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Characterising wetland hydrology and water quality in streams and wetlands of Khalong-la-Lithunya, Lesotho

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ABSTRACT

Wetland hydrology is important in understanding wetland systems, evaluating wetland functions and processes and assessing wetland conditions. Wetlands assimilate and transform pollutants and nutrients ensuring that quality water is discharged from the wetland into streams. The objective of this study was to characterise wetland hydrology and evaluate the water quality so as to determine the ecological functioning of the Khalong-la-Lithunya wetland. Wetland hydrology and water quality of the three sub-catchments were monitored from October 2015 to March 2016. Water levels in piezometers were recorded once a month and monthly water levels data for the years 2010, 2011, 2012 and 2013 previously recorded by the Millennium Challenge Account-Lesotho (MCA-L) project were integrated to this study's data. Rainfall, piezometer and stream water were similarly obtained once every month. These were analysed for δ2H and δ18O water stable isotopes and water quality parameters determined. The estimated overall hydro-period of Khalong-la-Lithunya from the years 2010 to 2016 was 11.4% of the sampled time. The wetland showed delayed response of piezometer water levels to rainfall and additional source of water to the wetland through sub-surface flow. The isotopic composition of piezometer and stream water showed that the water gets stored in the wetland before being discharged to the stream leading to a positive interaction between ground and surface water. Most water quality parameters (Na, pH, Mg, PO_4, COD, BOD, NO_3, K, Ca, EC) were higher in streams than in piezometers and were mostly within WHO permissible limits. There was a poorer water quality index in streams (59.71) when compared to that of piezometers (53.67). The principal component analysis (PCA) indicated that the parameters that were responsible for the variation in water quality were related to natural hydro-chemical processes, anthropogenic factors and geology and soil constituents. Temporally most parameters were highest during dry months. Due to a short hydro-period, a delayed interaction between surface and ground water and a poorer stream water quality index, it is concluded that the wetland was not in a good condition. Thus, it is not adequately performing its ecological function.

Keywords: Hydro-period, stable isotopes, water quality, wetlands, wetland ecological functioning

RÉSUMÉ

L'hydrologie est importante pour comprendre les systèmes des zones humides, évaluer leurs fonctions, processus et conditions. Les milieux humides assimilent and transforment les polluants et éléments nutritifs assurant ainsi que l'eau de qualité soit évacuée. L'objectif de cette étude est de caractériser l'hydrologie des zones humides et évaluer la qualité de l'eau afin de déterminer le fonctionnement écologique de la zone humide de Khalong-la-Lithunya. L'hydrologie et la qualité de l'eau dans trois sous-bassins versants ont été mesurées d'Octobre 2015 à Mars 2016. Les niveaux d'eau ont été enregistrés une fois par mois, et des données mensuelles sur les niveaux d'eau de 2010, 2011, 2012 et 2013, récemment enregistrées par le Millennium Challenge Account-Lesotho (MCA-L) ont été intégrées aux données de cette étude. Les précipitations, le piézomètre et l'eau de cours d'eau ont été obtenus de la même façon une fois par mois. Ils ont été analysés pour déterminer les isotopes stables à l'eau δ2H et δ18O et les paramètres de qualité de l'eau. La valeur globale estimée de l'hydro-période de Khalong-la-Lithunya des années 2010 à 2016 était de 11,4% de la période échantillonnée. La zone humide a montré une réponse tardive des niveaux d'eau du piézomètre par rapport aux précipitations, et une source additionnelle d'eau à la zone humide par écoulement souterrain. Les compositions isotopiques du piézomètre et du cours d'eau ont montré que l'eau est stockée dans la zone humide avant d'être déversée dans le cours d'eau, entrainant une interaction positive entre les eaux souterraines et de surface. La plupart des paramètres de qualité de l'eau (Na, pH, Mg, PO_4, DCO, DBO, NO_3, K, Ca, EC) étaient plus élevés dans les cours d'eau que dans les piézomètres et plus situés dans les limites acceptables. L'indice de qualité de l'eau dans les cours d'eau était plus faible (59,71) que celui des piézomètres (53,67). L'analyse en composantes principales (ACP) a indiqué que les paramètres responsables de la variation de la qualité de l'eau étaient liés aux processus hydro-chimiques naturels, aux facteurs anthropiques, à la géologie et aux constituants pédologiques. La plupart des paramètres étaient temporellement plus élevés pendant les mois secs. En raison d'une hydro-période courte, de l'interaction tardive entre les eaux de surface et souterraines et de l'indice de qualité du cours d'eau plus faible, il a été conclu que la zone humide n'était pas en bon état. Ainsi, elle ne remplit pas adéquatement sa fonction écologique.

Mots-clés: Hydro-période, isotopes stables, qualité de l'eau, zones humides, fonctionnement écologique des zones humides

BACKGROUND

Wetlands are unique structures of landscapes that influence the hydrology and water quality of surface and ground water (Rogers, 2006). Wetlands sequester water for prolonged period of time and this facilitates groundwater recharge through surface water infiltration. Further, excess nutrients that enter the wetland are trapped and adsorbed by plants, sediments and organisms, therefore the wetland acts as a natural purifier (Beutler, 2012; Yu *et al.,* 2015). Most wetlands in the world are under threat because of unrecognized changes in hydrological and water quality regimes (Mekiso, 2011). This is due to the fact that many countries, including Lesotho, lack a comprehensive assessment of the wetland hydrology and water quality as a result there is a gap on the information and understanding of wetland ecosystem services. Wetlands in Lesotho are located in mountain rangelands and play a vital role by sustaining the perennial water flow and at the same time regulating the water quality of the major Senqu-Orange River system (ORASECOM, 2000).

LITERATURE SUMMARY

Wetland hydrology is the storage and movement of water into and out of a wetland (Ishida *et al.,* 2006; Hoy, 2012; Xiaolong *et al.,* 2014). Mekiso (2011) states that a system is identified as having wetland hydrology when the surface of the top soil is waterlogged for several months or throughout the year in order to create anaerobic conditions. Monitoring of wetland hydrology involves observations on depth of water in soil, duration and frequency or seasonality of wetness (Troyer, 2013). Two of the most commonly used hydrologic variables to characterise wetland hydrology are hydro-period and residence time (Mitsch and Gosselink, 2007; Troyer, 2013). Hydro-period is the pattern of water level fluctuations that takes place in a wetland over time measured by the depth, duration, and frequency of water levels (Troyer, 2013). The higher water levels and longer durations of saturation during growing season indicate a healthy and functional wetland (Ford, 2014). Hydro-period requirement for a healthy wetland (hydrology criterion) is met when a water table falls within 30 cm of the soil surface for 14 consecutive days or 50% of the time during a growing season (United States Army Corps of Engineers, 2005; Ford, 2014).

Mean residence time (MRT) is described as how much time the water spent in the given system before leaving it through the outflow (Thompson, 2012). If the residence time is short it means surface and groundwater inflows and outflows are slow (Thompson, 2012). Over the past two decades, water stable isotopes have been used to explain wetland hydrological dynamics (Schwerdtfeger *et al.,* 2014; Tekleab *et al.,* 2014). Hydrologic applications of stable water isotopes include, among others, estimating MRT and evaluating ground and surface water interactions. Stable water isotopes estimate the MRT in catchments by comparing composition of water molecules of the input (recharge) with the output composition (discharge) in accordance with an assumed transit time distribution (Stewart *et al.,* 2010).

Stable isotopes of water molecule occur naturally as ^{2}H (deuterium, D) and ^{18}O for hydrogen and oxygen, respectively (Gilbert, 1999). The isotopic composition of surface and ground waters is primarily influenced by two processes which are phase change and mixing of water sources. The variations in stable isotopes composition during phase change (melting, condensation, and evaporation) are caused by isotopic fractionation (Beutler, 2012). During the process of evaporation, heavier isotopes (^{2}H and ^{18}O) prefer to remain in the liquid phase in relation to the lighter isotopes (^{1}H and ^{16}O) which kinetically prefer to enter a gaseous state. Similarly, during condensation, lighter isotopes (^{1}H and ^{16}O) remain in vapour or gaseous form while heavier isotopes (^{2}H and ^{18}O) preferentially return to a liquid state (Mekiso, 2011; Liescheidt, 2012). However, during precipitation, the lighter stable isotopes evaporate preferentially from the precipitation on its way to the ground leading to the precipitation event which is more enriched with ^{18}O and ^{2}H than ^{16}O and ^{1}H (Liescheidt, 2012). Poh (2013) used isotopes to evaluate groundwater and surface water interactions.

Water quality is defined differently by engineers, ecologists and hydrologists. Westbrook *et al.* (2011) defines water quality as "chemical, physical and biological descriptors that affect the structure and function of ecosystems as well as those that negatively impact human and livestock health if in elevated concentrations". Threatened wetland water quality is a global concern; some of the common threads include accumulation of nutrients and organic material, suspended solids, metals and pathogens (Yu *et al.*, 2015). The chemical composition of both wetland surface and ground water is the best criteria that explain the wetland water quality (Mohamed and Zahir, 2013).

Water quality parameters important in wetlands include pH, electrical conductivity (EC), base cations, chemical oxygen demand (COD), biochemical oxygen demand (BOD), phosphorus (P) and nitrogen (N) (Chuwdhury *et al.,* 2012; McKenzie *et al.,* 2012). The higher values of pH indicate the increased photosynthetic activity, high organic matter and input of nutrients into the wetland. High electrical conductivity points to mesotrophic conditions of the wetland (Bijoor *et al.,* 2011; Najeeb *et al.*, 2014). Base cations indicate the salt concentration and cause osmotic effects when their levels are high (Thompson, 2012). Osmotic effects will lead to plants not being able to absorb the available water. BOD and COD are the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to breakdown organic material and the amount of oxygen consumed to degrade organic matter, respectively (Vergeles *et al.,* 2015). High levels of BOD indicate the wetland environment with large amounts of organic material in the water and high demand of dissolved oxygen to decompose organic material (Westbrook, 2011). Increased COD levels indicate wetland environment with large amounts of humic matter which inhibits productivity of the microbes and also lowers the dissolved oxygen leading to mortality of aquatic life (Ahmad, 2009; Yao *et al.,* 2014).

Phosphorus and nitrogen are essential to plant growth; however, at high levels they become contaminants because they cause eutrophication which leads to extensive growth of algae in the wetland (Johannensson *et al.,* 2015; Yu *et al.,* 2015). Excessive growth of algae indirectly affects dissolved oxygen and result in high BOD (Pathak *et al.,* 2011). This study explored the applicability of wetland hydrology and water quality to assess wetland ecological functions. The study specifically assessed wetland ecological functioning by i) determining the hydro-period from the monthly water levels in the piezometers, ii) determining ground and surface water interactions in a wetland from ^{18}O and ^{2}H water stable isotopes composition in the rainfall, stream and piezometer water, and iii) evaluating the water quality from piezometers and adjacent streams in the three sub-catchments of Khalong-la-Lithunya.

MATERIAL AND METHODS

STUDY DESCRIPTION

The study was undertaken at Khalong-la-Lithunya palustrine wetland that is located at an altitude of 3100 – 3175 meters above sea level (asl), at points 28º53'50.84"S and 28º48'02.57"E. Khalong-la-Lithunya appears within the national topographic maps of 1:50 000, toposheet number 2828DD TIFGC (Figure 1). The Millennium Challenge Account – Lesotho (MCA-L) has installed piezometers (Figure 1) in the three sub-catchments and has been recording monthly water levels in piezometers for the years 2010, 2011, 2012 and 2013. These sub-catchments have been categorised by the MCA-L as reference (sub-catchment 1) and restored (sub-catchments 2 and 3) sites. The reference site covers an area of about 3280 hacters (ha) while the restored part is about 1332 hacters (ha) (Olaleye *et al.,* 2014). This area is used for grazing by cattle posts owners.

The objectives of the study were achieved in three approaches. The first approach was to monitor water levels once a month in piezometers from October, 2015 to March, 2016 and use the previously collected data by MCA-L to estimate the wetland hydro-period. The second was to determine soil properties from soil profiles adjacent to piezometers. The third approach was to collect water samples once a month from October, 2015 to March, 2016 from piezometers, streams and rainfall to determine the composition of stable isotopes and to determine wetland water quality. The sampling points from the three sub-catchments (C1, C2 and C3) are indicated in Figure 1.

DATA ANALYSIS

Water levels data recorded in the current study and previous data from MCA-L were used to construct hydrographs. Monthly rainfall was plotted as a bar-chart beneath piezometers hydrographs. Hydrographs were analysed to determine the hydro-period. Seasonal hydro-period was calculated as the proportion or frequency of the time that water at the site was ponded and or saturated within -0.30m below the surface as defined by Foster (2007), Troyer (2013) and Ford (2014). Variation in stable isotopes from different sampling points was explored using standard deviation in SPSS (version 24) and used to estimate the interaction between surface and ground water. The relationship between the water quality parameters was explored by the principal component analysis (PCA). Temporal variance in water quality parameters for the three sub-catchments was separated using Duncan mean test and plotted using the 2-D trend line plots for both stream and piezometers.

RESULTS AND DISCUSSION

Water level changes in piezometers in the three sub-catchments. Considerable amount of rainfall was received during summer (November to February) and autumn (March to May) in all years and little rainfall fell during winter and spring (June to October). However, hydrographs of the three sub-catchments showed delayed response to summer rainfall and more response in autumn. In some cases high water levels were observed after the rain had stopped. This indicates the presence of the sub-surface flow that feeds the wetland (Poh, 2013; Troyer, 2013). Sub-catchment 1 showed a longer hydro-period than other sub-catchments for most of the sampled time. The average catchment hydro-period of the three sub-catchments is 11.4 percent.
The observed average soil bulk density for the three sub-catchments ranged from 0.57 to 1.00 g/cm^3 with

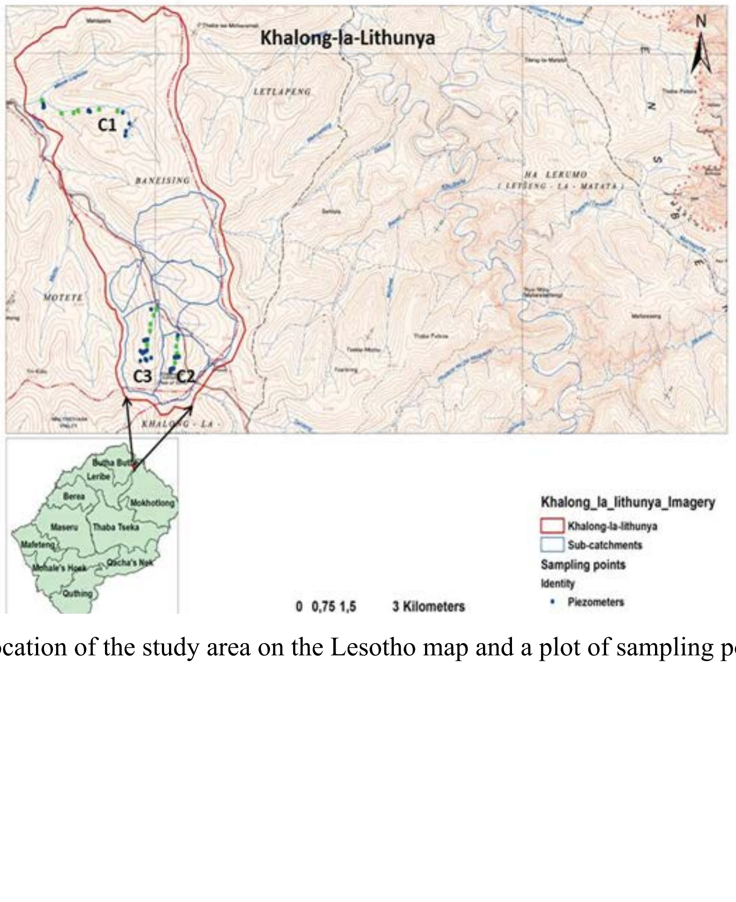

Figure 1: The location of the study area on the Lesotho map and a plot of sampling points

sub-catchment 2 having the highest bulk density. The estimated soil porosity was in a range 0.61 to 0.78. The high bulk density (1.00 g/cm^3) could be due to a short hydro-period which leads to loss of organic material thereby resulting into a peat with a higher bulk density and less permeable (Mandic-Mulec, 2014; Lewis and Feit, 2015), and could also be due to livestock trampling effects (Matano *et al.,* 2015). The low bulk density (0.57 g/cm^3) however, could be due to the development of peat in the top surface layer of mostly permanently wet soils (Dunne *et al.,* 2010; Mapeshoane 2013).

Variation of hydrogen (δ2H) and oxygen (δ^{18}O) isotopes of rainfall, stream and piezometers water in the three sub-catchments. Results showed depleted values in streams and piezometers water compared to rainfall in all sub-catchments with piezometers water being the most depleted (high negative values). The high negative minimum and maximum values obtained in piezometers in all sub-catchments indicate that the groundwater is "old" and that it is of previous rainfall not the recent. The negative minimum values in the stream also illustrate that the stream water contains old water which is likely from the groundwater discharge while the positive maximum values in stream water points to the influence of the recent rainfall. Therefore, the stream water is comprised of both "old" groundwater and recent rainfall (Schwerdtfeger *et al.,* 2014; Tekleab *et al.,* 2014). Further, the observed variation between groundwater isotopic compositions with rainfall demonstrates that the experienced rainfall never recharged the wetland groundwater; it only contributed to the surface water. Mixed surface water on the other hand confirms that there has been a groundwater discharge during the dry periods maintaining the flow of the wetland stream (McGuire *et al.,* 2002; Jin *et al.,* 2012).

The water chemical parameters means for stream and piezometer were compared with the World Health Organisation (WHO) water standards. The pH in stream (6.5249) is within the acceptable limits of the WHO pH standard (6.5 – 8.5). The piezometer pH (5.7001) is lower than the lower limit because of the acidic nature of Lesotho peatlands (Mapeshaone, 2013; Olaleye *et al.,* 2014). The obtained EC for both stream (0.1176 mS/cm) and piezometer (0.0904 mS/cm) falls within the prescribed limit by WHO (1.5 mS/cm).

Biochemical oxygen demand (BOD) in streams (9.0269 mg/L) exceeded WHO standard (5 mg/L) while that in piezometers (3.6334 mg/L) was within the limits. The COD in both stream (42.0513 mg/L) and piezometers (80.4706 mg/L) was beyond the WHO permissible limit (10 mg/L). The elevated BOD in streams points to organic pollution (Usharani *et al.,* 2010; Hettiarchchi *et al.*, 2011). The significantly high COD in piezometers is attributed to shallow, slow-moving waters in wetlands, which will often have large amounts of organic material in the water (Mohamed and Zahir, 2013). All bases (Mg, K and Na) except Ca in streams were below the higher limits of the WHO standards and noticeably lower than the limits (Table 2). Mating (2012) and Olaleye *et al.* (2014) also observed markedly very low base cations over years at Khalong-la-Lithunya.

Table 1: Summary statistics of hydrogen (δ^{2}H) and oxygen (δ^{18}O) isotopes values relative to VSMOW for water collected from different sources in the three sub-catchments of Lesotho in December, 2015.

Sub-catchments	Water source	*n*	Minimum (‰)		Maximum (‰)		Mean (‰)		Std. Deviation	
			δ^{2}H	δ^{18}O	δ^{2}H	δ^{18}O	δ^{2}H	δ^{18}O	δ^{2}H	δ^{18}O
1	Rainfall	1					64.0	10.28		
	Stream	7	-14.77	-3.43	8.35	0.28	-1.35	-1.39	7.69	1.27
	Piezometer	4	-23.03	-4.26	-12.45	-3.52	-18.39	-3.92	4.39	0.31
2	Rainfall	1					7.6	1.02		
	Stream	5	-11.57	-2.23	9.02	-0.17	-4.38	-1.44	7.82	0.79
	Piezometer	8	-23.62	-4.76	-13.29	-3.36	-17.37	-4.22	3.37	0.46
3	Rainfall	1					8.0	0.42		
	Stream	5	-7.86	-1.83	11.94	1.15	3.13	-0.29	7.45	1.12
	Piezometer	8	-20.69	-5.04	-12.33	-3.63	-16.10	-4.25	3.22	0.48

Water quality in streams and piezometers

Stream and piezometers nitrate levels were within WHO standard (50 mg/L) and were relatively low (1.3089 and 0.5728 mg/L for stream and piezometers respectively). Nitrates are low because under saturated anaerobic conditions nitrates are reduced as a result of N denitrification whereby the bacteria use nitrate as their electron acceptor instead of oxygen during decomposition of organic matter (Mohamed and Zahir, 2013; Sirajudeen *et al.,* 2014). Phosphate means in both stream (1.0742 mg/L) and piezometers (4.1464 mg/L) are relatively higher than permissible WHO levels (0.1 mg/L). High phosphates concentration agrees with the phosphates results obtained by Olaleye *et al.* (2014) on the same study area. The high phosphate is associated with insoluble complexes of phosphorus and calcium that are not readily available for plant uptake. Furthermore, under aerobic conditions, phosphates bind to iron (III) by forming strong complexes but when the conditions turn into anaerobic as a result of flooding, iron (III) gets reduced to iron (II) leading to release of the phosphates resulting in increased P concentration (Verhoeven *et al.,* 1999).

Water quality index for streams and piezometers. The concentrations of only four water quality parameters (pH, BOD, NO_3 and PO_4) were used to calculate the water quality index (WQI) according to the equation of Srivastava and Kumar (2013). The estimated WQI was 59.71 for streams and 53.67 for piezometers. The water quality for both streams and piezometers were classified as being poor according to Brown *et al.* (1972) because they fell within the range 51–75. The observed higher WQI in streams than piezometers indicate additional source of pollutants from surface flow.

The relationship between water chemical parameters. The principal component analysis (PCA) showed that three significant factors accounted for 52.56 % of the variation in the data set. Factor 1 made up of (Na, pH and Mg) reflects the origin from natural mineral related hydrochemistry such as ion exchange (Singh *et al.,* 2004). It suggests that Na gets displaced from the mineral surfaces by Mg and it ends up in the water leading to saline water (high EC) and this process is influenced by pH (Singh *et al.,* 2004; Al-Charideh and Hasan, 2013). Factor 2 made up of (BOD) points to high organic material and anthropogenic effects because of high BOD, it explains that large organic matter component gets decomposed and during the process, oxygen is used up leading to anaerobic fermentation. Factor 3 made up of (K, Ca and EC) indicates the influence of geology and soil consituents (Kumar *et al.,* 2010). It explains that there are additions of K and Ca in the water that result from dissolution of these cations from their original mineral rocks and from the soil constituents increasing the salinity of the water (McKenzie *et al.,* 2012).

The monthly trend analysis demonstrates that most parameters had a higher concentration during dry conditions, which could suggest that the water had been subjected to great evaporation which concentrates the water with these parameters (Mekiso, 2011). The low concentrations during the wet conditions indicate the mixing with fresh water (Yuan *et al.,* 2011; Poh, 2013).

Table 2: Rotated factor pattern matrix, rotation method: Oblimin with Kaiser

Variables	Factor 1	Factor 2	Factor 3
Na	0.856	0.000	0.057
pH	0.780	0.113	0.085
Mg	0.757	-0.220	0.057
PO_4	-0.586	-0.385	-0.040
COD	-0.324	0.098	0.046
BOD	0.127	0.861	0.015
NO_3	0.205	-0.388	0.011
K	-0.451	0.061	0.649
Ca	0.259	0.222	0.645
EC	0.165	-0.339	0.628

Temporal variation in water quality parameters

CONCLUSION

The hydrographs showed delayed response of groundwater recharge to rainfall which may indicate high runoff generation during rainfall and also additional source of water to the wetland through sub-surface flow. The delayed response is also substantiated by the most enriched rainfall isotopes composition than depleted groundwater. The average catchment hydro-period of the three sub-catchments was 11.4% and this is insufficient to meet the wetland hydrologic criterion which requires for 50% inundation of the sampled period or growing season. Depleted isotopes composition of piezometer water indicates that the wetland stores water for a certain time. The surface water isotopes composition indicated a mixture of both groundwater and rainfall, meaning there is a positive interaction between ground and surface water because the wetland stores water and release it to the surface gradually during dry periods to maintain the stream flow. Most water quality parameters monitored over a period of five months from October 2015 to March 2016 were higher in streams than in piezometers and were mostly within WHO permissible limits. The higher concentration of most parameters observed in stream water than in piezometer water was also substantiated by a poorer water quality index in streams (59.71) when compared to that of piezometers (53.67). The PCA however, indicates that the parameters that were responsible for the variation in water quality were related to natural hydro-chemical processes, anthropogenic factors and geology and soil constituents. The monthly trend analysis demonstrated that most parameters had a higher concentration during dry conditions. Due to a short hydro-period, a delayed interaction between surface and ground water and a poorer stream water quality, it was concluded that the wetland was not in a good condition and therefore was not performing well its ecological function. The observations from this study will contribute in ensuring effective management, rehabilitation or restoration of the wetlands by the responsible ministry departments.

STATEMENT OF NO CONFLICT OF INTEREST

We the authors declare that we have no conflict of interest in this publication.

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