Research Application Summary

Rainfall trends, soil organic carbon and N^{15} isotope status in selected wetlands in Lesotho

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Abstract

This research was carried out in Lesotho to characterize the SOC pool in three different agro-ecological zones of Lesotho. Specific objectives of this research are: (i) to determine the effect of land use on SOC pool; (ii) to establish the role of climatic parameters on soil organic carbon pool; and (iii) to assess the role of primary and secondary soil particles on the physical protection of soil organic carbon. The hypothesis tested is that soil organic carbon pool is significantly influenced by climate and land use, and its permanence is strongly dependent on the physical protection provided by stable aggregates and primary particles. Rainfall was highly variable and therefore unreliable. These wetlands had low soil organic pool, soil organic matter, silt, clay and total nitrogen, suggesting that they are highly degraded.

Key words: Climate change, Lesotho, rainfall trends, soil organic carbon, wetlands

Résumé

Cette recherche a été menée au Lesotho pour caractériser la réserve de carbone organique du sol (SOC) dans trois différentes zones agro-écologiques du Lesotho. Les objectifs spécifiques de cette recherche sont les suivants: (i) déterminer l'effet de l'utilisation des terres sur la réserve du SOC, (ii) établir le rôle des paramètres climatiques sur la réserve de carbone organique du sol, et (iii) évaluer le rôle des particules primaires et secondaires du sol sur la protection physique du carbone organique du sol. L'hypothèse testée est que la réserve de carbone organique du sol est fortement influencée par le climat et l'utilisation des terres, et sa permanence est fortement dépendante de la protection physique assurée par des agrégats stables et les particules primaires. Les précipitations ont été très variables et donc incertaines. Ces zones humides ont des réserves faibles en carbone organique du sol, matière organique du sol, limon, argile et azote total, ce qui suggère qu'elles sont très dégradées.

Mots clés: Changement climatique, Lesotho, tendances pluviométriques, carbone organique du sol, zones humides

Background

Wetlands occur in all agro-ecological zones of Lesotho and are estimated to occupy about 96, 381ha of the total land area (Olaleye and Sekaleli, 2011). The percentage area occupied by the aquuolls, aqualfs, aquents and aquepts are 45, 27, 18 and 9 percent respectively of the total land area. The wetlands in the Lesotho Highlands area largely occur in the headwaters of the Senqu River (Orange River in South Africa), an international watercourse. These wetlands also serve as a critical grazing resource for local farmers. The wetlands in Lesotho support more than 300,000 households through agriculture and fishery activities. There is a growing concern in the highlands about soil erosion due to overgrazing and subsequent soil degradation. Besides localized impact on ecosystems, continued degradation threatens the flow regime in the rivers, and the ecosystems supported by the rivers downstream. Besides localized impact on ecosystems, continued degradation threatens the flow regime in the rivers, and the ecosystems supported by the rivers downstream. There are several issues posing a challenge for water managers responsible for the basin as well as communities relying on the resources of the basin. Internal pressures on watersheds come from relatively high population growth in and around this river basin.

In Lesotho, some of the threats to rivers are livestock watering, weed infestation, agricultural runoff and eutrophication, land reclamation for agricultural uses and sedimentation of wetland beds. As the wetlands dry out during summer periods the exposed substrate becomes covered with vegetation. This is likely to be worsened by climate change. In the 1960s, the Lake Chad had an area of over 25,000 km^2 and by 1976, it reduced to 2,500 km^2. By 2000, it had come down to less than 1,500 km^2, translating into a recession rate of about 500 km^2 per annum (Nagatcha, 2005). This is one of the great consequences of climate change. Based on the above, this study was carried out to determine the trend of climate change and land-uses and its impact on selected wetlands of Lesotho. This research aims to characterize the SOC pool up to 1 m depth in three wetlands located in three different agro-ecological zones of Lesotho. Specific objectives of this research are: (i) to determine the effect of land use on SOC pool; (ii) to establish the role of climatic parameters on soil organic carbon pool; and (iii) to assess the role of primary and secondary soil particles on the physical protection of soil organic carbon. The hypothesis tested is that soil organic carbon pool is significantly influenced by climate and land use, and its permanence is strongly dependent on the physical protection provided by stable aggregates and primary particles.

Materials and Methods

Data were collected from two wetland sites (Table 1). Climate (rainfall) data for the nearest wetlands were collected between 1926 and 2006 from the Lesotho Metrological Services. These data were subjected to cumulative sum (CUSUM) techniques (Beamish *et al*., 1999):

$$\text{CUSUM} = \sum_{ti}^{tf}\left(xt - \bar{x}\right)$$

where xt is the monthly averaged variable at time t (varying between initial t_i and final t_f), and is the variable averaged over the whole period of investigation.

Table 1. Characteristics of wetlands examined.

Agro-ecological zones (AEZ)	Site	Typology of wetlands	Elevation	Co-ordinates (UTM)†	Level of Human impact
1. The Mountains	Butha-Buthe	Lacustrine	2638	3256612.20; 608767.30	Minimal
2. The Foot-Hills	Ha-Matela	Riverine	1820	3261705; 581192.44	Medium

†
UTM, Universal Transverse Mercator.

In CUSUM plots, positive and negative slopes reflect increasing and decreasing trends and it has been used as a tool for detecting intermediate term changes in the mean value of a sequence of regularly spaced observations (Beamish *et al*., 1999). Wetlands were characterized as either lowly or highly impacted wetlands based on local land-use characteristics (Hughes 1995; Stevenson 2001). Low impact wetlands had little (< 5%) or no agricultural activity within 150 m of the wetland boundary; most (80%) of these wetlands were located in the Mountains AEZ. While the highly impacted wetlands had agricultural activity within 10 m of at least one-third (H” 33%) of the wetland boundary (i.e., wetted area) and most of these are located in the Lowlands and Foot-Hills AEZ. Predominant agricultural activities included: (i) ploughing /planting (e.g., wheat or maize), (ii) cattle grazing, and/or (iii) the construction of roads or dikes. Although each of these activities, or combinations thereof, likely has varying impacts on wetland water quality and biota, we assumed that our conservative analytical approach would be reasonably robust for identifying major biological differences between low and high impact wetlands. Two types of wetlands (Riverine and Lacustrine) with varying level of degradation (low, medium and high) located in two AEZ at an elevation of between 1570 – 2638m above sea level (asl) were selected for investigation. Two or three transects (100m length) were chosen per site and mini-pits (0.50m) were dug at intervals of 10m. Climate data (rainfall) for 38 years (1867-2005) were collected form the Lesotho Meteorological Services. These were then subjected to moving average and cumulative sum (CUSUM) procedure (Beamish *et al.*, 1999). This was to evaluate if the rainfall is increasing or decreasing over these wetlands. Soil samples were collected from the demarcated horizons, bagged and air-dried in the laboratory. These were later screened using a 0.5mm and 2mm screens and then analyzed for soil physico-chemical properties (particle size analysis & organic carbon) (Walkley and Black, 1934)) and bulk density by core method. Soil organic carbon pool in these wetlands will be as calculated utilizing relation as given by (Wairiu and Lal, 2003):

C-pool = d x BD x C-content .... (2)

where, C-pool (kg C m^{-2}), d: soil layer thickness (m), BD: bulk density (kg/m^3), C-content (g/g).

The carbon pool in each soil depth was calculated using the above formula. Soil organic matter/silt + Clay) ratio was computed accoording to Pieri (1995) and Olaleye *et al*. (2011). Soil samples were taken to the laboratory for routine analysis (pH-water, total N, available P, K, Ca, Mg and Na). Soil data collected were subjected to Step-wise Discriminant Analysis (SMRA) using SAS (SAS Inst., 1999). Transects measuring 1000m each were chosen in the Palustrine and Lacustrine wetlands and mini-pits (0.50m) dug and soil samples collected at intervals of 200m. In the Riverine wetlands, three land use types (LUTs) were identified: wetlands, cropping and grazing/ pasture. Soil samples were collected from the transects that run across these three LUTs.

Nitrogen-15 application and analysis. Nitrogen (N^{15}) isotope was applied in form of Urea in wetlands located in the Thaba-Putsoa (Lacustrine) and Ha-Matela (Riverine) at the upper-slope (US), mid-slope (MS) and toe-slope (TS). The aim was to estimate the ^{d}C and ^{d}N in the plant samples and quantify the rate at which N applied moves within plants at different section of the toposequence. Plant samples were harvested after six months of applications, bagged, labeled and taken to the laboratory for oven-drying and subsequent grinding. Samples were later sent to the International Atomic Energy Agency (IAEA), Vienna, Austria for the determinations of ^{d}C and ^{d}N in the plant samples. Nitrogen isotopes, which are stable and non-radioactive, were used extensively to follow the dynamics of N in wetland soils and vegetation (Jordan *et al*., 1997). The Nitrogen (N^{15}) isotope was applied in three toposequence positions and replicated three times.

Statistical analysis. Data collected were subjected to descriptive statistics (mean, standard error, maximum, minimum, coefficient of variation (CV), and kurtosis) using the Proc means procedures of the Statistical Analysis System (SAS) (SAS Inst., 1998). The CV was used to evaluate the variability or the homogeneity of the heavy metal concentrations in the study area. Similarly, the analysis of variance (ANOVA), was used to analyse the differences in samples across sites and positions using the General Linear Model Procedure of SAS (SAS Inst., 1998). Means were separated using the Duncan Multiple Range Test (DMRT). Plant samples collected from the N^{15} isotope applied plots were subjected to analysis of variance (ANOVA) using the General Linear Model procedure (PROC GLM) of SAS (SAS Inst., 1998). Means were separated using Duncan Multiple Range Test at 5%.

Results and Discussion

The site characteristics of the wetlands studied are presented in Table 1. Wetlands located in the Mountains AEZ had minimal level of anthropogenic impact, while that in the southern Lowlands AND Foot-Hiulls AEZ had medium to high level of impact.

Rainfall trend. Rainfall trend also showed high variability. According to Smadi and Zghoul (2006), if CV $\geq$ 24%, rainfall is highly variable; 16-24% and moderately variable if $\leq$16%. It could be concluded that the CV of rainfall of Lesotho which was > 58% is highly variable suggesting that rainfall is not reliable. The CUSUM and moving average of rainfall results as shown in Fig. 1 indicated that rainfall had been decreasing at a decreasing rate (Fig. 1).

Physico-chemical properties of the wetlands. Results of physico-chemical property analysis of Ha-Matela wetlands are

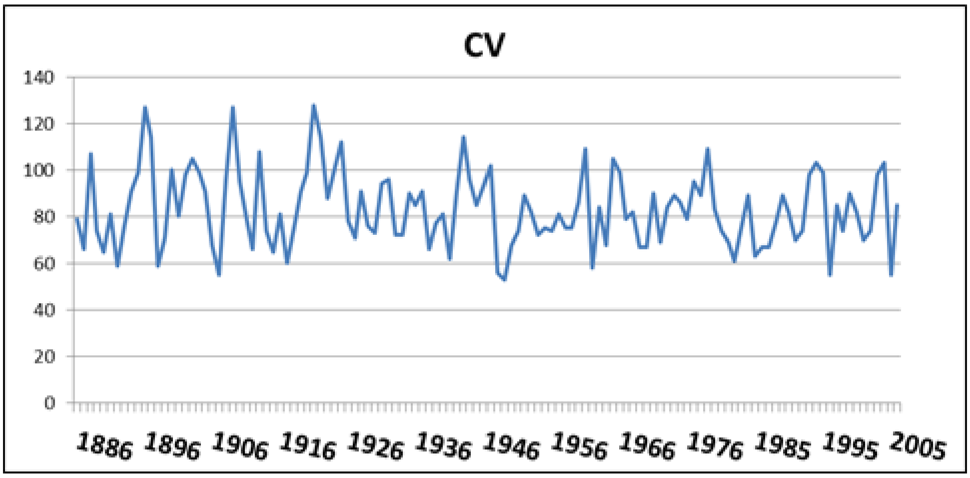

Figure 1. The coefficient of variations of rainfall in Lesotho (1886-2006).

presented in Tables 2a-d. Intrestingly, soils had low to medium contents of electrical conductivity (EC), micronutrients (Fe, Cu, Mn & Zn) and base cations (K, Ca. Mg & Na). The values of soil organic pool and SSCR are low suggestng that these wetlands are highly degraded (Tables 2b and d).

Results of physico-chemical properties of Butha-Buthe wetlands are presented in Table 3. Intrestingly, soils had low to medium contents of electrical conductivity (EC), micronutrients (Fe, Cu, Mn & Zn) and base cations (K, Ca. Mg & Na). It could be observed from the soil organic pool and SSCR that the values were high suggesting that these wetlands were not degraded (Table 3).

Isotope analysis. Results of summary statistics of the Isotope analysis in terms of C and ^{d}N of ^{13}C and ^{15}N is presented in Table 4 for both sites. Results showed that ^{d}C in Butha-Buthe (Minimal degradation) wetlands was higher compared to that in the degraded wetland (Ha-Matela) (Table 4). Furthermore, results showed that less N is lost in Butha-Buthe (BB) wetlands compared to Ha-Matela (HM). A breakdown of the ^{d}C and ^{d}N within both sites across toposequence is presented in Table 5. Results showed that that there is higher ^{d}C in the minimally degraded wetland (Butha-Buthe) compared with that from Ha-Matela. Furthermore, results showed that less ^{15}N is lost from BB compared to the HM (Table 5).

Recommendation

There is no doubt that globally there is a great need to reverse certain significant human-induced stressors to ecosystems

Table 2a. Mean separation for physio-chemical properties of the wetland soil at Ha-Matela for west and east site of the wetland.

PITs	Silt %	Sand %	Clay %	WP cm^3soil	FC cm^3soil	AW cm^3soil	EC mmhos/cm
				Transect 1 (west)			
1	32.000b*	28.300a	39.700a	0.220a	0.265a	0.235a	0.040b
2	28.000b	28.300a	43.700a	0.255a	0.385a	0.135a	0.085a
3	66.000a	19.967a	14.030b	0.1O667a	0.290a	0.180a	0.100a
				Transect 2 (west)			
1	51.600a	29.300b	19.100b	0.1200b	0.2780ab	0.1560a	0.1080a
2	25.000b	41.800ab	33.200a	0.1850a	0.3100a	0.1250b	0.1650a
3	35.500ab	46.800a	17.700b	0.1200b	0.3500b	0.1200b	0.1000a
				Transect 3 (east)			
1	17.000b	40.300a	42.700a	0.2350a	0.3550a	0.1150b	0.1000a
2	37.000a	31.300a	31.700a	0.1850a	0.3350a	0.1400a	0.0800a
3	34.000a	31.300a	34.700a	0.1950a	0.3250a	0.1400a	0.0850a

*Means with same letter in same column are not significantly different @ 5% Duncan Multiple Range Test (DMRT); Key: WP=Wilting Point, FC=Field Capacity, AW=Available Water, EC=Electrical Conductivity.

Table 2b. Mean separation for physio-chemical properties of the wetland soil at Ha-Matela for west and east site of the wetland.

PITs	BD g/cm^3	pHw	pHK	pH Change	OC %	CPOOL *kg C m-*^{2}	SOM%
				Transect 1 (west)			
1	1.285a*	5.910a	4.245b	0.945a	2.515a	124.26a	4.345a
2	0.685a	5.285a	4.195b	0.090a	2.663a	45.03a	4.850a
3	1.427a	5.640a	4.903a	0.737a	2.808a	126.35a	4.603a
				Transect 2 (west)			
1	1.3000a	5.3300a	4.600a	0.7300a	2.1125a	30.12b	3.650a
2	1.3350a	5.2350a	4.560a	0.6750a	1.7250a	68.48ab	2.975a
3	1.3150a	4.7600b	3.940b	0.8200a	1.9725a	86.21a	3.415a
				Transect 3 (east)			
1	1.3000a	5.3300a	4.600a	0.7300a	2.1125a	30.12b	3.650a
2	1.3350a	5.2350a	4.560a	0.6750a	1.7250a	68.48ab	2.975a
3	1.3150a	4.7600b	3.940b	0.8200a	1.9725a	86.21a	3.415a

*Means with same letter in same column are not significantly different @ 5% Duncan Multiple Range Test (DMRT); Key: BD=Bulk Density, pHw=pH Water, pHK= pH KCl, OC=Organic Carbon, CPOOL=Carbon Pool, SOM= Soil Organic Carbon.

Table 2c. Mean separation for Micronutrients of the wetland soil at Ha-Matela for west and east site of the wetland.

PITs	Cu cmol/kg	Fe cmol/kg	Zn cmol/kg	Mn cmol/kg	AvP ppm
			Transect 1 (west)		
1	2.8450a*	10.545a	0.12750a	16.818b	8.302a
2	1.4025a	10.456a	0.18000a	11.787b	2.142b
3	2.5100a	20.581a	0.25667a	33.133a	1.829b
			Transect 2 (west)		
1	2.3460a	15.570a	0.15000b	11.647a	3.640a
2	1.2875b	13.292a	0.11500b	14.323a	3.262a
3	1.8475ab	12.824a	0.41250a	16.043a	2.338a
			Transect 3 (east)		
1	3.1925ab	12.414b	0.2875b	11.277a	2.548a
2	2.1025b	26.294a	0.1025b	12.113a	2.520a
3	4.3100a	34.787a	0.7150a	14037a	3.430a

Key Cu=Copper, Fe= Iron, Zn=Zinc, Mn=Manganese and AvP= Available Phosphorus; *Means with same letter in same column are not significantly different @ 5% Duncan Multiple Range Test (DMRT).

Table 2d. Mean separation for chemical properties of the wetland soil at Ha-Matela for west and east site of the wetland.

PITs	SSCR	S:C	TN Ppm	K cmol/kg	Na cmol/kg	Ca cmol/kg	Mg cmol/kg	CEC meq/100g soil
				Transect 1(west)				
1	0.063a*	0.810b	0.0010a	0.00475a	0.0010a	0.00225a	0.1758a	0.17575a
2	0.073a	0.800b	0.0013a	0.00500a	0.0010a	0.00600a	0.1780a	0.17800a
3	0.057a	5.113a	0.0015a	0.00525a	0.0010a	0.009667a	0.1780a	0.17800a
				Transect 2 (west)				
1	0.0500a	2.752a	0.0014a	0.0036a	0.0010a	0.00475a	0.1768a	0.1768a
2	0.0625a	2.500ab	0.00125a	0.0035a	0.0010a	0.00420a	0.1728b	0.1728b
3	0.0750a	0.900b	0.0015a	0.0025b	0.0010a	0.00175a	0.1735ab	0.1735ab
				Transect 3 (east)				
1	0.06750a	0.3950b	0.00175a	0.00550a	0.00100a	0.00350ab	0.17375a	0.17375a
2	0.04500a	1.4200a	0.00300a	0.00475a	0.00100a	0.00225b	0.17350a	0.17350a
3	0.05500a	0.9900ab	0.00200a	0.00350b	0.00100a	0.00550a	0.17050a	0.17050a

*Means with same letter in same column are not significantly different @ 5% Duncan Multiple Range Test (DMRT); SSCR: Soil Organic Matter: Silt+Clay, S:C, Silt:Clay, TN: Total Nitrogen, K= Potassium, Na= Sodium, Ca= Calcium, Mg=Magnesium, CEC= Cation Exchange Capacity Organic Matter: Silt+Clay, S:C, Silt:Clay, TN: Total Nitrogen, K= Potassium, Na= Sodium, Ca= Calcium, Mg=Magnesium, CEC= Cation Exchange Capacity.

Table 3. Physico-chemical properties of the soils at Butha-Buthe.

Sand	Silt	Clay	Silt/ clay ratio	Bulk density	Water potential	Field capacity	Available water capacity	Electrical Conductivity	pHw	pHKcl	ÄpH
—— % ——				g/cm^3	— —	cm^{3}soil	— — —	mmhos/cm			
64.5	10.9	24.6	0.44	1.55	0.13	0.20	0.11	0.09	4.30	4.92	-0.62
Available P	Orga-nic C	Carbon-pool	SSCR	K	Ca	Mg	Na	ECEC			
mg/kg	%	kg C m-^{2}			— — —	c mol/kg	— — — —				
6.67	17.7	785.5	40.23	0.23	0.44	0.97	0.40	2.04			

*SSCR= Soil Organic matter/(Silt+ Clay ratio).

Table 4. Summary statistics for ^{d}C and ^{15}N within two wetlands sites in Lesotho.

Sites	Max	Min	Mean	Kurtosis	Coefficient of variation (%)
	— — — — —	— — — — —	$^{\delta}$C	— — — — —	— — — — —
Butha-Buthe	50.3	39.27	45.12	-1.2	8.65
Ha-Matela	44.14	30.09	39.50	-0.62	13.19
	— — — — —	— — — — —	^{15}N	— — — — —	— — — — —
Butha-Buthe	1.46	0.81	1.28	4.25	15.5
Ha-Matela	1.91	0.75	1.16	1.93	30.10

Table 5. Mean separation of ^{d}C and ^{15}N within two wetlands sites in Lesotho within each of the Toposequences.

Sites	Toposequence	$^{\delta}$C	^{15}N
Butha-Buthe	Upper slope	43.50a*	41.17ab
	Middle slope	49.36a	33.59b
	Lower slope	42.50a	43.73a
Butha-Buthe	Upper slope	1.35a	1.04ab
	Middle slope	1.39a	0.98b
	Lower slope	1.10a	1.45a

*Means within same letter in same column within same site are not significantly different at 5% (DMRT).

including drainage, flood control, and unsustainable development. We can do this by undertaking wetland restoration programs and implementing sustainable ecosystem management plans now as we continue to work on the task of reducing CO_2 emissions and reversing existing climate change trends. The following global recommendations are offered to scientists, practitioners and policymakers to provide some perspective as well as a stimulus for discussion with a goal toward developing a new direction for global wetland conservation in a changing world:

Significantly reduce non-climate stressors on ecosystems. The reduction of stressors causes by human activities will increase the resiliency of habitats and species to the effects of climate change and variability. In essence, this situation is what good management already seeks to accomplish. However, a changing climate amplifies the need for managers to minimize effects these stressors have on wildlife populations.

Protect coastal wetlands and accommodate sea level change. Impacts of sea level rise can be ameliorated with acquisition of inland buffer zones to provide an opportunity for habitats and wildlife to migrate inland. Setback lines for coastal development can be effective at establishing zones for natural coastal migration based on projected sea level rise. Storm surge should be considered in establishing buffer zones and setback boundaries. In other cases, restoration of natural hydrology could facilitate sediment accretion and building of deltaic coastal wetlands.

Monitoring. Monitoring is an essential element of ecosystem management, in that it is intended to detect long-term ecosystem change, provide insights to the potential ecological consequences of the change, and help decision makers determine how management practices should be implemented. Monitoring may be used as a starting point to define baseline conditions, understand the range of current variability in certain parameters and detect desirable and undesirable changes over time within reserve areas and adjacent ecosystems.

Training restoration scientists and practitioners. There will be a great need to monitor, design and implement wetland restoration and management projects globally on a large scale. Currently we have no global plan for improving expertise in these areas.

Invasive species control. Rapidly changing climates and habitats may increase opportunities for invasive species to spread because of their adaptability to disturbance. Invasive species control efforts will be essential, including extensive monitoring and targeted control to preclude larger impacts.

Wetland restoration and management must incorporate known climatic oscillations. Short-term periodic weather phenomena, such as El Niño, should be closely monitored and predictable. By understanding effects of periodic oscillations on habitats and wildlife, management options can be fine-tuned. For example, restoration of native plants during the wet phase of oscillations, avoiding the drought phase, could make the difference between success and failure.

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