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Mapping spatial variability of hydric soil properties to delineate Khalong-la-lithunya wetlands

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ABSTRACT
Spatial variability in wetland soils provide insight into underlying ecosystem processes and may itself give an indication of wetland condition. The study was conducted to characterise and delineate soil variability of wetlands of Khalong-la-Lithunya from hydric soil properties. Sampling was carried on three sub catchments within Khalong-la-Lithunya catchment. In each sub catchment soil samples were dug at 100m interval along three transects that were 200m apart. Detailed soil profile description of 36 pits was done following USDA-NRCS (2010) manual. Soil samples were collected to the depth of 90 cm at 15 cm interval and analyzed for soil organic carbon (SOC), Base Cations (Ca^{2}+, Mg^{2+}, Na^{+}, K^{+}) and Cation Exchange Capacity (CEC), available Phosphorus (Av-P), available Nitrogen (Av-N), Soil pH, percentage sand, clay and silt. Mean soil properties were 3.5 mg/kg Av-p, 3.0 mg/kg Av-N, 28.3 % SOC, 5.1 pH, Bulk density 0.7 g/cm3 and the texture is sandy. The means base cations were 2.8, 1.8, 7.9 and 2.3 cmol/kg for Na, K, Ca and Mg, respectively and CEC 82.5 cmol/kg. Av-P was the most variable property with CV ranging from 115 and 162 % in different soil depths while pH was the least variable with CV ranging from 6 and 12 %. The Nugget/Sill ratios were less than 56 %, indicating random heterogeneity. The semivariograms indicated moderate spatial dependence ($25 < DSD \leq 75\%$) for soil properties including SOC, Av-P, Av-N, pH and sand. Most properties indicate moderate spatial dependence and hence easily managed. Chemical properties were more variable than physical properties.

Keywords: Heterogeneity degradation, Lesotho, semivariogram geostatistics, wetlands spatial variability

RÉSUMÉ
La variabilité spatiale dans les sols humides permet de comprendre les processus écosystémiques et peut donner une indication des conditions de milieux humides. Cette étude a été conduite pour caractériser et différencier la variabilité des milieux humides de la région Khalong-la-Lithunya à partir des propriétés hydriques du sol. L'échantillonnage a été fait dans trois sous bassins versants dans la région Khalong-la-Lithunya. Dans chaque sous bassin versant, des échantillons de sol ont été creusés à 100 m d'intervalle le long de trois transects à 200 m d'écart. Une description détaillée du profil du sol a été effectuée suivant la méthode décrite dans le manuel USDA-NRCS (2010). Les échantillons de sol ont été prélevés à intervalle de 15 cm jusqu'à une profondeur de 90 cm et analysés pour évaluer le carbone organique du sol (COS), les cations de base (Ca2 +, Mg2 +, Na +, K +) et la capacité d'échange cationique, Phosphore disponible, Azote Disponible, pH du sol, pourcentage de sable, argile et limon. Les propriétés moyennes du sol étaient de 3,5 mg / kg P, 3,0 mg / kg N, 28,3% COS, 5,1 pH, densité apparente 0,7 g / cm3. Les valeurs moyennes des cations de bases étaient de 2,8, 1,8, 7,9 et 2,3 cmol / kg pour le Na, K, Ca et Mg, respectivement, et de 82,5 cmol / kg CEC. Le Phosphore était la propriété la plus variable avec un coefficient de variation variant de 115 à 162% à différentes profondeurs du sol, tandis que le pH était moins variable. Les semi-variogrammes ont indiqué une dépendance spatiale modérée pour les propriétés du sol, y compris COS, P, N, pH et sable. La plupart des propriétés indiquent une dépendance spatiale modérée. Les propriétés chimiques étaient plus variables que les propriétés physiques.

Mots-clés: Dégradation de l'hétérogénéité, Lesotho, géostatistique du semi-variogramme, variabilité spatiale des zones humides

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BACKGROUND

Wetlands are considered as areas that have hydrophytic vegetation, hydric soils, and wetland hydrology which can exhibit substantial spatial and temporal variability in soil properties (Grunwald *et al.,* 2006). In Lesotho, wetlands are located in mountain rangelands and are beneficial to local communities for the purposes of grazing, water provision and medicinal plants (Nkheloane *et al.,* 2012). In addition, these wetlands play pivotal role in biogeochemical processes including nutrient cycling, elements redistribution and toxicant retention and sustaining the perennial water flow and at the same time regulating the water quality of the major Senqu-Orange River system (ORASECOM, 2000). Available evidence shows that wetlands in many countries including Lesotho are degrading at a fast rate and are consequently losing their essential ecosystem and socio-economic values. However, the extent of wetlands degradation is not fully known, in terms of areal coverage and health status. Zhao *et al.* (2013) ascertained that best management of degraded land can be done by evaluating the spatial variability of soil properties.

LITERATURE SUMMARY

Spatial variability is the considerable differences in space in soil properties that can be attributed to systematic or random factors that can exist within a wetland area (Wilding and Drees, 1983; Stolt, 2001). In wetland systems this variability is due to numerous factors, including micro-relief, animal activity, human activity, and the effect of individual plants on soil microclimate and precipitation chemistry (Kavianpoor *et al.,* 2012; Panagopoulos *et al.,* 2015). Spatial variation includes horizontal variation across a landscape and vertical variation with horizon depth (Baharom *et al.,* 2015). Zhao (2007) reported that spatial variability of soil chemical and physical properties are affected by graze intensity and heavy grazing decreases soil water content and soil organic carbon but increases bulk density and shear strength.

Soil properties with strong spatial dependence are more readily managed (Nkheloane *et al.,* 2012). Classical statistics and geostatistical methods have been widely applied in studies about spatial distribution of soil properties such as coefficient of variation and range (Tesfahunegn *et al.,* 2011). Best management of degraded land can be done by evaluating the spatial variability of soil properties including chemical properties of degraded land and mapping such variations (Zhao *et al.,* 2013). Thus, understanding the patterns and processes of soil spatial variability is a key to efficient soil resource management (Ziadat and Tamimeh, 2013). Knowledge of soil spatial variability is also necessary to locate homogenous sites that need careful management for sustainable development. However, there are few studies on wetlands soil variability in Lesotho. Additionally, limited attention has been paid to the use of hydric soil spatial variability to evaluate ecological functioning of wetlands. Therefore the objectives of this study were to determine spatial variability and dependence of hydric soil properties and delineate Khalong-la-Lithunya wetlands.

MATERIAL AND METHODS

Study description. The study was conducted on three sub catchments within Khalong-la-lithunya catchment located in the mountain agro-ecological zone of Lesotho (Fig.1). Sampling design showing transection demarcation within sub catchment is shown on (Fig.2). The geology of the catchment is Lesotho formation with compact and amygdaloidal tholeiitic basalt (Schmitz and Rooyani, 1987). The catchment is mainly used as rangeland and is sparsely populated by herd boys and people on work camps. The mean annual rainfall often recorded is 1000-3000 mm. The temperature ranges from 7.6 - 22.4°C and snowfalls are common in winter.

Data analysis. The General linear model procedure (Prog GLM) SAS Inst., (1999) was carried out to establish statistical difference between depth and mean separation was carried out using Duncan's Multiple Range Test (DMRT) at 5% significance level. The coefficient of variation (CV) was employed to assess degree of variability for each soil property within each depth.

Statistical and geostatistical analysis. The data on soil properties were imported to the Geostatistical Analyst tool (ArcGIS 10.2.2) and subjected to descriptive analysis. Prior to geostatistics, a preliminary analysis was done to check data normality and global directional trends. Non-normal data were transformed using Natural

Logarithm and Box-Cox methods. Geostatistical methodology is based on the creation of a semivariogram defined by the Equation below (Ayoubi *et al.* (2007).

$$\gamma\,(h) = \frac{1}{2\,N\,(h)} \sum_{i=1}^{N\,(h)} [\,Z\,(Xi + h) - Z(Xi)]^2$$

Where γ (h) is the experimental semivariogram value at a distance interval h, m(h) is the number of sample value pairs within the distance interval h, $Z(X_i)$, $Z(X_i + h)$ are sample values at two points separated by the distance h. Using the Geostatistical Analyst tool (ArcGIS 10.2.2) and selecting the Ordinary Kriging methods, a semivariogram was created for each measured property using best evaluated fitting semivariogram functions with appropriate semivariogram models.

RESULTS AND DISCUSSION

Descriptive statistics of soil the properties in top 15 cm depth. The descriptive statistics of the soil properties within the top 15 cm depth are given on Table 1. A wide range was observed for SOC, which ranged from 1.95 to 81.57 with a mean of 25.41%. Values for Av-N ranged from 0.91 to 5.56 with a mean of 4.01 (mg/kg) and Av-P ranged from 0.05 to 21.27 with a mean of 2.40 (mg/kg). The low contents of available P may be attributed to high contents of Al and Fe-oxides coupled with a low pH (Mapeshoane, 2013). Low and high Av-N may be explained by wetland conditions as under anaerobic condition, soil organic matter (SOM) decomposition could have been low and hence more of the N fraction increased (Varennes, 2003). Mineralization of nitrogen under aerobic conditions enhanced an increase in Av-N which is quickly taken by plants and others are lost through denitrification and leaching. The maximum values of chemical properties were obtained at the interior of the catchment. The pH ranged from 4.37 to 5.88, indicating very strong acid to medium acidity. Similar soil pH levels were reported by Mapeshoane (2013) for Bokong wetlands soils in Lesotho. Schmitz and Rooyani (1987) attributed the high levels of organic matter in the mountain soils of Lesotho to the lower temperatures and evaporation. Cold temperatures lower the rates of decomposition of organic matter and result in high accumulations that are reflected on the organic carbon levels of the surface horizons with a mean of 25.41% (Table 1).

According to classification of coefficient of variation proposed by Wilding and Dress (1978), all soil chemical properties had high coefficient of variation (CV) except for CEC, Av-N, percentage sand, clay and silt with moderate variability. Soil pH had least variability with CV of 7%. Similar pH values were obtained in several studies including the study of Kavianpoor *et al.,* 2012 and Panagopoulos *et al.*, 2015. The Av-P was the most highly variable soil property with CV of 115%. In general, the study revealed that chemical soil

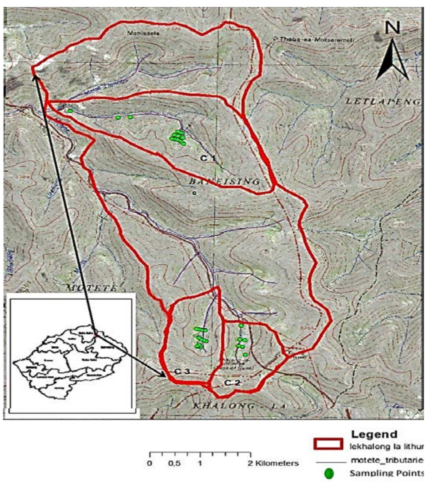

Figure 1. Location of Khalong-La-Lithunya in the Map of Lesotho and sampling points in three sub-catchments

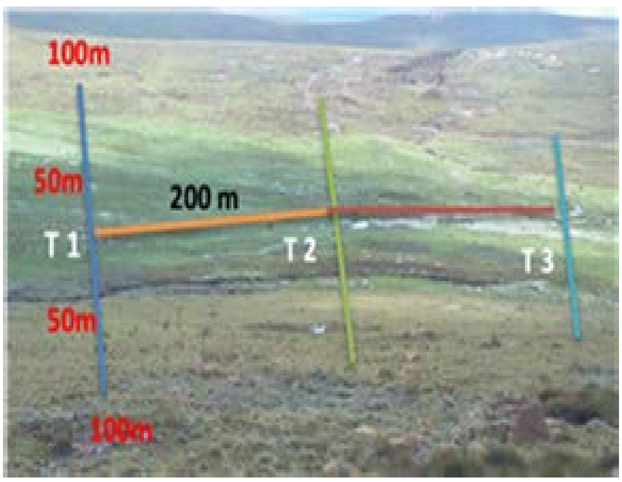

Figure 2. Sampling design showing transection demarcation within sub catchment (wetland)

properties were more variable than soil physical properties. Nkheloane *et al.* (2012) also reported similar observation from two contrasting wetlands of Lesotho.

The descriptive statistics of the soil properties of the study sub catchments also revealed moderate to high skewness for some soil properties. The SOC, Av-P, BD, and silt to clay ratio were highly skewed while others were approximately normally distributed. The local distribution was indicated by highly skewed soil properties with mostly low values and some high values at some sampling points (Tesfahunegn *et al.,* 2011). Soil properties with high skewness portrayed high kurtosis values exceeding a range between -3 to 3 for normal distribution (Table1). The normal or non-normal distribution of soil properties may be attributed to topography, vegetation cover, anthropogenic activities such as grazing and other management practices that may impose the variability.

The spatial dependency and distribution of soil properties. The results of geostatistical analyses of the soil properties showed their spatial dependence and fitted to different models (Table 2). All measured soil properties exhibited smaller range values, ranging from 0.001 to 0.017 m and this indicated that the soil was more disturbed. Tesfahunegn *et al.* (2011) reported that soil variables with smaller range are good indicators of the more disturbed soils. However, large range indicates that the measured soil parameter value is influenced by natural and anthropogenic factors over greater distances than parameters which have smaller ranges (Ayoubi *et al.,* 2007). The different ranges of the spatial dependence among the soil properties may be attributed to differences in response to the erosion–deposition factors, land cover, topography and parent material and human and livestock interferences in the wetland. In this study, the semivariograms indicated moderate spatial dependence ($25 < DSD \leq 75\%$) for SOC, Av-P, Av-N, pHw and sand; and the silt and silt/clay exhibited weak spatial dependence (DSD >75). The moderate spatial dependence of the soil properties may be controlled by extrinsic variations brought about anthropogenic factors (management practices). Clay exhibited a strong spatial dependence ($DSD \leq 25\%$). The strong spatial dependence of the properties may be controlled by the intrinsic variations in soil features including texture and mineralogy (Cambardella *et al.,* 1994). Properties with moderate and strong degree of spatial dependence are readily managed.

Table 1 Statistics of soil properties in the 0–15 cm soil depth across Khalong-la-Lithunya Catchment

Variable	N	Min	Max	Mean	SD	CV	Skewness	Kurtosis
SOC %	35	1.95	81.57	25.41	15.97	63	1.19	5.58
Av- P (mg kg-1)	35	0.05	21.27	4.01	4.62	115	2.00	7.54
Av-N (mg kg-1)	35	0.91	5.56	2.40	1.13	47	0.94	3.48
Ca (cmol kg-1)	31	352.8	3014.0	1652.6	648.1	39	0.19	-0.76
Mg (cmol kg-1)	7	147.2	463.8	294.0	120.2	41	0.17	-1.07
K (cmol kg-1)	26	173.0	2662.7	1102.3	792.5	72	0.46	-1.25
Na (cmol kg-1)	20	249.8	1512.7	831.1	341.5	41	0.29	-0.47
CEC (cmol kg-1)	7	67.8	97.4	85.2	12.2	14	-0.83	- 1.15
pHw	35	4.37	5.88	5.00	0.33	7	0.12	3.29
BD (g cm-3)	35	0.24	1.37	0.58	0.30	52	1.17	0.49
SAND %	35	42.12	85.01	60.34	10.29	17	0.54	2.52
CLAY %	35	6.00	24.00	16.16	4.42	27	-0.56	2.39
SILT %	35	8.00	42.35	23.50	8.28	35	-0.18	2.57
SILT / CLAY	35	0.61	4.96	1.57	0.91	58	2.62	10.29

† N = number of observations; Min = minimum. Max = maximum. SD = standard deviation. CV = coefficient of variation (%). Skewness provides an indication of symmetry, and a value of 0 indicates perfectly symmetrical distribution and values between -1 and +1 is considered approximately symmetric (normally distributed) for field data (Ott, 1977). ‡SOC – Soil organic carbon; Av-P – Available Phosphorus; Av-N – Available Nitrogen; pH water – soil pH in water; BD = - bulk density; Ca -Calcium; Mg - Magnesium; K - Potassium; Na - Sodium; CEC – Cation exchange capacity.

Table 2. Model parameters used to find the best semivariogram to predict soil parameter in Khalong La Lithunya catchments

Variables	Model	C_0	C_1	$C_0 + C_1$	RANGE	DSD (%)	SDL	MSE	G (%)
SOC	E*	141.48	190.23	331.71	0.001	43	Moderate	15.41	52
AV- P	E*	14.76	15.67	30.43	0.013	49	Moderate	4.38	56
AV-N	R-Q	0.50	1.30	1.8	0.007	28	Moderate	1.00	1
pHW	C	0.05	0.09	0.14	0.009	36	Moderate	0.31	7
Sand	J-B	42.99	43.22	86.21	0.002	50	Moderate	8.54	7
Clay	R-Q	6.24	20.75	26.99	0.012	23	Strong	3.72	6
Silt	J-B	52.72	16.92	69.64	0.001	76	weak	7.78	14
Silt/clay	R-Q*	0.82	0.05	0.87	0.017	94	weak	0.95	3

*Log and **Box-Cox transformation for normal distribution. Av-P = Available Phosphorus (mg/kg), Av-N =Available Nitrogen (mg/kg), SOC soil organic carbon (%), pHw = pH in water. BD = Bulk density (g/m-3), S= Stable, H-E =Hole-Effect, C = Circular, G = Gaussian, Sp = Spherical, K-B = K-Bessel, J-B =J-Bessel, T = Tetraspherical, E = Exponential, R-Q = Rational Quadratic. C_0= nugget effect; C_1= partial sill, C_0+ C_1= sill; DSD = $C_0/(C_0+ C_1)$ DSD: degree of spatial dependence; strong DSD (DSD ≤ 25%); moderate DSD (25 < DSD ≤ 75%); weak DSD (DSD > 75%) according to Cambardella *et al.* (1994). MSE = mean square error.

Ordinary Kriged map of soil properties. Spatial analysis indicated spatial variability of soils across the catchment. The semivariogram parameters were used for kriging that produced an interpolation map of the soil properties (Kriged maps are not given). From the spatial distribution map, SOC ranged from 5.9 to 49.8, with higher values in the eastern part (upper slope) and lower values in mid slope of sub catchment 1. In both sub catchments 2 and 3 higher values of SOC were obtained in the central part of the catchments ranging from 5.6 to 20.0% and 18.2 to 47.8 for sub catchment 2 and 3. Low SOC values were associated with severe degradation due to erosion and triggered SOC losses by enhancing high rate of decomposition. Loss of organic matter is expected as a result of soil aging and normal decomposition by a diverse community of invertebrates, microbes and physical processes (Yang *et al.,* 2011). Higher SOC values in the central part indicated wetter area (anaerobic condition) with low soil organic matter decomposition.

High value of Av-N were obtained at central to bottom slope with a decreasing trend from upper slope in all sub catchments ranging from 1.58 to 4.00, 0.56 to 3.10 and 1.03 to 5.24mg/kg for sub catchment 1, 2 and 3, respectively. This may be explained by leaching of Av-N leading to high content of such properties in the central to bottom part of the catchment. Under anaerobic condition, which is the case of the central part (wetter), soil organic matter (SOM) decomposition was low and hence more of the N fraction increased (Varennes, 2003).

The mineralization of nitrogen under aerobic conditions enhances an increase in Av-N but quickly taken by plants and others are lost through denitrification and leaching. Lower values were also attributed to high soil erosion that could have triggered OM decomposition and hence loss of nitrogen. The spatial distribution of Av-P exhibited low values at the central part and high values were obtained at upper and bottom part of sub catchments ranging from 0.30 to 5.41, 0.41 to 3.05 and 1.1 to 20.3 mg/kg for sub catchment 1, 2 and 3, respectively. Generally, Av-P depicted a decreasing trend with slope. Lower values at the bottom suggested that the wetland released less phosphate into the river bodies and thus implying good performance of the wetlands.

Ewing *et al.* (2012) observed increased solubility of excess P in a drained wetland as compared to natural wetland soils. However, increased solubility of residual P when wetland hydrology and anaerobic soil conditions are restored may degrade water quality. Low contents of available P may be attributed to high contents of Al and Fe-oxides coupled with a low pH that could lead to adsorption and precipitation of P. According to Fiedler *et al.* (2004), under reduced conditions P is mobilised and accumulates above the water table. This is as a result of increased solubility of Fe upon reduction, thereby releasing higher concentrations of adsorbed and precipitated P to the soil solution.

High pH values occurred in the middle of sub catchment 1 and 2 while low pH values occurred in the borders of sub catchments parts with sub catchment 3 having irregular soil pH distribution. Low soil pH in hydric soils may be associated with

H+ dissociation from acid parent material and organic acids during aerobic phase of ferrolysis (Behera *et al.,* 2016). Generally, the soil pH ranged from 4.47 and 5.86 in the study catchment. Bulk density varied considerably within the catchment and low and high values were obtain in different parts of the catchment ranging from 0.42 to 1.15, 0.34 to1,35 g/cm3. The central parts of sub catchment were dominated by fine textured soils (silt and clay) while the upper and bottom slope were dominated by coarse textured soils (high percentage sand). The coarse texture soils allow for more leaching, thus under similar conditions the soil pH of coarse textured soil is usually lower than that of the fine texture soils.

Vertical distribution of selected soil properties in the catchment. The mean, standard deviation and coefficient of variation of SOC, Av-P, Av-N, pHw, BD and base cations (Na, K and Ca), as well as sand, clay, silt and silt/ clay at a depth increment from 0 to 90 cm are presented in Table 3. Soil organic carbon was not significantly different throughout the profile. The profile has the mean SOC of 28.3% and this level was associated with partial decomposition of organic material due to anaerobic conditions that slow down the decomposition rate leading to accumulations and formation of peat (Mapeshoane. 2013). However, SOC exhibited high variation within each depth with CV higher than 60%.

The Av-P profile mean was 3.5 mg/kg and was not significantly different between depths. However, it showed inconsistent trend and tended to increase at lower depths. The distributions and dynamics of P forms in soil, especially in wetlands, can be significantly impacted by various biogeochemical and environmental factors such as soil moisture, soil organic matter, and clay content (Bai *et al.,* 2010). Yang *et al.* (2011) also observed high P values in topsoil to decrease with depth which reached their minima at 60 cm depth and increased again. Aldous *et al.* (2005) revealed that, under aerobic conditions, which is in the case of topsoil available P is subjected to iron adsorption and retention but down the profile the conditions turn into anaerobic and thus enhance the release of more phosphates. Av-P was the most highly variable soil property within depths. On the other hand Av-N profile mean was 3.0 mg/kg and significantly higher in the middle depth of 30-45 cm with moderate to high variability with CV ranging between 35 to 46%.

The mean soil pH of the profile was 5.1 and increased slightly from 5.0 to 5.2 from the surface layer down the profile. The pH was strongly acidic (Osuaku *et al.,* 2014). This could be explained by constant leaching by rainfall which leaves the soil saturated with more Al^{3+} and H^{+}. An increment in soil pH in deeper horizons indicated accumulation of bases. Soil pH was the least variable soil property and similar result for pH were also registered by Kaviapoor *et al.* (2012); Amuyou *et al.* (2013) and Panagopoulos *et al.* (2015). The mean bulk density for the profile was 0.7 g cm^{-3}. All the soil properties were moderate to highly variable except the soil pH. AV-P was the most variable property and only Av-N differed significantly between depths. Bastviken (2006) studied factors influencing spatial and temporal variations, and found out that available nitrogen was influenced by environmental factors such as alternate period of wetting and drying, level of water table, pH, water chemistry and other wetland conditions including climate, water depth and water flow. In the study of Yang *et al.*(2006), the results designated significant declines in available N and P concentration in soil solution that occurred with increase in depth, and reached their minima at 60 cm depth, except for available N, which increased with depth. Most nutrients changed much from 20 to 40 cm along the depth. Yang *et al.* (2006) further showed that soil at 0–60 cm depth was the active rhizoplane, with strong capability to remove the nitrogen and phosphorus in aquatic-terrestrial ecotone.

CONCLUSION

The spatial variability and distribution of soil physical and chemical properties in three sub catchments were assessed. The results based on classical statistics showed that soil physical and chemical properties had a total change varying from least to high variation and in that regard, soil pH was the least variable and Av-P was the most highly variable. Soil chemical properties were more variable than physical properties.

In conclusion soil physical and chemical properties exhibited heterogeneous pattern and thus varied

Table 3. Summary Statistic for soil physical and chemical properties for study area

Depth (cm)	0-15	15-30	30-45	45-60	60-75	75-90	Profile
SOC Mean (%)	25.4a	28.9a	29.7a	28.6a	29.5a	27.6a	28.3
N	36	35	36	33	27	17	184
CV (%)	63	62	64	66	63	73	64
Av-P Mean(mg/kg)	4.0a	3.3a	2.6a	2.5a	4.3a	4.9a	3.5
N	35	36	36	33	27	17	184
CV (%)	115	152	162	152	140	131	140
Av-N							
Mean (mg/kg)	2.4b	2.8ab	3.2a	3.4a	3.0ab	3.0ab	3.0
N	36	35	36	33	27	17	184
CV (%)	46	39	38	35	40	43	40
pH Mean (1:2.5)	5.0a	5.0a	5.1a	5.1a	5.1a	5.2a	5.1
N	36	33	34	32	26	17	178
CV (%)	6	10	10	10	12	10	10
BD Mean (g/cm)	0.6a	0.7a	0.7a	0.7a	0.6a	0.7a	0.7
N	25	25	24	24	18	11	127
CV (%)	50	57	43	57	50	71	57

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

† CV= Coefficient of variation; <15 – Least variable, 15 – 35 – Moderately variable, >35 – Most variable (Wilding and Dress, 1978).

‡BD = Bulk density, SOC= Soil Organic Carbon, Av-P = available Phosphorus, Av-N= Available Nitrogen. .

‡‡N is the number of observations

with space. The semivariogram analysis showed the presence of a strong for clay, moderate SOC, Av-P, Av-N and pH. Thus this implies that most soil properties are readily managed. Silt and silt/clay exhibited weak spatial dependence. Homogeneous profile and inconsistent trend of properties down the profile indicated the influence of biogeochemical processes that take place within the wetland. The vertical distribution of physico-chemical properties within the 90 cm depth varied from low to high with least and high average CV of 10 and 140% for soil pH and Av-P, respectively. The variability was probably due to catchment soil characteristics. Av-N and Av-P had inverse relationship with depth and showed a turning point of trend at depth of 60 cm. The SOC was relatively lower on the surface horizons and with exhibited inconsistent trend down the profile. Among all studied physico-chemical properties, Av-N alone differed significantly with depth and hence indicating that sampling at different depth brought variation. Soil pH in the study catchment showed acidity and the area was rated as strongly acidic to moderate acidic. To arrive at a healthy wetlands ecosystem status there is therefore a need to develop an integrated wetlands' catchment management approach to mitigate the effects of degradation and maintain viable ecosystems.

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STATEMENT OF NO CONFLICT OF INTEREST

We the authors of this paper hereby declare that there are no competing interests in this publication.

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