Chapter

Wetland Health in Two Agro-Ecological Zones of Lesotho: Soil Physico-Chemical Properties, Nutrient Dynamics and Vegetation Isotopic N^{15}

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Abstract

Monitoring is essential to evaluate the effects of wetland restoration projects. Assessments were carried-out after 6 years of restoration efforts on a wetland located in two agro-ecological zones (AEZ): the Mountains agro-ecological zone–*Khalongla-lithunya* (KHL) and the Foot Hills–*Ha-Matela* (HM). The former was under conservation and the latter non-conserved. Mini-pits were dug along transects for soil sampling. Runoff water was collected from installed piezometers into pre-rinsed plastic bottles with de-ionized water once a month for between 3 and 6 months. Soil and water samples were analyzed in the laboratory for Ca, Mg, K, Na, total nitrogen, and phosphorus, and soil samples were further analyzed for Cu, Fe, Zn, and Mn and vegetation isotopic N^{15}. Water quality, soil organic matter (SOM), carbon pools, base cations, ratios (silt:clay & SOM:silt clay), texture, and N-15 isotopes were chosen as indicators. Results showed that base cations were significantly ($p < 0.05$) higher in the groundwater and soils of KHL wetlands compared with those from the HM. The soils of the KHL wetlands have higher ($p < 0.05$) clay, silt contents, SOM, and silt clay ratios compared with the HM. Furthermore, results of the N^{15} isotopes were between 2.52 and 2.93% (KHL) compared with 2.00 and 6.18% (HM). Similarly, the results of the $\delta^{13}C$ showed significant negative values at KHL (28.13–28%) compared with HM (11.77–12.72%). The study concludes that after five years of rehabilitating the KHL wetlands, the soil indicators showed that restoration efforts are positive compared with the HM wetlands that are non-conserved.

Keywords: catchments, grazing, N^{15} isotopes, Lesotho, wetland, nutrient dynamics, restoration

1. Introduction

The Kingdom of Lesotho covers a land area of 30,355 sq. km and is situated within the Southern African plateau at an elevation of between 1500 m and 3482 m above sea level. It has four agro-ecological zones (AEZ) based on climate and elevation (**Table 1**). All the AEZ's are replete with wetlands. Wetlands locally called *mekhoabo* (*plural*) and *mokhoabo* (singular) occur as extensive bogs and sponge-lands especially in the Mountains AEZ, though may be small in extent, collectively, they could cover thousands of hectares.

In Lesotho, over the years, more emphasis of agriculture (cropping and grazing) has been placed on upland soils, but due to increasing degradation of uplands coupled with lack of vegetation for grazing, attention is now shifting to wetland soils as it now constitutes an important component of rural livelihoods for the *Basothos*. Wetlands are defined as "areas that have free water at (or on the surface) for at least the major part of the growing season" [1]. In Lesotho, land ownership is vested in the paramount chiefs, hence, no land is privately owned. These chiefs thus grant the right to cultivate lands to individuals or groups, but all citizens are free to graze livestock on all lands [2].

Wetlands are critical to maintaining and improving the quality of lives in sub-Saharan Africa (SSA) by improving livelihoods of rural populations and reducing poverty especially in the summer seasons and in times of droughts [3]. In Lesotho, wetlands are also known to support grazing, forestry and cropping activities, hence can be said to be ecologically, economically and socially important [3]. According to Grenfell et al. [4], wetlands in the Southern African region was classified into seven main groups: marine, estuarine/lagoon, endorheic, riverine, lacustrine, palustrine and man-made wetlands. However, the wetlands investigated were of lacustrine and riverine systems. Lacustrine wetlands include lakes, lagoons, and dams; riverine wetlands include rivers, streams and channels. Palustrine, lacustrine and riverine wetland systems are found in Lesotho with the palustrine system being the most dominant. The palustrine system in Lesotho comprises of mires (bogs and ferns) in the highlands region, while, lacustrine system comprises of artificial impoundments for water supply and riverine system found along streams are generally small and localized [5, 6].

Agricultural activities (such as grazing and cropping) are thought to be the major contributors to non-point wetland pollution in the highlands and foothills respectively while industrial effluents and domestic waste disposal are thought to contribute significantly to wetlands' pollution in urbanized and industrialized Lowlands AEZ. In Lesotho, wetlands are important for livestock grazing and the problems related to wetlands management, in particular, soil erosion, are related to overgrazing [3]. Land degradation in upland areas is thought to also be a major contributor to the conversion of wetlands into crop lands as the upland areas are degraded beyond use [7]. There are sparse data on the chemical characteristics of wetlands in *Khalong-la-Lithunya* (KHL) and *Ha-Matela* (HM) catchments which are located in

Agro-ecological zones	Area (km^2)	Altitude (m) above sea level	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

Table 1.
Agro-ecological characteristics of Lesotho.

two different AEZ of Lesotho. The former has been under conservation practices for over 6 years. A restoration project was introduced in some wetlands in Lesotho 2006 to restore some degraded wetlands back to their original status in view of their importance in the country. The latter wetland (HM) is still being used for livestock grazing, watering, cropping and gathering of biodiversity. In 2006, the country was awarded a grant by the Millennium Challenge Corporation (MCC), USA to plan restoration and conservation activity in selected wetlands in Lesotho which will address the widespread overgrazing and degradation of wetlands which are prevalent throughout the highlands of Lesotho. These wetlands are an important ecological and economic resources as they naturally regulate flow in the Senqu/Orange River Basin and provides livestock pasture, medicinal plants, thatch, and other rural livelihood benefits. Several reports abound on wetland restoration activities (Gray et al., 2002; [8–12]). These authors reported that wetland restoration focuses on restoring three key components—hydrology, biology, and soil—of wetlands. It is required that detailed investigation of these components is examined and how they change during the ecosystem restoration process. Some of the properties that may be observed include changes in hydro-periods and water chemistry [9, 13–15]; changes in the wildlife habitats [12, 16].

The effects of wetland restoration are commonly evaluated by analyzing changes in the hydrology, biological components and the physical and chemical properties of soil [9, 10, 17]. Also of importance is the changes in the vegetation composition and structure, in terms of percent cover, biomass, plant diversity associated with re-establishment of species [18–20] as well as the changes in the soil microbial communities, and functioning [21, 22] and isotopes.

Stable nitrogen isotope measurements may be used to examine the nitrogen cycle within landscapes [23, 24]. Biological discrimination between the two stable isotopes ^{14}N and ^{15}N often leads to natural isotopic fractionation [23, 24]. It is well established that denitrification results in isotopic changes in the nitrate (NO_3^-) pool, as bacteria preferentially reduce $^{14}NO_3^-$ over $^{15}NO_3^-$, leaving an enriched pool of $^{15}NO3^-$ [23, 24]. The isotopic signature has been used to identify regions of significant denitrification in groundwater aquifers, streams and riparian buffer zones [23, 24]. Partitioning carbon contributions from different species to the soil carbon is challenging. Among the numerous methods, the carbon isotopic technique based on the difference in stable carbon isotope composition ($\delta^{13}C$) ratios between older soil carbon and inputs of new carbon appears promising [25, 26]. This technique studies soil carbon dynamics over a few years or several 100 years, and the results can help to understand the consequences of human induced land use change [27, 28].

This study focused on changes in soil characteristics, especially selected soil physico-chemical characteristics and hydrochemistry of the run-off water. The hypothesis was that conservation/restoration of wetlands coupled with the introduction of freshwater/rainwater would alter the soil characteristics resulting in increased accumulation of SOC, total N (TN), base cations (Ca, Mg, Na & K), C-pool as well as increased clay and silt contents, increase in silt:clay and soil organic matter:siltclay ratios (SSCR). The aim of the management effort was to reduce the wetland degradation, which is the primary threat to the wetlands in Lesotho, and provide conducive habitats for wetlands vegetation and faunal species. The specific objectives of the current study were to evaluate whether there were differences in the soil (i) physicochemical properties and (ii) hydrochemistry of a wetlands under conservation and the one that is not conserved to assess the effect of restoration after 5 years; the results are intended to support the ongoing restoration efforts in selected wetlands in Lesotho and (iii) to estimate the $^{\delta}C$ and $^{\delta}N$ in the plant samples of the conserved and non-conserved wetlands.

2. Methodology

2.1 Climate

The climate of Lesotho is largely determined by the country's location in the centre of the Southern African Plateau. It is sub-humid to temperate cool with warm and rainy summers and cool to cold dry winters. The mean minimum temperature during winter is around 0°C which is common in June (the coldest month), with the lowlands recording −1 to −3°C and the highlands recording −6 to −8.5°C. The mean annual temperatures recorded are 15.2°C and 7°C for the lowlands and the highlands respectively. In January, which produces the highest mean maximum temperatures throughout the country, temperatures range from 20°C in the highlands, and 32°C in the lowlands. The mean annual precipitation ranges from 500 mm in the Senqu River Valley to 1200 mm in the North and East of the country. Eighty-five percent of the rainfall is received between the months of October and April. Frost and snow are common in winter. The mountains of Lesotho are regularly covered by snow during winter months.

2.2 Land use

Land use is often used as a surrogate for disturbance and has been correlated with biological attributes in wetlands [11, 29]. In Lesotho, agricultural activity (i.e. grazing and livestock watering) coupled with climatic change is the predominant disturbance to seasonal wetlands in all agro-ecological zones. Wetlands can be characterized into low or high impact based on local land use characteristics [5, 30], with low impact wetlands having little or no agricultural activity within 150 m of the wetland boundary and high impact wetlands having agricultural activity within 10 m of the wetland boundary.

2.3 Descriptions of the experimental sites

The study sites were located within Lesotho at an elevation ranging between 1800 m and >2000 m above sea level (asl) (**Table 1** and **Figures 1** and **2**) in two agro-ecological zones (AEZ): the Foot-Hills and the Mountains. Shrubs co-dominate at higher elevations in the Mountains AEZ, wile in the Foot-Hills, the dominant vegetation is grasses (i.e. *Cyperus spp*).

2.4 Selections of wetlands in relation to utilization

Wetlands were selected for this research were characterized as either low, medium or highly impacted based on (i) local land-use characteristics [31]; and (ii) the intensity of anthropogenic pressures such as mining, smelting, and discharge of an industrial pollutant into the wetlands. Low impacted wetlands has little (i.e. <5%) or no agricultural activity within 150 m of the wetland boundary [5, 32]. The wetlands 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. Using the probability sampling approach [33], coupled with accessibility and ease of continuous monitoring, two wetland types—lacustrine and riverine systems were identified in two different AEZs of Lesotho (**Table 1**).

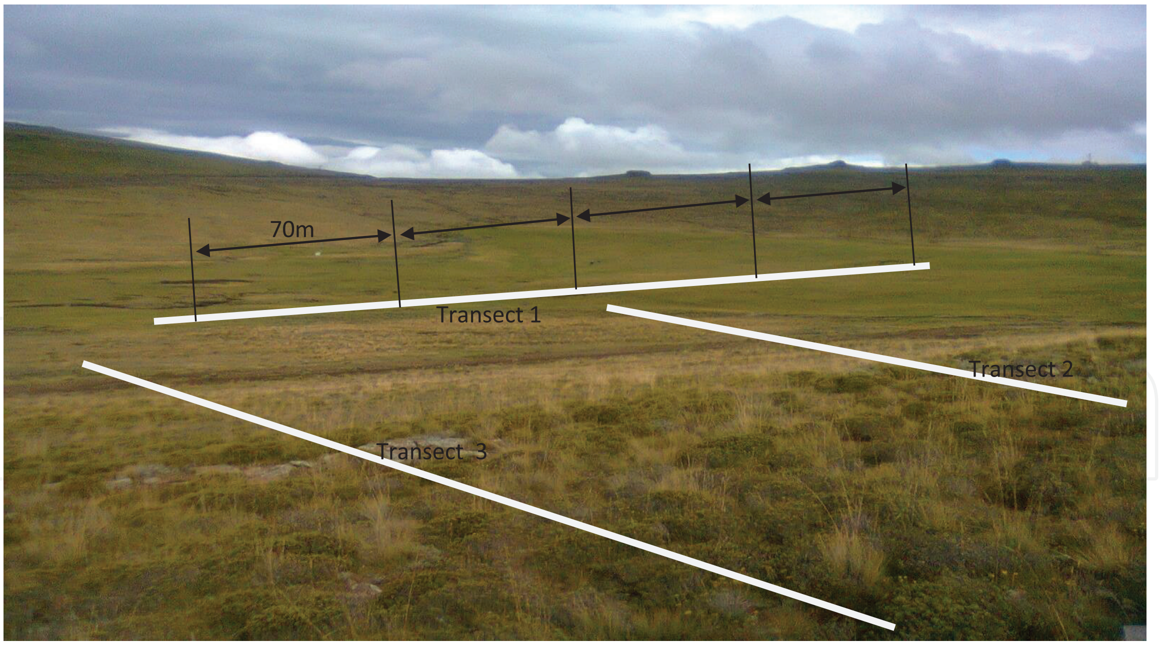

Figure 1.
view of Khalong-la-Lithunya *showing the three transects.*

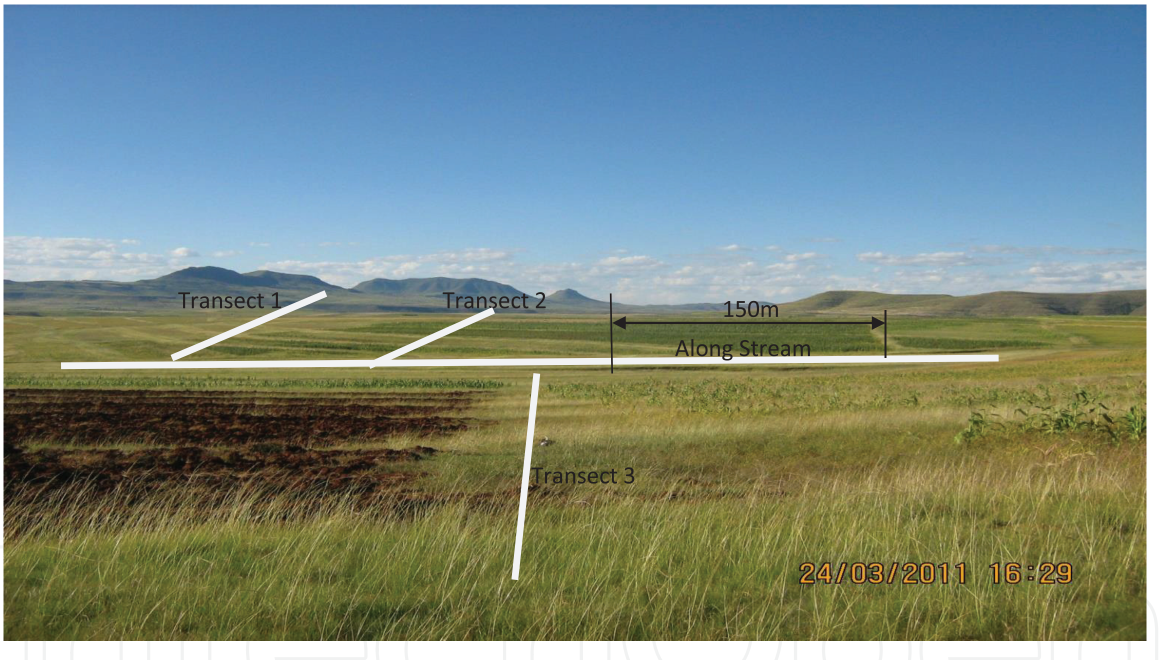

Figure 2.
View of Ha-Matela *showing transects and stream.*

2.5 Locations of study sites

Khalong la Lithunya (KHL) wetland is a palustrine wetland and it is situated in the Mountain AEZ (**Figure 1**). 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 geology of this land is Lesotho formation [5, 34]. There is a very sparse population in this area, as it is used only by those people who live in the animal posts and on work camps; however, there is remarkable damage done to the wetland area by soil erosion resulting from previous overgrazing of the land. Thus, with current protection from the Millennium Challenge Account (MCA), Lesotho wetland Restoration project, this piece of land is currently classified as low impact because currently there are no agricultural activities taking place. The mean annual rainfall often recorded for this area is 1000 mm deep.

Ha Matela (HM) wetland is a Riverine wetland situated in the Foothills AEZ at an elevation of 1820 m above sea level, at points; Latitude: $-29^{0}38.3333$ /Longitude: $27^{0}76.6667$ (**Figure 2**). The geology of this land is Lesotho formation [5, 34] with sedimentary and volcanic clastics. The land use types (LUTs) found in this area are pasture and cropping and it has been highly impacted. The mean annual rainfall often recorded for this area is 65 mm deep.

2.6 Soil sampling and analysis

A Garmin GPS (Geko 301) was used to determine the elevations of the study sites and to track the position of the points at which samples were collected. At KHL catchments, three transects, of approximately 1000 m each, were chosen and mini-pits (0.5 m) were dug at intervals of 70 m. At HM catchments, two transects were chosen on one side of the stream and one transect on the other side and the mini-pits (0.5 m) were dug at the upper, the middle and the lower slope of each transect and at 150 m interval along the stream.

At both sites, soil samples were collected from every exposed horizon in the mini-pits. The soil samples were put into polythene bags and taken to the laboratory where they were air-dried at room temperature for 72 h and then crushed to pass through a 2 mm sieve. The soil samples were then analyzed for total nitrogen [35]; available Phosphorus [36]; Base cations (Mg, Ca, Na and K) extracted using the Ammonium acetate at pH 7 and determined using the Atomic Absorption Spectrometer (Spectro AA 300). The soils were also analyzed for micronutrients (i.e. Cu, Fe, Zn, and Mn).

At both sites, water samples were collected from December 2010 to March 2011 across from installed plastic water bottles (DWB) which have been pre-rinsed with de-ionized water at a depth of 0.50 m in duplicates. Five DWB were installed in each of the three transects at KHL catchments. However, at HM catchments, the DWB were installed at the upper, middle and toe-slopes and the land use types (LUTs). The mainland use type (LUT) at HM catchment was mainly for livestock grazing, watering, and cropping. Run-off water samples were collected in duplicates using into a 20 mL plastic bottle and acidified with 0.1 N HCl. Following sample collections, samples were preserved in the icebox to restrain microbial activities before getting to the laboratory. All the parameters mentioned above were determined, based on standard methods [37] using the Atomic Absorption Spectrometer (Spectro AA 300). Four indicators—base cations (K, Ca, Mg & Na), total P (TP) and Total N (TN) were used to describe the water quality of samples. The base cations, TN and TP were analyzed in the laboratory.

2.7 Vegetation sampling and analysis

Nitrogen isotope (^{15}N) was applied in the form of urea to wetlands at both sites located in the KHL and HM at the upper-slope (US), mid-slope (MS) and toe-slope (TS). At both sites, vegetation samples were collected in triplicates from the three sections of the toposequence. Dominant vegetation at KHL was *Helichrysum trilineatum* and at HM it was *Cyperus* spp. The enrichment of ^{15}N ($\delta^{15}N$) is expressed in a conventional manner as parts per thousand relative to the isotopic ratio in standard air:

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

where R-sample and R-standard are the ratios between ^{15}N and ^{14}N of the sample and the standard, respectively.

Samples were collected at each site by clipping four healthy, intact, mature plants at the soil surface avoiding senescent plant leaves. Live samples were wiped cleaned to remove surface debris and then chopped into approximately 10-cm sections for drying. The vegetation samples were put into labeled paper bags and dried at a temperature of 55°C and subsequently sent by courier service to the International Atomic Energy Agency (IAEA), laboratory, Seibersdorf, Vienna, where they were then crushed, weighed, and analyzed for N^{15} and $13^{\delta}C$ isotope signatures.

2.8 Statistical analysis

Data collected (soils, water) were subjected to summary statistics (N, max, min, range, standard deviation, standard error, kurtosis, and skewness) using the means procedure of SAS (PROC Means) [38]. Data (soils, water, and vegetation N^{15}) were also subjected to one-way analysis of variance (ANOVA) using the general linear model procedure (PROC GLM) [38] and means were separated using Duncan multiple range test at 5% level of significance. Results of the selected soil properties were compared across sites using analysis of variance procedure of SAS (PROC ANOVA) [38] and means were separated using Duncan multiple range test at 5% level of significance.

3. Results and discussion

3.1 Summary statistics and characteristics of the restored wetland (Khalong-la-Lithunya) (KHL)

Soils of KHL wetland have a texture that is rich in sand and ranged between 49.28% and 87.28% with a mean of 68.76 ± 1.07%; silt content ranged between 4 and 40% with a mean of 23.49 ± 0.97% and clay between 0.72 and 21% with a mean of 7.71 ± 0.51%. The soil organic carbon (SOC) content ranged from 1.30–5.76% with a mean of 3.92 ± 0.13% and the soils have low bulk densities. These soils have an acidic pHw of 3.85–5.90 and mean of 5.04 ± 0.05 and pH in KCl of between 3.24 and 5.67 with a mean of 4.46 ± 0.04. Generally, the cation exchange capacity (CEC) ranged between 0.02 and 8.33 cmol/kg with a mean of 3.32 ± 0.30 cmol/kg and base cations (K, Ca, Mg and Na) generally ranged between 0.01 and 38.36 mg/L. The total nitrogen (TN) and available P (AvP) ranged between 0.01 and 1.70 mgN/L with a mean of 0.01 ± 0.05 mgN/L and 0.06–11.55 mgP/L and a mean of 2.79 ± 0.21 mgN/L. The SOC-pool within KHL wetlands (i.e. has a mean of 11.62 ± 0.72 kg cm^2). The silt:clay ratio ranged between 0.2 and 112.98 and has a mean of 4.73 ± 1.63. According to Asamoa (1973) and Zhang et al. [39], soils of old parent materials (PM) have ratios of <0.25, while those with ratios of >0.25 are of indicative of low degree of weathering. This suggests that despite the restoration efforts the PM of the restored wetlands are at different degree of weathering. The coefficient of variation (CV) varies widely and using the ranged given by Wilding [40], only sand, pHw and pH_{KCl} had CV of <15%, while all other properties had CV > 30% (**Table 2**).

Mean soil physicochemical properties for KHL wetland across pits and transects are presented in **Table 3**. An observation of the mean separation within transects at the KHL wetlands revealed that across transects one and two all soil properties examined were significantly different except pH-water, pH-KCl and total N as well as pH_{KCl} and TN that were not significantly different. An examination of the soil properties across transect three in KHL showed that there all soil properties were not significantly different except pH-water. Mean separation of soil micronutrients in KHL wetlands is presented in **Table 3**. The results showed that the Cu, Fe, Zn and

Variable	N	Maximum	Minimum	Mean	Coefficient of variation	Std dev	Std error	Kurtosis
Khalong-la-Lithunya (KHL)								
Sand	88	87.28	42.28	68.76	14.65	10.07	1.07	−0.83
Clay	88	23.00	0.72	7.71	60.39	4.66	0.50	1.17
Silt	88	44.00	4.00	23.49	38.56	9.06	0.97	−0.76
BD	88	1.67	1.00	1.39	19.61	0.27	0.03	−1.43
pHw	88	5.90	4.00	5.04	8.50	0.43	0.05	−0.58
pH_{KCl}	88	5.62	3.24	4.46	8.62	0.35	0.04	1.23
AvP	88	11.55	0.01	2.79	71.54	2.00	0.21	2.82
Tot. N	88	0.01	1.70	0.01	168.65	0.42	0.05	−0.78
Silt:clay	88	41.67	0.02	5.84	134.27	7.84	0.84	10.62
Org C	88	5.76	1.30	3.92	31.43	1.23	0.13	−0.63
SOM	88	9.96	2.25	6.77	31.43	2.13	0.23	−0.63
C-pool	88	39.90	1.34	11.62	58.14	6.76	0.72	2.68
Ca	88	101.56	3.54	14.61	70.49	10.30	1.10	59.61
K	88	9.63	0.01	0.28	500.93	1.38	0.15	41.03
Na	88	10.64	0.02	3.90	80.84	3.15	0.34	−1.23
CEC	88	8.83	0.02	3.32	86.05	2.86	0.30	−1.34
SSCR	88	112.98	0.2	4.73	322.44	15.26	1.63	41.66
Ha-Matela (HM)								
Sand	80	65.10	9.00	37.22	32.20	11.98	1.34	−0.07
Clay	80	62.10	10.70	10.50	40.12	12.24	1.37	0.14
Silt	80	73.00	0.00	32.86	44.92	14.76	1.65	0.55
BD	80	1.49	1.00	1.34	5.75	0.08	0.01	3.68
pH_w	80	6.15	4.23	5.25	7.80	0.41	0.05	0.12
pH_{KCl}	80	5.34	3.64	4.50	9.03	0.41	0.05	−0.39
AvP	80	15.62	0.56	3.34	73.51	2.45	0.27	7.14
Tot N	80	0.01	0.001	0.01	86.75	0.00	0.00	19.53
Silt:clay	80	5.99	0.00	0.79	147.25	1.17	0.13	6.87
Org C	80	3.21	0.23	2.14	39.77	0.85	0.01	−0.43
SOM	80	5.56	0.40	3.69	39.81	1.47	0.16	−0.44
C-pool	80	38.67	1.44	11.14	62.34	6.95	0.78	2.37
Ca	80	3.30	0.00	0.78	81.21	0.63	0.07	1.66
K	80	0.91	0.10	0.41	42.75	0.18	0.02	0.66
Na	80	1.99	0.03	0.32	163.00	0.53	0.06	2.97
CEC	80	0.18	0.17	0.17	2.72	0.00	0.00	−1.46
SSCR	80	260.00	0.20	31.67	121.42	38.47	4.30	14.58

N = number of observations, Std dev = standard deviation, Std err = standard error, CV = coefficient of variation, OC = organic carbon (%), SOM = soil organic matter(%), BD = bulk density (g/cm^3), pH_W = pH in water, pH_{KCl} = pH in potassium chloride, ΔpH = change in pH, Tot N = total nitrogen(%), AvP = available phosphorus (mg/L), C-pool = carbon pool (kg C/cm^2) CEC = cation exchange capacity (cmol/kg), Na = sodium (cmol/kg), Ca = calcium (cmol/kg), Mg = magnesium (cmol/kg), K = potassium (cmol/kg), SSCR = sand to silt + clay ratio.

Table 2.
Summary statistics of the soil properties at Khalong-la-lithunya *and Ha-Matela wetlands.*

Pits	pH_w	pH_{KCl}	mg/L						Meq/100 g soil	%		kg/m^2	Silt:clay
			AvP	TN	Mg	Na	Ca	K	CEC	SOM	OC	Cpool	
Transect 1													
1	5.5a	4.5a	0.96b	0.89a	16.06b	1.1b	20.7a	0.05c	4.8a	4.0b	2.32b	7.2ab	1.78b
2	5.4a	4.9a	1.84ab	0.70a	18.7ab	5.2a	14.3bc	0.05c	5.6a	5.0ab	2.87ab	10.6ab	2.20b
3	5.2a	4.5a	3.04ab	0.90a	19.8ab	3.0ab	21.2a	9.2a	4.0ab	6.0ab	3.48ab	13.9a	3.07ab
4	5.4a	4.8a	2.10ab	0.77a	22.5ab	6.9a	15.8abc	0.5b	3.1ab	4.1b	2.39b	8.1ab	2.53b
5	5.3a	4.6a	2.67ab	0.38a	18.0ab	6.4a	10.9c	0.08c	2.1bc	7.4a	4.27a	13.7a	2.77ab
6	5.2a	4.5a	3.20ab	0.53a	19.21ab	3.9ab	15.2abc	0.05c	0.06c	3.8b	2.22b	5.6b	3.29ab
7	5.4a	4.8a	1.04b	0.48a	13.9b	6.9a	15.3abc	0.05c	0.06c	5.1ab	2.96ab	7.1ab	4.46ab
8	5.2a	4.5a	1.46ab	0.38a	29.24a	0.4b	18.4ab	0.06c	0.05c	5.4ab	3.14ab	10.0ab	2.88ab
9	5.3a	4.6a	3.81a	1.05a	12.75b	0.1b	13.7bc	0.05c	0.03c	3.6b	2.10b	4.0b	6.75a
Transect 2													
1	4.7bc	4.4b	3.25a	0.23a	17.0a	2.2de	7.1b	0.05bcd	5.9abc	9.0a	5.23a	17.8a	16.98a
2	5.2ab	4.5b	3.32a	0.92a	14.7a	6.1ab	12.7b	0.04bcd	4.1bc	7.9abc	4.6abc	9.4a	5.17a
3	4.8bc	4.5b	2.12a	0.61a	25.5a	5.7abc	9.9b	0.03d	6.7ab	8.7ab	5.0ab	17.4a	13.60a
4	4.7bc	4.2b	2.88a	0.62a	21.4a	0.1e	12.3b	0.04bcd	5.8abc	8.1abc	4.7abc	13.0a	10.19a
5	4.6c	4.2b	2.03a	0.62a	17.4a	0.1e	10.7b	0.04 cd	6.8ab	7.5abc	4.3abc	14.2a	8.11a
6	4.7bc	4.3b	2.89a	1.34a	24.8a	4.0bcd	13.0b	0.05bcd	3.2c	7.4abc	4.3abc	23.9a	1.49a
7	5.0abc	4.4b	2.92a	0.63a	26.1a	5.0abc	11.2b	0.06abc	4.7abc	8.4abc	4.8abc	12.5a	7.56a
8	4.8bc	4.2b	2.83a	0.67a	25.9a	7.1a	11.7b	0.03d	4.1bc	8.3abc	4.8abc	13.4a	2.63a
9	4.7bc	4.3b	1.90a	0.37a	28.6a	7.1a	14.2b	0.06ab	4.2bc	6.1c	3.5c	12.3a	4.78a
10	5.4a	5.1a	3.88a	0.44a	25.6a	0.3e	14.1b	0.05abcd	7.8a	8.6ab	5.0ab	22.9a	1.98a

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Pits	pH_w	pH_{KCl}	mg/L						Meq/100 g soil	%		kg/m^2	Silt:clay
			AvP	TN	Mg	Na	Ca	K	CEC	SOM	OC	Cpool	
11	5.4a	5.1a	3.47a	1.06a	19.0a	3.4 cd	8.7b	0.07a	7.3ab	8.9ab	5.1ab	13.4a	21.98a
12	4.7bc	4.3b	4.88a	0.71a	17.aa	0.1e	56.5a	0.05abcd	3.0c	6.6bc	3.8bc	12.5a	4.50a
Transect 3													
1	5.2a	4.3a	3.74a	0.61a	16.4a	5.7a	16.2a	0.03a	0.05a	7.6a	4.42a	12.4a	5.41a
2	4.6b	4.0a	3.77a	0.93a	23.6a	2.1a	14.4a	0.04a	0.05a	7.5a	4.33a	8.8a	3.55a

Means with same letter in one column are not significantly different at 5% according to Duncan multiple range test (DMRT). pH_w = pH in water, pH_{KCl} = pH in potassium chlorite, AvP = available phosphorus (mg/L), TN = total nitrogen (%), Mg = magnesium (cmol/kg), Na = sodium (cmol/kg), Ca = calcium (cmol/kg), K = potassium (cmol/kg), CEC = cation exchange capacity, SOM = soil organic matter, OC = organic carbon, Cpool = carbon pool.

Table 3.
Mean separation for Khalong-la-Lithunya *soil physico-chemical properties across pits and transects.*

Mn ranged between 0.06–1.49 mg/L, 0.12–2.89 mg/L, 0.04 mg/L and 0.35 mg/L and 4.62–22.15 mg/L. All were statistically significantly different. Ewing et al., [41] reported that wetlands in Juniper Bay were crop production had occurred had in their surface horizons significantly greater amounts of extractable P, Ca, Mg, Mn, Zn, and Cu, along with higher base saturation and pH than soils in the reference bays. Similarly, Zedler and Kercher [16] and Kotze et al. [11] reported that the nutrient-rich soils resulting from agricultural production make wetland restoration more difficult. Thus, the reasons for the slow rate of restoration of the KHL wetlands may be attributed to higher contents of base cations in the surface and subsoils compared to the HM wetlands where no restoration efforts are yet to be embarked upon. Bedford et al., [42], Reddy et al., [43] and Harvey et al. [9] also reported that higher nutrient levels affect restoration success by decreasing plant diversity, and potentially increasing the solubility and export of P from wetlands to downstream waters once anaerobic soil conditions have been restored.

3.2 Summary statistics and characteristics of the restored wetland (*Ha-Matela*) (HM)

The most dominant soil separates in the texture of Ha-Matela wetland soils is silt and it ranged between 14 and 73% with a mean of 32.86 ± 1.65%; sand content ranges between 9.0 and 65.10% with a mean of 37.22 ± 1.34% and clay ranged between 10.7 and 62.10% with a mean of 10.50 ± 1.37% (**Table 2**). The SOC content ranged from 0.23 to 3.21% and has a mean of 2.14 ± 0.01% and the pH which is acidic ranged between 4.23 and 6.15 pH-water and between 3.54 and 5.34 pH-KCl. The CEC and the exchangeable cations (K, Ca, Mg and Na) were very low when compared with the restored wetlands (**Table 2**). This suggests that restoration of wetlands favored built-up of base cations in KHL wetlands as compared to the HM wetlands which are still not being restored. These ions, except for Na, are nutrients for forest ecosystems and vegetation and are thus of importance for the sustainability of the ecosystem [44, 45]. The results of the CVs showed that only a few properties (i.e. pH-water, pH-KCl, BD and CEC had CVs of <15% according to the classification of Wilding [40]. Other soil properties had CVs of >30% suggesting that these are highly variable (**Table 2**). The results of the silt:clay ratios also showed that the PM is mixed (0.00–5.99) and are at different age of weathering (Asamoa 1973; [39]). The SOC-pool in the HM wetlands were not significantly different from those at KHL wetlands and it ranged between 1.44 and 38.67 kg cm^2 with a mean of 11.14 ± 0.78 kg cm^2.

Mean soil physicochemical properties, for *Ha-Matela* wetland, across pits and transects are presented in **Table 4**. The results indicated that the soils are moderately to strongly acidic (pH_{KCl} of 4.94–3.95) and their CEC (≈0.175 $cmol_c$/kg); base cations (Mg ≈ 0.15 mg/L, Ca = 0.2–1.45 mg/L and K ≈ 0.5 mg/L) and total nitrogen (≈0.001 mg/L) are very low, while available phosphorus content (1.9–8.3 mg/L) raises no concern. They are also shown to be less prone to aggregate dispersion as their sodium content (0.01–1.15 mg/L) is very low. Mean separation for micronutrients' content of *Ha-Matela* wetlands is also presented in **Table 4**. The results of the micronutrients status in both wetlands are presented in **Table 5** and showed that the soils contain varying concentrations of micronutrients within and across transects. The Cu content was significantly different ranged between 0.06 and 1.49 mg/L (KHL) and in HM wetland between 1.29 and 4.31 mg/L, but higher compared to the former wetland. Similarly, the Fe contents ranged between 0.2 and 2.89 mg/L IN (KHL), while in HM it ranged between 10.46 and 34.79 mg/L, though higher (**Table 5**). The Zn and Mn contents in HM were significantly different within and across sites, but slightly higher in HM compared to KHL wetlands.

Mini-pits	pH_w	pH_{KCl}			mg/L				$cmol_c/kg$		%	kg/m^2	Silt:clay
			AvP	TN	Mg	Na	Ca	K	CEC	SOM	OC	Cpool	
Upper slope													
1	5.20a	4.24b	8.3a	0.0010a	0.176a	0.09a	0.23a	0.5a	0.18a	4.35a	2.52a	12.24a	0.45a
2	5.90a	4.20b	2.1b	0.0013a	0.178a	0.10a	0.60a	0.5a	0.18a	4.85a	2.81a	15.26a	0.44a
3	5.78a	4.94a	1.9b	0.0015a	0.178a	0.09a	1.05a	0.5a	0.18a	4.43a	2.56a	12.97a	0.43a
Middle slope													
1	4.88a	4.13b	4.0a	0.0014a	0.177a	0.09a	0.20b	0.4a	0.18a	3.62a	2.10a	11.02a	1.40a
2	5.08a	4.36ab	3.3a	0.0013a	0.173b	0.10.0a	0.18b	0.4a	0.17b	3.62a	2.10a	12.17a	0.49a
3	5.10a	4.69a	2.3a	0.0015a	0.174ab	0.09a	0.48a	0.3a	0.17b	3.97a	2.30a	9.33a	1.38a
Toe slope													
1	5.3a	4.59a	2.55a	0.0018a	0.174a	0.11a	0.35ab	0.55a	0.17a	3.65a	2.11a	4.64a	0.23a
2	5.2a	4.58a	2.52a	0.0030a	0.174a	0.10a	0.23b	0.49a	0.17a	2.98a	1.73a	6.85a	0.76a
3	4.8b	3.95b	3.43a	0.0020a	0.174a	0.10a	0.55a	0.36b	0.17a	3.42a	1.97a	8.58a	0.57a
Along stream													
1	5.69a	4.72ab	3.30ab	0.0013ab	0.173a	1.15a	1.28a	0.4b	0.17a	2.94ab	1.70ab	6.67c	0.43a
2	5.36ab	4.88a	2.97ab	0.0013bc	0.174a	0.71ab	1.45a	0.5b	0.17a	4.32a	2.50a	17.25ab	0.37a
3	4.75c	4.23b	2.16b	0.0035ab	0.172a	0.36b	0.62a	04b	0.18a	4.33a	2.50a	15.77abc	0.70a
4	5.31ab	4.55ab	2.56b	0.0012c	0.170a	0.15b	0.80a	0.4b	0.17a	3.96ab	2.29ab	13.05abc	0.45a
5	5.06bc	4.56ab	3.78ab	0.0018abc	0.173a	0.41ab	1.12a	0.3b	0.17a	3.53ab	2.04ab	8.36bc	0.41a
6	5.46ab	4.88a	3.02ab	0.0018abc	0.175a	0.17b	1.38a	0.4b	0.17a	4.37a	2.53a	19.23a	1.23a
7	5.44ab	4.34ab	5.58a	0.0017abc	0.173a	0.73ab	0.88a	0.3b	0.17a	2.05b	1.18b	7.69bc	1.40a
8	5.45ab	4.44ab	2.77ab	0.0037a	0.170a	0.17b	1.05a	0.7a	0.17a	2.98ab	1.72ab	7.45c	0.85a

Means with same letter in one column are not significantly different at 5% according to Duncan multiple range test (DMRT). pH_w = pH in water, pH_{KCl} = pH in potassium chlorite, AvP = available phosphorus, TN = total nitrogen, Mg = magnesium, Na = sodium, Ca = calcium, K = potassium, CEC = cation exchange capacity, SOM = soil organic matter, OC = organic carbon, Cpool = carbon pool.

Table 4.
Mean separation for Ha-Matela *soil across pits and transects.*

Mini-pits	mg/L			
	Cu	Fe	Zn	Mn
Khalong-la-Lithunya				
Transect 1				
1	0.54bc	0.44b	0.12abc	5.87c
2	0.27cd	0.20b	0.08bc	6.20c
3	0.42bcd	2.89a	0.22a	10.30b
4	0.74ab	0.12b	0.07c	4.85c
5	0.31cd	0.20b	0.10bc	14.02a
6	0.41bcd	0.33b	0.08bc	4.62c
7	1.07a	0.29b	0.19ab	6.96bc
8	0.13d	0.19b	0.11abc	7.05bc
9	0.51bc	0.45b	0.10bc	4.65c
Transect 2				
1	0.09b	0.44ab	0.05c	8.02b
2	0.09b	0.40ab	0.25ab	22.15a
3	0.06b	0.63ab	0.09bc	18.00ab
4	0.12b	0.20b	0.24ab	6.28b
5	0.20b	1.02a	0.04c	5.96b
6	0.25b	0.72ab	0.35a	8.14b
7	0.11b	0.54ab	0.04c	6.64b
8	0.17b	0.72ab	0.10bc	10.94ab
9	0.51b	0.51ab	0.09bc	4.77b
10	3.44a	0.76ab	0.22bc	16.81ab
11	0.86b	0.26b	0.11bc	10.76ab
12	0.63b	0.36ab	0.14bc	8.22b
13	0.32b	0.40ab	0.14bc	8.59b
14	1.49b	0.27b	0.11bc	12.14ab
Ha-Matela				
Upper slope				
1	2.85a	10.55a	0.13a	16.82b
2	1.40a	10.46a	0.18a	11.79b
3	2.51a	20.58a	0.26a	33.13a
Middle slope				
1	2.35a	15.57a	0.15b	11.65a
2	1.29b	13.29a	0.12b	14.32a
3	1.85ab	12.82a	0.41a	16.04a
Toes slope				
1	3.19ab	12.41b	0.29b	11.28a
2	2.10b	26.29a	0.10b	12.11a
3	4.31a	34.79a	0.72a	14.04a

Means with same letter in one column are not significantly different at 5% according to Duncan multiple range test (DMRT).

Table 5.
Mean separation for Khalong-la Lithunya *and* Ha-Matela *soil micronutrients.*

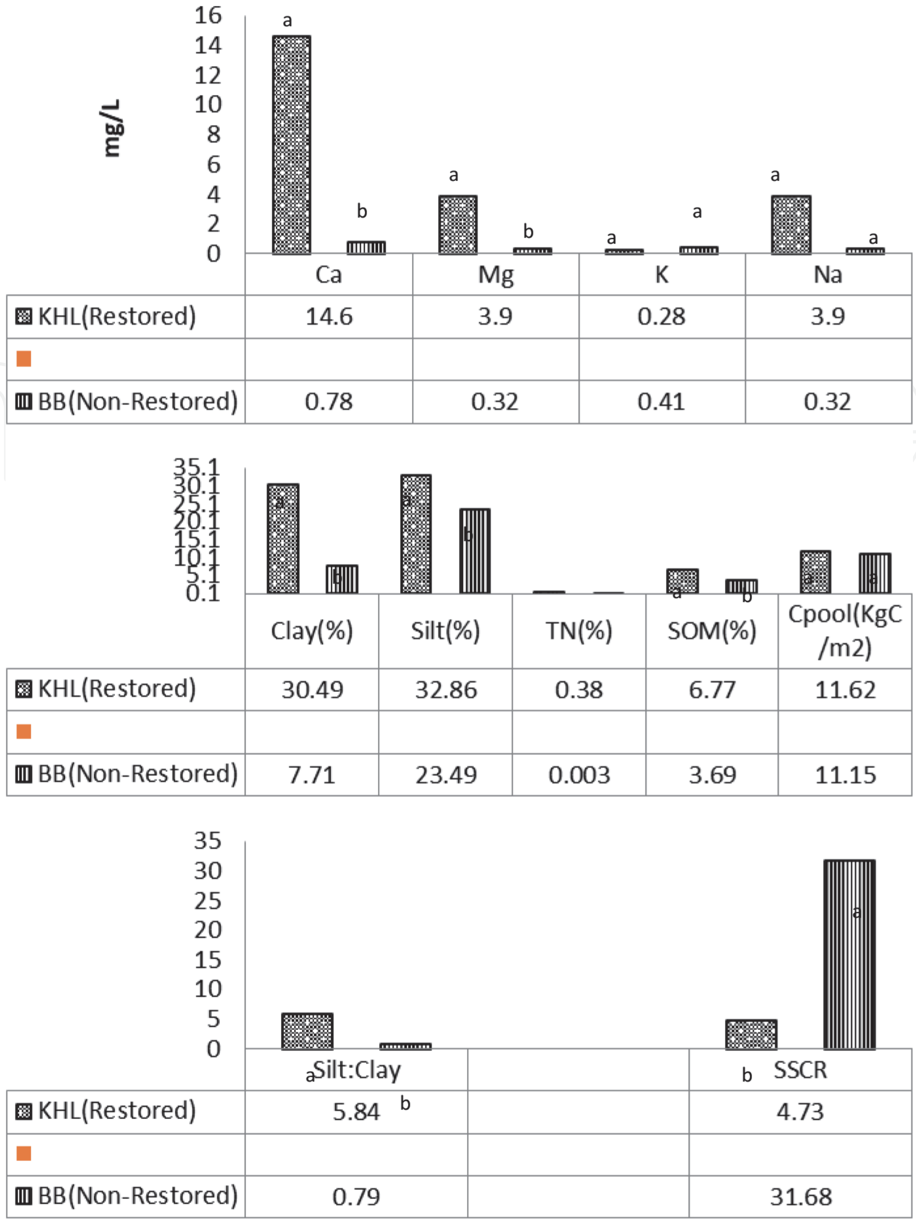

Figure 3.
Mean separation of selected properties from both restored and non-restored wetlands.

3.3 Compassion of sites

Comparing both sites in terms of selected soil physicochemical properties (**Figure 3**), results showed that after 5 years of restoration the significantly higher exchangeable Ca and Mg were observed in the KHL catchments compared to HM. Similarly, significantly higher clay, silts and soil organic matter contents were observed in the former catchments compared to the latter. Higher silt:clay ratio in the KHL suggests that the soil PM are basically of younger age compared to that of the HM. An observation of the SSCR showed that higher values (i.e. 31.68) were observed in the HM compared to the KHL suggesting that the soils of the HM will have better-rooting volumes for the plants grown on it compared to the KHL. This was in agreement with the findings of Napoli et al. [46] and Olaleye et al. [47].

3.4 Seasonal changes in water chemistry

3.4.1 Khalong-la-Lithunya and Ha-Matela

Mean nutrient concentrations in *Khalong-la-Lithunya* and Ha-Matela wetlands runoff-water are presented in **Tables 6** and 7. There were significant differences

Date	Pit	mg/L					
		Ca	Mg	K	Na	Total P	Total N
Transect 1							
Dec'10	1	1.64a	78.86a	5.94b	4.09a	1.74a	0.36a
Feb'11	1	1.63a	0.37b	2.25b	2.89a	0.41b	0.36a
Apr'11	1	0.12c	78.86a	45.07a	2.22a	1.74a	0.003b
Dec'10	2	0.94b	0.37b	1.64b	2.25a	0.24b	0.31a
Feb'11	2	1.41a	0.37b	1.49b	2.25a	0.39b	0.31a
Apr'11	2	0.19c	115.39a	230.7a	3.25a	2.22a	0.004b
Transect 2							
Dec'10	1	0.58a	0.38b	1.25b	2.84a	0.39b	0.11a
Feb'11	1	0.5a	0.37b	1.12b	2.89a	0.34b	0.11a
Apr'11	1	0.28a	101.01a	339.6a	2.65a	2.53a	0.003a
Dec'10	2	0.5a	0.37b	1.05b	1.27a	0.10b	0.18a
Feb'11	2	0.54a	0.37b	1.25b	2.43a	0.38b	0.18a
Apr'11	2	0.16a	75.01a	274.4a	2.44a	2.19a	0.003a
Transect 3							
Dec'10	1	0.32b	0.35b	0.28a	0.20c	0.24a	0.49a
Feb'11	2	0.63a	0.37b	1.36a	2.27b	0.35a	0.49a
Apr'11	3	0.07b	194.49a	153.55a	2.61a	1.84a	0.004a

Ca = calcium, Mg = magnesium, K=potassium, Na = sodium; means with the same letter in one column are not significant at 5% Duncan multiple range test (DMRT).

Table 6.
Nutrient concentrations in water for Khalong-la-Lithunya *wetland.*

Date	mgL					
	Ca	Mg	K	Na	Total P	Total N
Transect 1						
Dec'10	0.002a	0.001a	0.012a	0.015a	1.70a	0.002a
Feb'11	0.002a	0.002a	0.007a	0.009a	1.19a	0.002a
Apr'11	0.002a	0.006a	2.052a	0.003a	0.38a	0.682a
Transect 2						
Dec'10	0.002a	0.001a	0.008a	0.012a	1.84a	0.002a
Feb'11	0.002a	0.004b	0.010a	0.003b	7.23a	0.002a
Apr'11	0.001a	0.002ab	4.017a	0.006a	0.46a	0.687a
Transect 3						
Dec'10	0.002a	0.001a	0.008a	0.013a	2.27a	0.002a
Feb'11	0.002a	0.004b	0.010a	0.002b	2.88a	0.002a
Apr'11	0.002a	0.002b	4.801a	0.004a	0.38a	0.685a

Ca = calcium, Mg = magnesium, K=potassium, Na = sodium, means with the same letter in one column are not significant at 5% Duncan multiple range test (DMRT).

Table 7.
Mean selected water chemical properties for Ha-Matela *wetland transects.*

	mg/L	
Eutrophic status	Total P	Total N
Oligotrophic water	0.005–0.01	0.25–0.60
Moderately eutrophic	0.01–0.03	0.50–1.10
Eutrophic	0.03–0.10	1.10–2.00
Hypertrophic	>0.10	>2.00

Sources: [48–50].

Table 8.
Burden of N and P in various eutrophicated water.

Variables	Surface water quality classification				
	I	II	III	IV	V
pH			6–9		
Total N (mg/L)	≤0.20	≤0.50	≤1.0	≤1.50	≤2.0

Source: [51].

Table 9.
Criteria for surface water quality for lakes and reservoir.

within and across sites. Generally, higher base cations (K, Ca, Mg and Na) could be observed in the KHL compared to the HM wetlands. The total P and total N in both wetlands were very high when compared with the values provided in **Table 8** [48–50]. Both wetlands could be classified as hypertrophic in terms of TN and TP contents (**Table 8**). The surface water quality according to CENPA [51] could be classified in class II (**Table 9**). High N and P in surface water of wetlands is a well-recognized cause of the level of degradation [4, 52]. Th**is** author asserted that much of this N and P delivery is the consequence of changing land use. Omernik et al. [53] compared 175 small watersheds differing in land use and lacking point source inputs. These authors demonstrated that a strong correlation of N and P concentrations occurs with a fraction of land in agriculture. In a related study, Johnson et al. [54] found that in small sub-watersheds of the Saginaw Basin, land use explained over half of the variation in nitrate and TN. In Southern Africa, the threshold of TP in freshwater was estimated to be 0.73 mg/L. However, close observation of **Tables 8** and **9** compared with **Tables 6** and **7** indicated that the water quality of Lesotho's wetlands are excessively enriched and are considered to be highly eutrophic. Eutrophication is generally indicated by accumulation of metabolic products (e.g. hydrogen sulphide in deep waters), discolorations or turbidity of water (resulting in low or poor light penetration), deterioration in the taste of water, depletion of dissolved oxygen and an enhanced occurrence of cyanobacterial bloom-forming species as shown on **Tables 6** and **7** [55, 56].

3.5 Nitrogen and carbon isotopic signatures

The vegetation ^{15}N and ^{13}C isotopic signatures for KHL and HM wetlands are presented in **Table 10**. The result indicates that $\delta^{13}C$ in KHL wetland was higher, indicated by more negative values, compared to that in HM wetland. This shows that the KHL wetland is less degraded compared to HM wetland. Furthermore, results showed that less N is lost in KHL wetlands compared to that at HM. These

Sites	Toposequence	^{13}C (‰)	^{15}N (‰)
Khalong-la-Lithunya	Upper slope	−28.84a*	−2.52a
	Middle slope	−28.90a	−2.97a
	Lower slope	−28.13a	−2.93a
Ha-Matela	Upper slope	−12.72b	2.00ab
	Middle slope	−11.77b	2.61a
	Lower slope	−13.85b	6.18b

**Means with same letter in same column within sites are not significantly different @ 5% (DMRT).*

Table 10.
Isotopic signatures of $\delta^{13}C$ and $\delta^{15}N$ in two wetlands sites.

may be attributed to high overgrazing and over-cultivation observed at HM as opposed to KHL wetland which is now under conservation. A breakdown of the $\delta^{13}C$ and $\delta^{15}N$ within both sites across the toposequence (**Table 10**) showed that there is higher $\delta^{13}C$ in the minimally degraded wetland (KHL) compared with that from HM. Furthermore, the results of the breakdown also showed that less $\delta^{15}N$ is lost from KHL compared to the HM [23, 57, 58]. The variation in the $\delta^{13}C$ across sites can be ascribed to differences in vegetation species. The increased $\delta^{15}N$ in plants is often interpreted as an indicator of sewage or pollution [59, 60]. The HM wetland is still being used for human activities (i.e. livestock grazing and watering and cropping especially maize and sorghum). Therefore, higher $\delta^{15}N$ in the vegetation samples (i.e. 2.00–6.18‰) may as a result of build-up of pollutants. It could be observed that higher $\delta^{15}N$ (i.e. 6.18‰) was observed in the lower slopes/wetlands compared to other section of the toposequence.

4. Conclusion and recommendations

Results of the study showed that higher base cations were observed in the soils and water samples of the KHL wetlands compared to that of the HM wetlands. Also, the results of the isotopic signatures of were significantly higher (i.e. $\delta^{13}C$ and $\delta^{15}N$) in HM wetlands (shown by less negative and high positive values) compared to the KHL wetlands. The result indicated that $\delta^{13}C$ in KHL wetland was higher, indicated by more negative values, compared to that in HM wetland suggesting that the former wetland is less degraded compared to the latter confirming that if other wetlands in the country will revert to their original status if conserved/rehabilitated. Results also showed that both wetlands have higher levels of total N and total P in run-off water samples suggesting that both wetlands can be classified as hypertrophic. However, higher base cations in the soils and water samples of the KHL wetlands may be related more to the geology of the site as this has been under conservation for about 6 years. Avoiding the restoration of agricultural land with high nutrient levels in favor of land with lower amounts of nutrients may increase the likelihood of restoration success.

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References

[1] Mathon B, Coquery M, Miège C, Vandycke A, Choubert J-M. Influence of water depth and season on the photodegradation of micropollutants in a free-water surface constructed wetland receiving treated wastewater. Chemosphere. 2019;**235**:260-270

[2] Makhetha E, Maliehe S. 'A concealed economy': Artisanal diamond mining in Butha-Buthe district, Lesotho. The Extractive Industries and Society. 2020; **7**(3):975-981

[3] Jaramillo F, Desormeaux A, Hedlund J, Jawitz JW, Clerici N, Piemontese L, et al. Priorities and interactions of sustainable development goals (SDGs) with focus on wetlands. Water. 2019;**11**(3):619

[4] Grenfell S, Grenfell M, Ellery W, Job N, Walters D. A genetic geomorphic classification system for southern African palustrine wetlands: Global implications for the management of wetlands in drylands. Frontiers in Environmental Science. 2019;**7**:174

[5] Sieben EJ, Chatanga P. Ecology of palustrine wetlands in Lesotho: Vegetation classification, description and environmental factors. Koedoe: African Protected Area Conservation and Science. 2019;**61**(1):1-16

[6] Wetlands PIU, ESIA MCA-L, DWA. Report on District Stakeholders Workshops Held in Quthing, Butha-Buthe and Mokhotlong Districts on 27th-28th May 2009 and 1st-5th June 2009. Lesotho: Millennium Challenge Account and Ministry of Natural Resources; 2009

[7] Millennium Challenge Account-Lesotho (MCA-L). The Prime Minister Launches the Wetlands Restoration and Conservation Project. 2011. Newsletter Vol. 2. Issue 4.

[8] Gilbert AJ, van Herwijnen M, Lorenz CM. From spatial models to spatial evaluation in the analysis of wetland restoration in the Vecht river basin. Regional Environmental Change. 2004;**4**:118-131

[9] Harvey MC, Hare DK, Hackman A, Davenport G, Haynes AB, Helton A, et al. Evaluation of stream and wetland restoration using UAS-based thermal infrared mapping. Water. 2019;**11**(8): 1568

[10] Konisky RA, Burdick DM, Dionne M, Neckles HA. A regional assessment of salt marsh restoration and monitoring in the Gulf of Maine. Restoration Ecology. 2006;**14**(4): 516-525

[11] Kotze DC, Tererai F, Grundling PL. Assessing, with limited resources, the ecological outcomes of wetland restoration: A South African case. Restoration Ecology. 2019;**27**(3): 495-503

[12] Wantzen KM, Alves CBM, Badiane SD, Bala R, Blettler M, Callisto M, et al. Urban stream and wetland restoration in the global south—A DPSIR analysis. Sustainability. 2019;**11**(18):4975

[13] Bossio DA, Fleck JA, Scow KM, Fujii R. Alteration of soil microbial communities and water quality in restored wetlands. Soil Biology and Biochemistry. 2006;**38**:1223-1233

[14] Niedermeier A, Robinson JS. Hydrological controls on soil redox dynamics in a peat-based, restored wetland. Geoderma. 2007;**137**:318-326

[15] Wilcox DA, Sweat MJ, Carlson ML, Kowalski KP. Awater-budget approach to restoring a sedge fen affected by diking and ditching. Journal of Hydrology. 2006;**320**:501-517

[16] Zedler JB, Kercher S. Wetland resources: Status, trends, ecosystem services, and restorability. Annual Review of Environment and Resources. 2005;**30**:39-74

[17] Cui BS, Yang QC, Yang ZF, Zhang KJ. Evaluating the ecological performance of wetland restoration in the Yellow River Delta, China. Ecological Engineering. 2009;**35**: 1090-1103

[18] Dalle-Laste KC, Durigan G, Andersen AN. Biodiversity responses to land-use and restoration in a global biodiversity hotspot: Ant communities in Brazilian Cerrado. Austral Ecology. 2019;**44**(2):313-326

[19] Jin CH. Biodiversity dynamics of freshwater wetland ecosystems affected by secondary salinization and seasonal hydrology variation: A model-based study. Hydrobiologia. 2008;**1**:257-270

[20] Walker KJ, Stevens PA, Stevens DP, Mountford JO, Manchester SJ, Pywell RF. The restoration and re-creation of species-rich lowland grassland on land formerly managed for intensive agriculture in the UK. Biological Conservation. 2004;**119**:1-18

[21] Robertson HA, James KR. Plant establishment from the seed bank of a degraded floodplain wetland: A comparison of two alternative management scenarios. Plant Ecology. 2007;**188**:145-164

[22] Smith RS, Shiel RS, Millward D, Corkhill P, Sanderson RA. Soil seed banks and the effects of meadow management on vegetation change in a 10-year meadow field trial. Journal of Applied Ecology. 2002;**39**:279-293

[23] Guiry E. Complexities of stable carbon and nitrogen isotope biogeochemistry in ancient freshwater ecosystems: Implications for the study of past subsistence and environmental change. Frontiers in Ecology and Evolution. 2019;**7**:313

[24] Mariotti A. Natural N^{15} abundance measurements and atmospheric nitrogen standards. Nature. 1984;**311**: 251-252

[25] Cheng CH, Lehmann J, Thies JE, Burton SD, Engelhard MH. Oxidation of black carbon by biotic and abiotic processes. Organic Geochemistry. 2006; **37**:1477-1488

[26] Zhang W, Zhang Y-L, Cao F, Xiang Y, Zhang Y, Bao M, et al. High time-resolved measurement of stable carbon isotope composition in water-soluble organic aerosols: Method optimization and a case study during winter haze in eastern China. Atmospheric Chemistry and Physics. 2019;**19**(17):11071-11087

[27] Bernoux M, Arrouays D, Cerri CC, Bourennane H. Modeling vertical distribution of carbon in oxisols of the western Brazilian Amazon. Soil Science. 1998;**163**:941-951

[28] Pironti C, Motta O, Ricciardi M, Camin F, Cucciniello R, Proto A. Characterization and authentication of commercial cleaning products formulated with biobased surfactants by stable carbon isotope ratio. Talanta. 2020;**219**:121256

[29] Rader RB, Batzer DP, Wissinger SA. Bio-assessment and Management of North American Freshwater Wetlands. New York: John Wiley and Sons Inc.; 2001

[30] Stevenson RJ. Using algae to assess wetlands with multivariate statistics, multi-metric indices and an ecological risk assessment framework. In: Rader RB, Batzer DP, Wissinger SA, editors. Bioassessment and Management of North American Freshwater Wetlands. New York: John Wiley and Sons Inc.; 2001. pp. 113-140

[31] Teels BM, Adamus P. Methods of evaluating wetland condition: Developing metrics and indexes of biological integrit. EPA 822-R-01-007f. Washington, DC, U.S.A: U. S. Environmental Protection Agency, Office of Water; 2001

[32] Chipps SR, Hubbard DE, Werlin KB, Haurerud NJ, Powell KA, Thompson J, et al. Association between wetland disturbance and biological attributes in floodplain wetlands. Wetlands. 2006;**26**(2):497-508

[33] McEwan B. Sampling and validity. Annals of the International Communication Association. 2020; **44**(3):235-247

[34] Schmitz G, Rooyani F. Lesotho Geology, Geomorphology, Soils. Lesotho: National University of Lesotho; 1987

[35] Keeney DR, Nelson DW. Nitrogen—inorganic forms. In: Page AL et al., editors. Methods of Soil Analysis: Part 2. Agronomy Monogr. 9. 2nd ed. Madison, WI: ASA and SSSA; 1982. pp. 643-687

[36] Bray RH, Kurtz LT. Determination of total, organic, and available forms of phosphorus in soils. Soil Science. 1945; **59**:39-45

[37] APHA, AWWA, W. P. C. F. Standard Methods for the Examination of Water and Wastewater. 20th ed. Washington, DC: American Public Health Association, American Water Work Association, Water Environment Federation; 1998

[38] Statistical Analysis System. SAS/STAT. Version 8e. Cary, New Caldeonia: Statistical Analysis Institute, Inc.; 1999

[39] Zhang Y, Tigabu M, Yi Z, Li H, Zhuang Z, Yang Z, et al. Soil parent material and stand development stage effects on labile soil C and N pools in Chinese fir plantations. Geoderma. 2019;**338**:247-258

[40] Wilding LP. Spatial variability: Its documentation, accomodation and implication to soil surveys. In: Soil spatial variability; Las Vegas NV; 30 November-1 December, 1984. Proceedings of a Workshop of the ISSS and the SSA. Las Vegas PUDOC: Wageningen; 1985. pp. 166-194

[41] Ewing JM, Vepraskas MJ, Broome SW, White JG. Changes in wetland soil morphological and chemical properties after 15, 20 and 30 years of agricultural production. Geoderma. 2012;**179-180**:73-80

[42] Bedford BL, Walbridge MR, Aldous A. Patterns in nutrient availability and plant diversity of temperate North American wetlands. Ecology. 1999;**80**(7):2151-2169

[43] Reddy KR, Kadlec RH, Flaig E, Gale PM. Phosphorus retention in streams and wetlands: A review. Critical Reviews in Environment Science and Technology. 1999;**29**(1):83-146

[44] Abhilash PC. Restoring the unrestored: Strategies for restoring global land during the UN decade on ecosystem restoration (UN-DER). Land. 2021;**10**(2):201

[45] Draaijers GPJ, van Leeuwen EP, De Jong PGH, Erisman JW. Base cation deposition in Europe—Part II. Acid neutralization capacity and contribution to forest nutrition. Atmospheric Environment. 1997;**31**(24):4159-4168

[46] Napoli RE, Costantini AC, Egidio GD. Using pedostratigraphic levels and a GIS to generate three-dimensional maps of the quaternary soil cover and reconstruct the geomorphological development of the Montagnola Senese (central Italy). Quaternary International. 2006;**156-157**: 167-175

[47] Olaleye AO, Akinbola GE. Gravel, soil organic matter and texture in

fallowed alfisols, entisols and ultisols in south western nigeria: Implications for root & tuber crops. Communications in Soils & Plant Analysis (USA). 2011; **42**(21):2624-2641

[48] Cheng XY, Li SJ. An analysis on the evolvement processes of lake eutrophication and their characteristics of the typical lakes in the middle and lower reaches of Yangtze River. Chinese Science Bulletin. 2006;**51**(13):1603-1613. DOI: 10.1007/s11434-006-2005-4

[49] Likens GE, Bormann FH, Pierce RS. Biogeochemistry of a Forested Ecosystem. New York: Springer-Verlag; 1977

[50] Richardson CJ, King RS, Qian SS, Vaithiyanathan P, Qualls RG, Stow CA. Estimating ecological thresholds for phosphorus in the Everglades. Environmental Science and Technology. 2007;**41**(23):8084-8091. DOI: 10.1021/es062624w

[51] China National Environmental Protection Administration (CENPA). Monitoring and Analysis Methods of Water and Wastewater (in Chinese). 4th ed. Beijing: China Environmental Science Press; 2002

[52] Correll DL. The role of phosphorus in the eutrophication of receiving waters: A review. Journal of Environmental Quality. 1998;**27**:261-266

[53] Omernick JM. The Influence of Land Use on Stream Nutrient Levels. Office of Research and Development Report. Corvallis, Oregon; 1977

[54] Johnson LB, Richards C, Host GE, Arthur JW. Landscape influences on water chemistry in midwestern stream ecosystems. Freshwater Biology. 1997; **37**:193-208

[55] de Villiers S. 2007. The deteriorating nutrient status of the Berg River, South Africa. Water SA. 2007;**33**(5): 659-664

[56] Hallett CS, Valesini FJ, Kilminster K, Wells NS, Eyre BD. A rapid protocol for assessing sediment condition in eutrophic estuaries. Environmental Science: Processes & Impacts. 2019;**21**(6):1021-1037

[57] Dawson TE, Mambelli AH, Plamboeck PH, Templer., Tu, K.P. Stable isotopes in plant ecology. Annual Review of Ecological Systems. 2002;**33**: 507-559

[58] Inglett PW, Reddy KR. Investigating the use of macrophyte stable C and N isotopic ratios as indicators of wetland eutrophication: Patterns in the P-affected Everglades. Limnology and Oceanography. 2006;**51**(5):2380-2387

[59] Ćeranić A, Doppler M, Büschl C, Parich A, Xu K, Koutnik A, et al. Preparation of uniformly labelled 13 C- and 15 N-plants using customised growth chambers. Plant Methods. 2020; **16**:1-15

[60] Cole ML et al. Assessment of d15N isotopic method to indicate anthropogenic eutrophication in aquatic ecosystems. Journal of Environmental Quality. 2004;**33**:124-132