration efforts started in 2007, though there is no documented evidence that the wetlands have actually been restored. According to Chipps et al. (2006), the intensity of anthropogenic pressures such as mining, smelting, and industrial pollutions could be low, when wetlands has little (<5%) or no agricultural activity within 150 m of the wetland boundary, while high impacted wetlands had agricultural activities, within 10 m of at least one-third (≅33%) of the wetland boundary. The medium impacted wetlands will have agricultural



a: Location of Lesotho in Southern Africa

b: Agro-ecological zones of Lesotho

Fig. 1. a: Location of Lesotho in Southern Africa. b: Agro-ecological zones of Lesotho.

activities between 5 and 32% of the wetland boundary. From the above criteria, the *Khalong-la-Lithunya* catchment has medium anthropogenic impact (a.i.) (i.e. grazing) (Hughes, 1995; Teels and Adamus, 2001). The geology is Lesotho formation and it falls within the Afroalpine Grassland zone characterised by grasses: *Festuca caprina*, *Merxmuellera disticha* and *Pentaschistis oreodoxa*; shrubs and woody plants: *Chrysocoma ciliata*, *Erica dominans* and *Euryops evansii.*

2.2. Climate

The climate of Lesotho is defined as temperate and continental climate. Lesotho has four seasons: summer, autumn, spring and winter. The summer is known to have high rainfall and temperature. The winter is characterised by cold, snowing and low rainfall, while the spring and autumn are transitional seasons between summer and winter respectively. The maximum rainfall and maximum and minimum temperatures respectively of the sampling site are presented in Table 2. The annual rainfall often recorded for this site ranged from 1000 and 3000 mm (Table 2).

2.3. Field work and soil sampling

At the KLC two transects each of between 250 m and 700 m-length were chosen and observations were made at intervals of 50 m. Transect-1 was 100-m away from the stream bank compared Transect-2 which ran parallel to the stream/bank. Soil samples were either collected from *dongas* or incised channels to a depth of 0.50 m after demarcating the depths and samples collected were replicated two times. Where this

Table 2
Mean maximum rainfall, and temperature distribution patterns for Butha-Buthe District, Lesotho (1997–2007).
Source: Lesotho Meteorological Service (LMS, 2008).

Year	Mean monthly rainfall (mm)	Minimum temperature (°C)	Maximum temperature (°C)
1997	77.1	7.6	21.2
1998	77.6	8.0	22.5
1999	49.8	7.8	22.9
2000	99.0	7.7	21.9
2001	67.2	8.1	21.9
2002	64.4	8.1	22.2
2003	49.1	8.1	22.8
2004	63.0	8.0	22.1
2005	65.1	8.1	22.6
2006	95.6	8.1	21.3
2007	63.2	7.1	22.4

Table 3
Water quality parameters and abbreviations, units and analytical methods used.

Variables	Abbreviations	Units	Analytical methods	WHO limits[a]
pH	pH	pH unit	pH-meter	6.5–8.5
Electrical conductivity	EC	mS/cm	Electrometric	1.5
Phosphate	PO_4	mg/L	Spectrophotometer	0.01–0.10[b]
Nitrate-N	NO_3-N	mg/L	Spectrophotometer	50
Calcium	Ca	mg/L	Flame photometer	100
Magnesium	Mg	mg/L	Flame photometer	50
Potassium	K	mg/L	Flame photometer	12
Sodium	Na	mg/L	Flame photometer	200

[a] WHO (2004).

[b] USEPA/NOAA (1988).

Table 4
Soil morphological properties of *Khalong-la-Lithunya* catchments.

Mini-pits	Horizon	Depth	Colour	Boundary	Texture	Structure	Consistency	Roots	Concretions	Pores
Transect 1										
1	1	0–23	10YR3/2	Clear/smooth	Loamy sand	Crumb	None	Many	None	Many
1	2	23–37	7YR2.5/1	Clear/wavy	Sandy loam	Crumb	None	Few	None	Common
2	1	0–25	10YR3/3	Smooth	Silt	Crumb	None	Many	None	Many
2	2	25–45	10YR3/3	Smooth	Silt	Crumb	None	Few	None	Many
3	1	0–26	5Y3/1	Clear	Silt	Crumb	Slightly-sticky	Many	None	Many
4	2	0–17	10YR3/2	Clear	Sandy-loam	Crumb	Sticky	Few	None	Common
4	1	17–37	2.5Y3/1	Smooth	Loam	Crumb	Sticky	Many	None	Many
5	1	0–21	10YR3/1	Smooth	Loam	Crumb	Slightly-sticky	Many	Fe/Mn	Many
5	2	21–31	10YR3/2	Smooth	Loam	Crumb	Slightly-sticky	Few	Fe/Mn	Many
6	1	0–20	5YR3/3	Smooth	Sandy-loam	Crumb	None	Few	None	Common
6	2	20–30	5YR3/3	Smooth	Sandy-loam	Crumb	None	None	None	None
7	1	0–20	10YR3/1	Clear	Sandy-loam	Crumb	None	Many	Fe/Mn	Common
7	1	20–49	10YR3/2	Smooth	Silt	Crumb	Sticky	Many	None	Many
8	1	0–12	10YR3/1	Smooth	Silt	Crumb	Sticky	Few	None	Common
9	2	0–20	10YR2/1	Clear	Silt	Massive	None	Many	None	Many
9	3	20–34	10YR3/2	Clear	Silt	Crumb	None	Few	None	Common
Transect 2										
1	1	0–10	2.5Y2.5/1	Smooth	Peat	Crumb	Slightly-sticky	Many	None	Many
1	2	10–43	10YR2/2	Smooth	Silt	Crumb	None	Few	None	Common
2	1	0–10	7.5YR2.5/1	Smooth	Peat	Crumb	None	Many	None	Many
2	2	10–20	7.5YR3/4	Clear	Silt	Crumb	None	Few	Fe/Mn	Common
2	3	20–30	7.5YR2.5/1	Smooth	Silt	Crumb	None	Few	Fe/Mn	Common
3	1	0–15	10Y2.5/1	Smooth	Peat	Massive	None	Many	None	Many
3	2	15–45	5YR3/2	Smooth	Silt	Massive	None		None	Many
4	1	0–24	7.5YR2.5/1	Smooth	Silt	Massive	Slightly-sticky	Many	Fe/Mn	Many
4	2	24–43	7.5YR3/2	Smooth	Silt	Massive	Slightly-sticky	Few	Fe/Mn	Common
5	1	0–27	10YR3/1	Clear	Peat	Massive	None	Many	None	Many
5	2	27–40	7.5YR2.5/1	Clear	Silt	Massive	Slightly-sticky	Few	None	Many
6	1	0–34	7.5YR2.5/3	Smooth	Silt	Massive	Slightly-sticky	Many	Fe/Mn	Many
7	1	0–27	7.5YR2.5/1	Smooth	Silt	Massive	Sticky	Few	Fe/Mn	Many
7	2	27–46	7.5YR2.5/3	Smooth	Silt	Massive	None	Many	Fe/Mn	Common
8	1	0–20	7.5YR2.5/1	Clear	Peat	Massive	None	Many	Fe/Mn	Many
8	2	20–35	7.5YR2.5/1	Clear	Silt	Massive	Slightly-sticky	Few	Fe/Mn	Common
9	1	0–20	10YR2/1	Clear	Silt	Crumb	None	Many	None	Many
9	2	20–40	10YR2/1	Clear	Silt	Crumb	None	Common	None	Common
10	1	0–30	10Y2.5/1	Smooth	Loam	Crumb	None	Many	None	Many
11	1	0–10	10YR5/1	Clear	Silt	Crumb	None	Many	Fe/Mn	Many
12	1	0–24	2.5YR2.5/1	Smooth	Loam	Crumb	None	Many	None	Common

is not possible, mini-pits were excavated and samples collected. These were subsequently covered and grassed to prevent erosion.

2.4. Laboratory analyses

Soil morphological properties were described after *Soil Taxonomy* (Soil Survey Staff, 1993) in the soil profile excavated. Soils collected were labelled, bagged and transported to the laboratory for routine soil analysis. These were air-dried for 72 h and crushed to pass through a 2-mm sieve and some to pass through 0.5-mm sieve. Samples were analysed for pH water (1:2 soil–water ratio) and pH-KCl (1:1 soil–water ratio), particle size analysis (Bouyoucos, 1962), total N (by macro-Kjeldahl method, Bremner, 1965) and available P (Bray-1-P) (Bray and Kurtz, 1945). From the soils extracted with 1N HCl, the following were determined: Fe, Mn, Zn & Cu. The organic carbon (OC) (Walkley and Black, 1934), assuming that soil organic matter contains 58% carbon soil organic matter (SOM) was calculated by multiplying OC by a factor of 1.729. The soil organic matter: silt + clay ratio was after Quiroga et al. (2006). Soil samples extracted with 1N NH_4OAc (pH 7) were used for the determination of base cations (Ca, Mg, Na and K). Potassium in the filtered extracts was determined with an atomic absorption spectrophotometer (Perkin Elmer, 2007 AAS model WinLab, version 6.5.0.0266). The effective cation exchange capacity (ECEC) was by the summation of the exchangeable cations.

2.5. Water sampling and analysis

Water samples were collected monthly (Jan–Dec) for four years (2009 to 2012) from side-perforated piezometers (1.5 m) installed to a depth of 2.0 m into the soil and these were replicated two times. In each transect, four piezometers were installed at intervals of 50 m. Water samples were collected from 0800 h to 1300 h GMT using open water grab sampler (1.5 L capacity). To evaluate the wetland water quality, water samples were kept in a 2-L polyethylene plastic bottles that have been pre-cleaned with metal free soap, rinsed many times with distilled water. These were subsequently soaked in 10% nitric acid for 24 h and then rinsed with ultrapure water. All water samples were stored in insulated cooler containing ice-packs and transported to the laboratory after each sampling on the same day. Subsequently, water samples were acidified with 0.1 N HCl and were kept at 4 °C until processing and analysis (Clesceri et al., 1998).

Table 5
Physico-chemical properties of selected wetland soils at *Khalong-la-Lithunya*.

Transect	Pits	Sand	Silt	Clay	SOM*	OrgC†	SSCR**	Silt:clay ratio
1	1	62.53a‡	22.61a	14.86a	4.02b	23.20b	0.12a	0.107f
1	2	71.78a	19.00a	9.22ab	4.97ab	28.70ab	0.18a	0.176e
1	3	58.28a	31.28a	10.22ab	6.01ab	34.8ab	0.15a	0.145f
1	4	62.28a	24.75a	9.97ab	4.13b	23.90b	0.14a	0.119f
1	5	62.28a	27.50a	10.22ab	7.39a	42.70a	0.13a	0.196e
1	6	67.28a	22.43a	10.29ab	3.84b	22.2b	0.19a	0.117f
1	7	59.78a	31.75a	8.47ab	5.12ab	29.60ab	0.10a	0.127f
1	8	69.28a	23.00a	7.72ab	5.43ab	31.40ab	0.20d	0.177e
1	9	62.96a	30.57a	5.97b	3.63b	21.00b	0.28cd	0.09g
2	1	63.71de	32.82a	3.47b	5.85a	46.00a	0.35abc	0.161e
2	2	71.28bcde	21.6abcde	7.12ab	7.78a	24.50a	0.41abc	0.271c
2	3	72.03abcde	22.75abcd	5.22b	8.51a	49.20a	0.39abc	0.304c
2	6	83.28a	10.00e	6.72ab	8.14a	47.10a	0.49ab	0.487b
2	7	83.78a	13.00de	3.22b	8.38a	48.50a	0.54a	0.516a
2	8	70.53bcde	20.00bcde	9.47ab	7.04a	40.70a	0.24cd	0.239ab
2	9	63.53de	28.75abc	8.72ab	7.33a	42.40a	0.19d	0.196d
2	10	63.88de	22.5abcd	13.36a	8.89a	51.40a	0.25cd	0.248c
2	11	70.28bcde	25.00abcd	4.72b	8.07a	46.70a	0.27cd	0.271c
2	12	69.78cde	24.5abcd	5.72ab	6.21a	35.90a	0.21d	0.205ab

Transects	Pits	pHw	pHKCl	Ca	K	Na	Mg	ECEC	NH_4-N	AVP♥	Mn	Fe	Zn	Cu
				cmol/kg					mg/l					
1	1	5.30a*	4.72a	20.69a	0.05c	1.12b	16.06b	37.92de	0.89a	0.96b	5.87c	0.44b	0.12abc	0.54bc
1	2	5.21a	5.00a	14.32bc	0.05c	5.22a	18.7ab	38.29de	0.70a	1.84ab	6.2c	0.2b	0.08bc	0.27cd
1	3	5.16a	4.54a	21.21a	9.24a	3.07ab	19.81ab	53.33a	0.90a	3.04ab	10.3b	2.89a	0.22a	0.42bcd
1	4	5.34a	4.80a	15.81abc	0.45b	6.93a	22.5ab	45.69b	0.77a	2.10ab	4.85c	0.12b	0.07c	0.74ab
1	5	5.29a	4.59a	10.89c	0.08c	5.43a	18.04ab	34.44ef	0.38a	2.67ab	14.04a	0.2b	0.17abc	0.31cd
1	6	5.21a	4.46a	15.18abc	0.05c	3.93ab	19.21ab	38.37de	0.53a	3.20ab	4.62c	0.33b	0.08bc	0.41bcd
1	7	5.42a	4.82a	15.35abc	0.05c	6.92a	13.9b	36.22de	0.48a	1.04b	6.96bc	0.29b	0.19ab	1.07a
1	8	5.16a	4.49a	18.39ab	0.06c	0.43b	29.24a	48.12ab	0.38a	1.46ab	7.05bc	0.19b	0.11abc	0.13d
1	9	5.34a	4.58a	13.74bc	0.05c	0.08b	12.75b	26.62gh	1.05a	3.81a	4.65c	0.45b	0.1bc	0.51bc
2	1	4.59a	4.44cd	4.5b	0.72a	2.54bcd	17.02a	24.78h	0.23a	13.87a	8.02b	0.44ab	0.05c	0.09b
2	2	5.22a	4.44cd	13.00b	0.04a	6.30ab	14.65a	33.99ef	0.92a	3.33b	22.15a	0.40ab	0.25ab	0.09b
2	3	4.74a	4.58cbd	9.93b	0.03a	5.67abc	25.49a	41.12cd	0.61a	2.28b	18.0ab	0.63ab	0.09bc	0.06b
2	4	4.49a	4.24cd	12.34b	0.04a	0.05d	21.4a	33.83ef	0.62a	2.79b	6.28b	0.2b	0.23ab	0.12b
2	5	4.49a	4.27cd	10.71b	0.04a	0.51d	17.41a	26.67gh	0.62a	2.92b	5.96b	1.02a	0.04c	0.2b
2	6	4.67a	4.35cd	13.00b	0.05a	4.00abcd	24.79a	41.84cd	1.34a	1.83b	8.14b	0.72ab	0.35a	0.25b
2	7	4.67a	4.77abc	11.19b	0.06a	5.04abc	26.14a	42.43cd	0.63a	3.18b	6.64b	0.54ab	0.04c	0.11b
2	8	4.79a	4.19cd	11.69b	0.03a	7.09a	25.88a	44.69b	0.67a	2.36b	10.94b	0.72ab	0.1bc	0.17b
2	9	4.67a	4.35cd	14.22b	0.07a	7.13a	28.63a	50.50a	0.37a	2.54b	4.77b	0.51ab	0.09bc	0.51b
2	10	5.33a	5.18ab	14.12b	0.05a	0.26d	25.58a	40.01cd	0.44a	1.20b	16.81ab	0.76ab	0.22ab	3.45a
2	11	5.21a	5.35a	8.73b	0.08a	3.90abcd	18.97a	31.68ef	1.06a	6.1b	10.76ab	0.26b	0.11bc	0.86b
2	12	4.70a	4.29cd	5.69a	0.05a	0.06d	17.11a	22.91h	0.71a	2.66b	8.22b	0.36ab	0.14bc	0.63b

SOM = soil organic matter; † Org C = organic carbon (g C kg^{-1}); **SSCR = soil organic matter: silt + clay ratio; ‡Means with same letter(s) in same column are not significantly different at 5% (DMRT).

♥Av P: available phosphorus (ppm); K: potassium (ppm); Ca: Calcium (cmol/kg); Na: sodium (cmol/kg); ECEC: effective cation exchange capacity (cmol/kg); pHw: pH in water; pHKCl: pH in potassium chloride; NH_4-N (mg/l); Mg: magnesium (cmol/kg); Mn: manganese; Zn: zinc; Fe: iron; Cu: copper. *Means with the same letters in same column are not significant at 5%.

2.5.1. Analytical procedure

Water quality parameters, their units and methods of analysis are summarized in Table 3. The temperature, pH and electrical conductivity (EC) for each sampling points were determined during sampling collection by a thermometer, digital pH and EC meter. In the laboratory, the samples were divided into two batches: (i) some for analysis of selected anions (phosphates and Nitrate-N) and others for selected physico-chemical properties (Ca, Mg, K, & Na). Physico-chemical properties of all samples were analysed within 48 h. The phosphates were measured by the molybdate–ascorbic acid method (AOAC method, 1995; Clesceri et al., 1998) and Nitrate-N (AOAC method, 1995). The quality of the analytical data was ensured through careful standardization, procedural blank measurements and triplicate samples.

2.6. Isotopic studies

An enriched (2%) urea was obtained from the International Atomic Energy Agency (IAEA) Vienna and then sprinkled at the rate of 40 kg/ha at the upper-slope (US), mid-slope (MS) and toe-slope (TS) of the wetland. Each section of the slope was sub-divided into three replicates. The enrichment of ^{15}N ($\delta^{15}N$) is expressed in the conventional manner as parts per thousand relative to the isotopic ratio in standard air:

$$\delta^{15}N = (R\,sample/R\,standard-1) * 1000$$

where R-sample and R-standard are the ratios between ^{15}N and ^{14}N of the sample and the standard, respectively. The aim was to track the amount of N & C in wetlands vegetation.

2.7. Vegetation sampling and analysis

At *Khalong-la-Lithunya*, vegetation samples were collected monthly (Jan, Apr and Aug) of 2010 from transects (upper slope, middle and toe-slopes) on which $\delta^{15}N$ isotope was applied. The vegetation samples were put into labelled paper bags and taken to the laboratory where they were oven dried at 70 °C for 72 h. They were then crushed, weighed, re-packaged and sent to the Soil & Plant laboratory of the IAEA, Sideroff, Vienna for analyses.

2.8. Statistical analysis

Data collected (soil and vegetation samples) were subjected to one way analysis of variance using the general linear model (PROC GLM) of SAS (SAS Inst., 1998). Means were separated using Duncan Multiple Range Test at 5%. In addition, soil data collected were subjected to cluster analysis using cluster procedures of SAS (SAS Inst., 1998).

3. Results and discussion

3.1. Soil morphological properties

The results of the soil morphological properties for all the pedons across both transect are shown in Table 4. Texture in the first transect varied between loamy sand and sandy loam, while those in the second transect varied between peat to silt and loam. Structure varied between crumb and massive and roots were many in the top soils of both transects. Generally, there were few Fe/Mn concretions in pedons of both transects. The presence of Fe/Mn concretions is an indication of rise and fall of the water-table resulting in cyclic reduction and oxidation reactions (Ahn, 1970). Furthermore, according to Olaleye et al. (2009) the morphological features such as grey or low chroma (<3) colours, mottles, and concretions observed in these pedons are indications of soil wetness brought about by the oxidation–reduction cycles due to groundwater fluctuations. The reduced iron present in these soils imparts greyish colour on the soil matrix.

3.2. Soil physico-chemical properties

The results of the soil physic-chemical properties are presented in Table 5 across both transects. Sand contents were high across all the pits compared with the silt and clay contents. The soil organic carbon & soil organic matter were slightly higher, though most of the mini-pits have higher SOC in the surface soils compared to the sub-surface soils (Table 6). Higher contents of SOC were observed for mini-pits in Transect-2 compared to Transect-1. The storage of SOC in wetlands has been found to depend on several factors including topography, landscape pattern, hydrological regime, plant community and soil characteristics (e.g. temperature, pH and salinity) (Collins and Kuehl, 2001). The results from this investigation showed that the transect closer to the stream bank had higher SOC contents compared to that farther away (Transect-1). Bernal and Mitsch (2008) studied SOC in three different environments — temperate humid (TrH), tropical humid (TH) and tropical dry (TD). Their results showed that the mean SOC were of the order 158.6 ± 6.6, >81.50 ± 8.5, >32.8 ± 2.2 g kg^{-1} for TrH, TH and TD wetlands respectively. Thus, from this investigation, the SOC values for the *Khalong-la-Lithunya* wetlands in Lesotho can be said to vary between the TH and the TD wetlands reported by Bernal and Mitsch (2008) (i.e. 14.50 ± 0.11–53.50 ± 0.42 g kg^{-1}). The decrease in SOC with depth in Tansect-1 compared with Transect-2 is an indication that little of the SOC is stored in the former transect compared to the latter. This is typical of the wetlands in the Tropical Rain Forest where organic material and nutrients do not accumulate in the soils but are rapidly used by the biotic systems (Bernal and Mitsch, 2008; Odum and Pigeon, 1970). Results of the silt:clay ratio (SSCR) ranged from 0.09 to 0.176 (Transect-1) and from 0.19 to 0.516 (Transect-2).

According to Napoli et al. (2006) and Olaleye et al. (2011), pedons with silt:clay ratio of ≤0.70, 0.70–1.14, 1.14–3.88 and ≥3.89 are considered strongly, moderate, and non-weathered. From Table 5, a close observation showed that all the pedons had the SSCR of ≤0.70 suggesting that even after five years of conservation and rehabilitation, the soils in the area have not yet reverted to its original status, though the soil organic carbon contents ranged from 31.20 to 49.20 g kg^{-1} (Transect-1) and from 24.50 to 51.40 g kg^{-1} (Transect-2). It is also reported that grazing animals can alter the hydrology and the drainage pathways at a site by compacting the topsoil, which is indicated by increased bulk

Table 6
Soil organic carbon (g kg^{-1} ± S.E.) at two soil depths across each of the two transects with the wetlands at *Khalong-la-Lithunya*.

Transect 1			Transect 2		
Pits	Depths (cm)	Organic C (g kg^{-1})	Pits	Depths (cm)	Organic C (g kg^{-1})
1	0–23	32.20 ± 0.25	1	0–10	51.20 ± 0.64
	23–37	13.20 ± 0.20		10–43	53.50 ± 0.42
2	0–25	38.80 ± 0.38	2	0–10	50.70 ± 0.21
	25–45	18.70 ± 0.19		10–20	45.20 ± 0.04
3	0–26	34.80 ± 0.63		20–30	41.90 ± 0.44
			3	0–15	50.80 ± 0.10
4	0–17	31.40 ± 0.36		15–45	49.90 ± 0.36
	17–37	16.50 ± 0.27	4	0–24	43.90 ± 0.24
5	0–21	35.90 ± 0.13		24–43	50.30 ± 0.06
	21–31	49.50 ± 0.02	5	0–27	49.70 ± 0.19
6	0–20	29.99 ± 0.14		27–40	36.90 ± 1.29
	20–30	14.50 ± 0.11	6	0–34	42.50 ± 0.04
7	0–20	37.30 ± 0.01			
	20–49	21.90 ± 0.17	7	0–27	48.70 ± 0.24
8	0–12	31.40 ± 0.32		27–46	48.80 ± 0.51
9	0–20	22.90 ± 0.72	8	0–20	48.90 ± 0.27
	20–44	19.10 ± 0.15		20–35	47.30 ± 0.21
			9	0–20	34.60 ± 1.25
				20–40	36.10 ± 1.06
			10	0–30	49.99 ± 0.06
			11	0–10	51.20 ± 0.23
			12	0–24	38.10 ± 0.63

*±S.E. = standard error.

Table 7
Results of cluster analysis of wetland soils at *Khalong-la-Lithunya*.

Clusters	Members	Variation explained	Proportion explained	Eigen value
1	5	2.905	0.5811	0.9557
2	5	2.396	0.4791	1.0191
3	5	2.669	0.5399	0.9236
4	4	1.743	0.4358	1.0466

Cluster	Variable	R^2 with		1-R^2 ratio
		Own cluster	Next closest	
Cluster 1	Sand	0.8721	0.1229	0.1458
	Silt	0.8019	0.0611	0.2110
	Field capacity	0.4651	0.1614	0.6378
	Available water capacity	0.6980	0.0899	0.3319
	Exch. K	0.0684	0.0069	0.9361
Cluster 2	Clay	0.7440	0.0754	0.2769
	Bulk density	0.6453	0.0268	0.3645
	Wilting point	0.1303	0.0070	0.8758
	Silt:clay ratio	0.6890	0.0381	0.3233
	SSCR	0.1871	0.0129	0.8236
Cluster 3	Organic carbon	0.8895	0.0539	0.1168
	Soil organic matter	0.8892	0.0540	0.1170
	C-pool	0.5507	0.0262	0.4614
	Exch. Ca	0.1192	0.0065	0.8866
	CEC	0.2509	0.0627	0.7990
Cluster 4	pHw	0.6612	0.1308	0.3898
	pHKCl	0.7528	0.0828	0.2695
	Available P	0.0549	0.0184	0.9628
	Exch. Na	0.2742	0.0149	0.7366

density and decreased macroporosity (MP) (Singleton et al., 2000). Also, a strong correlation between climate and soil carbon pools where organic OC decreases with increasing temperatures was reported by Kirschbaum (1995) and Albrecht and Rasmussen (1995). This is because decomposition rates (microbial respiration) double with every 10 °C increase in temperature (Schlesinger, 1997). Thus decomposition rates in wetlands are a function of climate (temperature and moisture enhanced microbial activity) and the quality (chemical composition) of the organic matter entering the system (Schlesinger, 1997). Dick and Gregorich (2004) compared relative decomposition rates of organic matter in tropical (Nigeria) and cold dry climates (Canada), and found that decomposition rates were ten times faster in the tropical site.

The soil pH across both transects showed that the soils have moderate acidity, and this may have been responsible for the low available P (AVP) contents. The moderately low pH-KCl ($\geq$4.0) value in both transects may be due to Al saturation in soil solution (Soil Survey Laboratory Staff, 1993). The positive ΔpH (e.g. for Pedon 1, Transect-1; $5.30–4.72 = 0.58$) suggests the predominance of net negative change. The soil exchangeable Ca and Mg dominated the cation exchange capacities (CECs) on all pits on both transects. The contents of the extractable micronutrients (Fe, Mn, Zn & Cu) were low except Mn that varied between 4.65 and 14.04 mg/kg (Transect-1) and between 4.77 and 22.15 mg/kg (Transect-2).

3.3. Cluster analysis

The results of the cluster analysis of the soil variables along both transects are presented in Table 7 and results showed that clusters 1, 2, and 3 had five members and cluster 4 has four members. Highest proportion of the variation explained was of the order cluster 1 > cluster 3 > cluster 2 > cluster 2. Cluster 1 is related more to the water holding capacity of the land, cluster 2 is related more to the soil weatherability, while cluster 3 is related to the soil ability to store carbon (carbon mitigation) and cluster 4 is related to the soil's acidity. It is interesting to observed that high sand contents coupled with low cation exchange capacity (CEC) of the soil is an indicator that most of the cations — especially Ca, Mg & K will be easily lost from the soil solum and this is evidenced by the high water soluble Mg and Ca recorded in the soil water across years.

3.4. Vegetation isotopic analyses

Results of the δ^{13}C data for both transects varied slightly with slope positions though not significantly different ($p < 0.05$) but higher negative values of the vegetation −28.13 to −28.90‰ were observed (Fig 2a and b). Generally, there is less enrichment in δ^{13}C across slope section and months, though not significantly. This suggests that after five years of rehabilitating this wetland, the organic carbon increased across slope positions and months, though not significantly. Alwell et al. (2011) reported increase in the δ^{13}C of close to −30‰ for young/poorly drained wetland soils in Abisco valley of northern Sweden. Other authors reported pronounced δ^{13}C increases with depth up to 5‰ for typical mature, well-drained soils due to aerobic

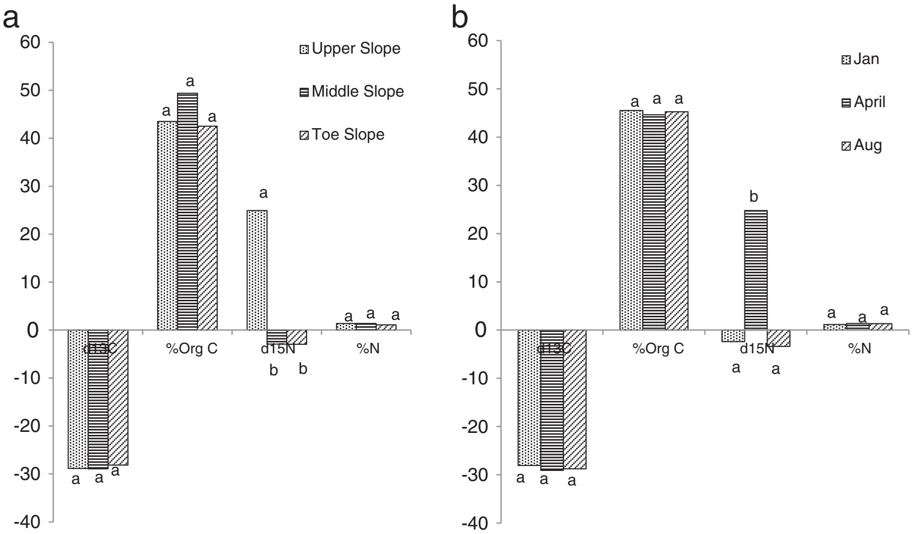


Fig. 2. a. The δ^{13}C, δ^{15}N, organic carbon, and N in vegetation samples *Khalong-la-Lithunya* catchment (KLC) in the Mountains AEZ of Lesotho across toposequence. b. The δ^{13}C, δ^{15}N, organic carbon, and N in vegetation samples *Khalong-la-Lithunya* catchment (KLC) in the Mountains AEZ of Lesotho across months.

decomposition which favours selective loss of ^{12}C (Agren et al., 1996; Beckerheidmann and Scharpenseel, 1989; Nadelhoffer and Fry, 1988). The results of the δ^{15}N ranged from −2.52‰ to −2.93‰ with a mean of −2.81‰. The δ^{15}N values of wetland plants can help wetland managers monitor changes in inputs of N. The considerable differences in δ^{15}N observed across slope position is as a result of the differences between sites, slopes, vegetation type, differences in the land use types and differences in N sources in the watersheds. The low mean δ^{15}N values observed in the site may be most likely be related to the lower anthropogenic activity in catchment (McClelland and Valiela, 1998).

3.5. Hydrochemical characteristics of the run-off water

The EC ranged from 0.11 mS/cm (2011) to 0.33 mS/cm (2010); while pH ranged from 6.13 (2011) to 6.44 (2009) (Table 8). The cations (Ca. Mg, K & Na) were observed to be within the normal limits specified by the WHO (2004). The Nitrate-N was also observed to be very low when compared to the WHO (2004) limits. However, the phosphate concentration was high when compared to the USEPA/NOAA (1988) standard. Results of the detailed water quality across months and years are presented in Table 9. The water quality parameters fluctuated irregularly across months and years and were statistically significantly different. When compared with the limits set by the WHO (2004) and USEPA/NOAA (1988), the EC, pH, Ca, Mg, Na and Nitrate-N were all in the normal range reported for pristine waters. However, a close observation of the phosphate concentrations across years and months showed that these values are higher when compared to these limits (USEPA/NOAA, 1988; WHO, 2004). Studies have reported that wetlands reduce nutrients by encouraging sedimentation (Furukawa et al., 2005), sorbing nutrients to sediments, and taking up nutrients in plant biomass. Phosphate is usually not readily available for uptake in soils. Phosphate is only freely soluble in acid solutions and under reducing conditions. In the soil it is rapidly immobilized as calcium or iron phosphates. Most of the phosphorus in soils is adsorbed to soil particles or incorporated into organic matter (Craig et al., 1988; Holtan et al., 1988; Olaleye, 2012; Smith, 1990). Lakes and reservoir sediments serve as phosphorus sinks (Holtan et al., 1988; Smith, 1990). These authors reported that phosphorus-containing particles settle to the substrate and are rapidly covered by sediment. Continuous accumulation of sediment will leave some phosphorus too deep within the substrate to be reintroduced to the water column. The EPA water quality criteria state that phosphates should not exceed 0.05 mg/l if streams discharge into lakes or reservoirs, 0.025 mg/l within a lake or reservoir, and 0.1 mg/l in streams or flowing waters not discharging into lakes or reservoirs to control algal growth (USEPA, 1986). Surface waters that are maintained at 0.01 to 0.03 mg/l of total phosphorus tend to remain uncontaminated by algal blooms.

Table 8
Hydrochemistry of surface water at *Khalong-la-Lithunya* wetland in the Mountains AEZ of Lesotho (2009–2012).

Variables	Years			
	2009	2010	2011	2012
pH	6.44a†	6.35ab	6.13b	6.38ab
EC (mS/cm)	0.29a	0.33a	0.11a	0.13a
Ca (mg/L)	1.18ab	1.28a	1.04bc	0.94c
Mg (mg/L)	0.38ab	0.38a	0.36b	0.37ab
K (mg/L)	3.55a	3.63a	0.87b	1.85b
Na (mg/L)	3.56a	2.57ab	2.01b	2.58ab
P (mg/L)	0.51a	0.39b	0.30b	0.32b
NO_3-N (mg/L)	0.36a	0.32a	0.31a	0.30a

†Means with same letters in same column are not significantly different at 5% (DMRT); n = 24.

Table 9
Monthly data of the hydrochemistry of surface water at *Khalong-la-Lithunya* wetland in the Mountains AEZ of Lesotho (2009–2012).

Months	EC	pH	mg/L					
			Ca	Mg	K	Na	P	NO_3N
2009								
Jan	0.23ab†	6.50ab	1.67a	3.66a	6.71ab	3.66a	0.60a	0.77a
Feb	0.42ab	7.03a	1.11b	0.38a	8.15a	5.33a	0.32a	0.40e
Mar	1.01a	6.70ab	1.69a	4.07a	3.49abc	4.07a	0.49a	0.43d
Apr	0.29ab	6.55ab	1.00b	5.81a	3.80abc	6.48a	0.50a	0.37f
May	0.11ab	6.18ab	1.01b	2.29a	1.89bc	2.29a	0.29a	0.68b
Jun	0.11ab	6.17ab	0.97b	0.38a	1.16bc	1.86a	0.89a	0.52c
Jul	0.09b	5.60b	1.37ab	2.13a	3.62abc	2.13a	0.37a	0.23h
Aug	0.33ab	6.15ab	0.96b	1.95a	0.54c	1.95a	0.68a	0.31g
Sept	0.25ab	6.51ab	1.31ab	0.370a	5.25abc	5.81a	0.81a	0.17i
Oct	0.31ab	6.71ab	1.01b	5.06a	4.33abc	5.06a	0.34a	0.03k
Nov	0.230	6.84a	0.94b	3.06a	1.27bc	3.06a	0.48a	0.23h
Dec	0.11ab	6.32ab	1.11b	1.01a	1.13bc	1.01a	0.40a	0.13j
2010								
Jan	0.47ab	6.45ab	1.24ab	0.38a	9.24a	1.50a	0.37ab	0.30f
Feb	0.06b	6.30abc	1.26ab	0.38a	5.72a	5.93a	0.35ab	0.51c
Mar	0.56ab	7.08a	1.05b	0.38a	1.91a	3.45a	0.44ab	0.80a
Apr	0.15ab	6.73a	0.95b	0.38a	4.65a	1.26a	0.47ab	0.06j
May	1.56a	6.51ab	1.12b	0.37a	4.79a	4.71a	0.31ab	0.30f
Jun	0.17ab	6.45ab	1.95a	0.37a	5.95a	3.09a	0.96a	0.16i
Jul	0.43ab	6.62ab	1.31ab	0.38a	3.65a	2.24a	0.27b	0.31e
Aug	0.13ab	6.31abc	1.23ab	0.39a	3.09a	1.89a	0.36ab	0.21g
Sept	0.12ab	6.21abc	1.29ab	0.39a	0.43a	1.07a	0.28b	0.43d
Oct	0.12ab	6.33abc	1.29ab	0.38a	0.46a	2.37a	0.22b	0.52b
Nov	0.09b	5.75bc	1.38ab	0.36a	1.66a	1.28a	0.35ab	0.18h
Dec	0.09b	5.40c	1.25ab	0.36a	1.97a	2.04a	0.35a	0.05k
2011								
Jan	0.11ab†	6.27a	1.24a	0.19a	1.30ab	1.20b	0.19b	0.21h
Feb	0.11ab	6.40a	0.98ab	0.36a	0.78ab	1.49b	0.33a	0.35c
Mar	0.10ab	6.15a	0.91ab	0.37a	1.53ab	1.61b	0.37a	0.43b
Apr	0.09b	5.96a	0.87ab	0.36a	2.58a	1.38b	0.29ab	0.20i
May	0.11ab	5.52a	0.87ab	0.37a	0.22b	1.52b	0.32ab	0.22g
Jun	0.09b	6.20a	0.93ab	0.37a	1.64ab	1.34b	0.23ab	0.01j
Jul	0.11ab	5.66a	0.67b	0.38a	0.67ab	2.51b	0.26ab	0.81a
Aug	0.10ab	6.01a	0.91ab	0.36a	0.37ab	6.77a	0.29ab	0.32d
Sept	0.10ab	6.25a	1.12ab	0.37a	0.40ab	1.44b	0.31ab	0.25e
Oct	0.11ab	6.33a	1.19a	0.36a	0.28ab	1.53b	0.33ab	0.23f
Nov	0.11ab	6.27a	1.33a	0.36a	0.37ab	1.63b	0.33a	0.25e
Dec	0.12a	6.52a	1.33a	0.36a	0.30ab	1.61b	0.28ab	0.35c
2012								
Jan	0.12a	6.50a	1.44ab	0.37abc	0.50a	2.81b	0.28a	0.45c
Feb	0.11a	6.37a	1.39ab	0.37abc	1.13a	2.26b	0.28a	0.01j
Mar	0.23a	6.72a	1.83a	0.37abc	5.13a	6.90a	0.35a	0.43d
Apr	0.24a	6.03a	1.25abc	0.37abc	3.89a	3.08b	0.33a	0.21f
May	0.10a	6.37a	1.25abc	0.37ab	2.77a	1.81b	0.47a	0.78b
Jun	0.09a	5.99a	0.91bcd	0.37abc	2.30a	2.02b	0.36a	0.07i
Jul	0.10a	6.27a	0.53cd	0.37abc	1.10a	2.93b	0.40a	0.21f
Aug	0.10a	6.46a	0.54cd	0.38a	1.25a	2.80b	0.32a	0.01j
Sept	0.09a	6.37a	0.51cd	0.36c	1.07a	1.72b	0.25a	0.11h
Oct	0.10a	6.48a	0.52cd	0.36cb	1.21a	1.97b	0.22a	0.23e
Nov	0.11a	6.33a	0.47d	0.37abc	0.59a	1.21b	0.31a	0.85a
Dec	0.08a	6.80a	0.25d	0.32d	0.47a	0.26b	0.21a	0.12g

n = 24; †Means with same letter(s) in same column, same year are not significantly different at 5% (Duncan Multiple Range Test, DMRT).

4. Conclusions

There is sparse data on the soil morphological, physic-chemical properties, vegetation isotopic signatures and hydrochemistry of Peatlands in *Khalong-la-Lithunya* catchments of Lesotho. Results showed that the δ^{13}C data for both transects varied slightly with slope positions though not significantly different ($p < 0.05$) but higher negative values of the vegetation −28.13 to −28.90‰ were observed. Since the δ^{13}C in the vegetation is between −32 and −20‰, results suggested that majority of the plant in the wetland soils is of C-3 origin. The results of the δ^{15}N ranged from –2.52‰ to –2.93‰ with a mean of –2.81‰. The δ^{15}N values of wetland plants can help wetland managers monitor changes in inputs of N. Results of the hydrochemistry from the installed piezometers showed that across years and months, only the phosphate concentrations are elevated beyond the limits set by the USEPA/NOAA (1988).

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