Hydro-period, surface-ground water interactions and water quality to assess wetland condition of Khalong-la-Lithunya

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Thesis

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Dissertation Approval

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Dedication

The dissertation is dedicated to my mum and dad; ‘Makereo and Masilo Mots’ets’e for their life time support and unconditional love. I hope I have made both of you proud.

Abstract

Wetland degradation may pose effects on wetland functioning. Wetland hydrology and water quality are important in understanding wetland systems in evaluating wetland functions and processes hence are used to assess the wetland condition. The study was carried out to assess the ecological functioning of Khalong-la-Lithunya wetland by determining hydro-period, surface – ground water interactions and the effect of the wetland on water quality. Wetland hydrology and water quality of the three sub-catchments were monitored. Water levels in piezometers were recorded once a month from October 2015 to March 2016 and the monthly water levels data for the years 2010, 2011, 2012 and 2013 previously recorded by the Millennium Challenge Account-Lesotho (MCA-L) project were also used. Rainfall, piezometers and streams water also collected once a month were analysed for $\delta^{2}H$ and $\delta^{18}O$ water stable isotopes and water quality parameters were 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. However, there was additional source of water to the wetland through sub-surface flow during dry conditions. The piezometers water isotopes were highly depleted (-10.663 to -11.153‰ for $\delta^{2}H$ and $\delta^{18}O$) while stream water (1.419 to -2.913‰ for $\delta^{2}H$ and $\delta^{18}O$) had a mixture of both piezometer and rainfall water (7.6 to 64.0‰ for $\delta^{2}H$ and 0.42 to 10.28‰ for $\delta^{18}O$) hence these showed that the water gets stored in the wetland for some time before it gets discharged to the stream. This indicates a positive interaction between ground and surface water. Most water quality parameters were higher in streams than in piezometers, however, they were mostly within WHO permissible limits. The concentrations of BOD (9.03mg/L) and PO_4 (1.07mg/L) were extremely higher than WHO standards hence contributed to the poor water quality index in streams (59.71). While the high phosphate levels (4.15mg/L) contributed to the poor water quality index (53.67) in piezometers. 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 as well as geology and soil constituents. Most water quality parameters were highest during dry months (October and December 2015). Short hydro-period, delayed interaction between surface and ground water together with poor stream water quality may indicate affected wetland ecological functioning.

Declaration

I declare that the dissertation hereby submitted by me for the Degree of Master of Science in Soil Science and Resource Conservation at the National University of Lesotho is my own independent work and has not previously been submitted for any award of degree. Where information from other sources has been coded, it has accordingly been acknowledged by means of references. I furthermore authorize the National University of Lesotho to supply copies of this dissertation to libraries and individuals upon request.

Signature: …………………………………...   Date: ………………………………..

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List of Acronyms

MCA-L	Millennium Challenge Account - Lesotho
LHWP	Lesotho Highlands Water Project
WHO	World Health Organisation
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
δ^2H	Delta Deuterium
$\delta^{18}O$	Delta ^{18}Oxygen
EC	Electrical Conductivity
Na	Sodium
Ca	Calcium
K	Potassium
Mg	Magnesium
NO_3	Nitrate
PO_4	Phosphate
WQI	Water Quality Index
PCA	Principal Component Analysis
USDA	United States Department of Agriculture
GMWL	Global Meteoric Water Line
VSMOW	Vienna Standard Mean Ocean Water
AAS	Atomic Absorption Spectrophotometry

1. Introduction

1.1 Background

Wetlands are unique structures of landscapes that markedly influence the hydrology and water quality of surface and ground waters (Rogers, 2006). Wetlands sequester water for prolonged period of time and this allows for groundwater recharge through surface water infiltration, also excess nutrients that enter the wetland are trapped and adsorbed by plants, sediments and organisms, reciting wetlands as natural purifiers (Beutler, 2012; Yu *et al*., 2015).

Wetlands have no single definition because of their diversity. They are traditional zones that occupy an intermediate position between dry land and open water, often occurring at the edge of aquatic or terrestrial systems (Seelig *et al.*, 2006; Rani *et al.*, 2011; Troyer, 2013). The definition given by the Ramsar (1971) refers to wetlands as "*areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters*". They include those areas that are covered or saturated by surface or ground water at a frequency and duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil conditions (Troyer, 2013; Neuhaus, 2013; Hoy, 2012). They are characterised by their hydrophytic vegetation, hydric soils and wetland hydrology (Richardson and Vepraskas, 2001; Mapeshoane, 2013). They occur in variety of types in different landscapes such as swamps, marshes, bogs, fens and sea-grass beds (Sieben and Morris, 2010; Mekiso, 2011; Moreno-Mateos*et al.*, 2012).

Wetlands are important components of the terrestrial ecosystems and play vital roles to human health, safety and welfare (Mekiso, 2011; Mwakalila, 2011). They support agricultural activities, improve water quality, improve flood storages, groundwater recharge and discharge, they offer a habitat for wildlife and are critical in supporting biodiversity and livelihoods (Melesse *et al*., 2007; Enwright *et al*., 2011). Wetlands also play a significant role in the hydrological cycle and their formation, persistence, size and function are governed and correlated with hydrological processes that occur within them (McCartney *et al*., 2011; Mekiso, 2011).

Mostly, the world's wetlands are under threat as a result of unrecognized changes in hydrological and water quality regimes (Mekiso, 2011). They are mostly affected by anthropogenic disturbances and unsustainable use (Sandham *et al*., 2008). Wetlands in Lesotho are located in mountain rangelands and are beneficial to local communities for the purposes of grazing, water provision and medicinal plants (Deschamps, 2006; Nkheloane *et al*., 2012). Lesotho mountain wetlands are palustrine (Nkheloane *et al*., 2012; Mapeshoane, 2014), meaning they are "*typically not, or rarely, flooded 'land'-based systems*" (Thompson, 2012). The palustrine wetlands in Lesotho consist of mires (bogs and fens) and are referred to as peatlands (Schwabe, 1995; Mapeshoane, 2016). Peatlands are "*wetlands that have a peat substrate and have vegetation that encourages peat formation*" (Tiner, 1999; Mapeshoane, 2016).

Few studies have been carried out to investigate the hydrology and water quality of the wetlands of Lesotho (Millennium Challenge Account - Lesotho, 2012; Mapeshoane *et al*., 2014; Olaleye *et al*., 2014). The current study is a continuation on the study carried out by the Millennium Challenge Account - Lesotho (MCA-L) under the Wetlands Unit in the Department of Water Affairs, Lesotho. MCA-L implemented a Wetlands Restoration and Conservation Project at Khalong-la-Lithunya where part of the catchment was restored and the other left as reference site. The monitoring activities that were carried out from both reference and restoration sites included groundwater monitoring in the piezometers installed at different depths and water quality monitoring at the gauging stations (Millennium Challenge Account - Lesotho, 2012). However, data is scanty and not continuous (Mokhatla, 2014).

The same wetlands of Khalong-la-Lithunya have also been studied by Olaleye *et al*. (2014) looking at its hydrochemistry and found that pH, electrical conductivity, cations and anions were within WHO (2004) standard ranges except for Phosphorus. This study however, did not look at other important water quality parameters such as biochemical oxygen demand (BOD), chemical oxygen demand (COD) and dissolved organic carbon (DOC). Mapeshoane *et al*. (2014) also studied the same area by characterising soil hydrology of the reference and restored wetland sections. The results showed high bulk density and low porosity and hydraulic conductivity in reference wetlands and they were significantly different from the restored wetlands, hence the soil hydraulic properties revealed that the reference wetlands may still exhibit compaction to some extent.

There is lack of a comprehensive assessment of the wetlands hydrology and water quality owing to the fact that the monitoring is not continuous. Without this comprehensive baseline information it is difficult to make inferences about good potential indicators of wetland health (Wray and Bayley, 2006). The objective of the current study is therefore to characterise wetland hydrology from hydro-period and surface and ground water interactions, and assess the water quality of the wetland.

1.2 Statement of the problem

In many countries, wetlands are not being able to be managed to sustainably meet current and future demands of providing enough water of good quality because there is lack of information on water quality and hydrology (Mapeshoane, 2013). In Lesotho, wetlands play a major role in sustaining the perennial water flow and regulating the water quality of the major Senqu-Orange River system (ORASECOM, 2000). Khalong-la-Lithunya wetlands form part of the sub-catchments that make up the main quaternary catchment that act as headwater of Motete River. Motete River on the other hand, is part of the main tributaries of Katse Dam, and the latter supplies water to South Africa through the Lesotho Highlands Water Project (Treaty on the Lesotho Highlands Water Project (LHWP), 1986).

The wetlands catchments also provide livestock grazing and have a grazing value estimated at U.S. $100,000 per year (Turpie and Malan, 2010). These wetlands are however subjected to degradation of their ecological functioning making wetlands rather more to be malfunctioning (Sieben and Morris, 2010). The threads to wetlands include high soil erosion and altitude system associated with increased grazing pressure and steep topography (Sieben and Morris, 2010).

Due to these threads, the wetlands seem to be drying up and this could have an effect on their ecological functions, hence why the study is carried out to assess the state of wetland ecological functioning using hydro-period, the interaction between ground and surface waters and water quality. Consequently, research has shown that even though some restoration projects have been done, their most significant problem limiting their success is inadequate hydrological regimes. The problem with wetlands in Lesotho is also aggravated by the fact that Lesotho and most African countries have very little infrastructure in the mountains, such as weather stations and climate monitoring systems, to give long-term reliable hydrological data. Hence, this has restricted the use of hydrologic data for assessment of wetland hydrology.

1.3 Justification

In Khalong-la-Lithunya wetlands several studies have been carried out but were mostly based on the assessment of the restoration process not on estimating the degree of change in wetland functioning. Olaleye *et al*. (2014) studied soil characteristics, hydrochemistry of the surface waters and vegetation isotopic signatures in order to assess the extent to which conservation and rehabilitation practices have allowed the wetlands to return to their former status. The results generally showed that even after five years of conservation and rehabilitation the wetlands have not returned to their original status. According to these results the status of the wetland was indicated by pedons which had the silt: clay ratio ≤ 0.70, increase in bulk density and decrease in macro porosity as a result of compaction associated with animal grazing and also elevated phosphate concentrations beyond the limits set by USEPA/NOAA (1988). The results also showed less enrichment in $\delta^{13}C$ across slope section and that organic carbon increased across slope positions and months.

The Khalong-la-Lithunya wetlands are experiencing a severe degradation which is anticipated to be aggravated by increased levels of soil erosion and drying off and thus hinder the wetland ecological functioning (MCA-L, 2012). However, there is sparse information which can be used to quantify minimum hydrological thresholds for wetland ecological functioning in Lesotho. Given that wetland restoration projects and hydrologic models have not yet disentangled or straighten out hydrologic variables responsive to degradation, there is a great need to determine the hydrology and quality of water from Khalong-la-Lithunya wetlands. This is the best strategy for a better understanding of the wetland hydrologic regimes since hydro-period influences the biodiversity and productivity of wetland ecosystems and consequently will improve wetland water quality. The interactions however, characterise the movement of water within the wetland. Conducting a study where these three parameters of wetlands are assessed will be beneficial in that it will show the extent of wetland degradation in relation to wetland hydrology and water quality, which points to respective corrective measures for rehabilitation or restoration of the wetlands.

1.4 Hypotheses of the study

It is hypothesized that longer hydro-period or saturation of wetlands, will result in longer anaerobic biological processes and less nutrients being discharged from the wetland system.

1.5 Objectives

The general objective of this study is to assess wetland ecological functioning of the Khalong-la-Lithunya from wetland hydrology and water quality. Specific objectives are as follows:

- To determine wetland hydro-period from water levels in piezometers and interactions between surface and ground water using water stable isotopes.
- To determine the effect of Khalong-la-Lithunya wetland on water quality of the piezometers and adjacent streams.

2. Characterizing wetland hydrology of Khalong-la-Lithunya, Lesotho

2.1 Introduction

Wetland hydrology is the storage and movement of water into and out of a wetland (Ishida *et al*., 2006; Mekiso, 2011; Hoy, 2012; Troyer, 2013; Xiaolong *et al*., 2014). Mekiso (2011) states that 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). Prolonged saturation and periodically changing water levels defines wetland's unique properties (Mekiso, 2011), and ecological services (Ishida *et al*., 2006; Neuhaus, 2013; Xiaolong *et al*., 2014). The most commonly used hydrologic variables to characterise wetland hydrology are water budget, hydro-period and water residence time (Mitsch and Gosselink, 2007; Troyer, 2013). Therefore, changes in these hydrologic variables are the leading causes of wetland degradation or destruction (Poh, 2013). Troyer (2013) stated that the wetland system's rich biodiversity is associated with the seasonal fluctuations of water levels.

The key to understanding the hydrology of a wetland lies in the water budget; an accounting of the balance between water inputs (precipitation, surface water inflow, and ground water inflow) and water outputs (evapotranspiration, surface water outflow and ground water outflow) of the wetlands, as well as the storage within them (Messaros, 2013; Enwright *et al*., 2011). However, from an ecological perspective, water budget is not as important to wetland ecological functions as the depth of water and length or timing of inundation, collectively referred to as hydro-period (Troyer, 2013). Hydro-period is the pattern of water level fluctuations that take place in a wetland over time measured by the depth, duration, and frequency of water levels (Troyer, 2013). Hydro-period is normally represented by a hydrograph which displays the change in water levels over a period of time (Hoy, 2012). These fluctuations may exhibit short-term, seasonal, or inter annual patterns. 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 30cm of the soil surface for 14 consecutive days or 50% of the time during a growing season (United States Army Corps of Engineers, 2005; Mekiso, 2011; Troyer, 2013; Ford, 2014).

Water levels are measured by use of water table monitoring wells and piezometers (Troyer, 2013). Piezometers are devices or instruments that measure pressure (piezometric head) by measuring the height to which a column of liquid rises against gravity (Troyer, 2013). They are also referred to as monitoring wells that consist of a section of unslotted pipe open at both ends and or a pipe slotted only at the bottom. Piezometers allow water to enter at the bottom of the pipe only, or have a very small screened interval at the bottom of the pipe (Richardson and Vepraskas, 2001).

Hydrologic behaviour of a wetland is greatly influenced by the wetland watershed topography and nature of the soil (Stibinger, 2014). Soil hydraulic properties (bulk density, porosity and soil water content) influence hydro-period and the groundwater recharge and discharge (Holden and Burt, 2003; Mekiso, 2011; Troyer, 2013). They affect the ability of the soil to transmit water (Stibinger, 2014). Bulk density affects the pore size and alters water velocities as well as paths; they influence water infiltration and percolation (Ronkanen *et al.*, 2005; Matano *et al.*, 2015). Matano *et al.* (2015) observed a higher bulk density which lead to low infiltration and resulted in generated runoff. The pore size was reduced and water table was not recharged therefore; there was no rise in water level. Lower bulk density corresponds to greater hydro-period (Dunne *et al*., 2010; Lewis and Feit, 2015). A highly porous wetland soil will hold large amounts of water; short hydro-period in peats encourages loss of organic matter mass, shrinkage and consolidation of peat (Neuhaus, 2013; Mandic-Mulec, 2014). The peat becomes denser and less permeable and result in reduced storage capacity of wetlands (Tuxen *et al*., 2011). Antecedent soil moisture content that is higher than field capacity leads to faster groundwater recharge (Kasischke *et al*., 2009; Kogelbauer, 2010). Riddell *et al*. (2013) observed measured groundwater levels in piezometers near the erosion head cut to show a clear hydraulic drawdown due to the uncontrolled drainage through the erosion gully.

Mean residence time (MRT), or transit time or turnover period is described as how much time the water spent in the given system before leaving it through the outflow (Thompson, 2012). The residence time also as a parameter of storage is important. If the residence time is short it means surface and groundwater inflows and outflows are slow (Thompson, 2012). 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).

Mekiso (2011) defines stable isotopes as those isotopes that do not undergo radioactive decay and therefore, their nuclei are stable and their masses do not change. Stable isotopes of water molecule occur naturally as ^{2}H (deuterium, D) and ^{18}O for hydrogen and oxygen respectively (Gilbert, 1999). Over the past two decades, water stable isotopes have been used to explain wetland hydrological dynamics (Gibson, 2001; Clay, 2004; Rodgers *et al*., 2005; Garvelmann *et al*., 2012; Hoy, 2012; Liescheidt, 2012; Poh, 2013; Schwerdtfeger *et al*., 2014; Tekleab *et al*., 2014). Hydrologic applications of stable water isotopes include among others; tracking of water sources in wetland (Liescheidt, 2012). Water normally maintains its isotopic composition unless it is mixed with water of different composition from other sources and this allows for accurate water source identification (Hoy, 2012). Poh (2013) used isotopes to evaluate groundwater and surface water interactions.

The variations in stable isotopes composition are caused by isotopic fractionation when water undergoes a phase change (melting, condensation, and evaporation) (Beutler, 2012). The isotopic composition of surface and ground waters is primarily influenced by two processes which are phase change and mixing of water sources. Changes in phase produce kinetic effects that are dependent on the element's mass and consequently influence isotopic composition. Mixing of distinct water sources can also change the isotopic composition of the resulting mixture because it incorporates water from different sources with different compositions (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. Hunt (2005) found that evaporation preferentially enriches surface water in ^{18}O relative to ^{2}H. 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 (Beutler, 2012; Liescheidt, 2012; Mekiso, 2011). 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). Consequently, as part of precipitation runoff, the other infiltrates and recharges the groundwater, the latter will maintain the stable water isotope composition of the precipitation while the precipitation that forms the runoff component is subjected to further evaporation which results with higher composition of heavier isotopes of water (Steinbruch *et al*., 2014). Accordingly, runoff has higher composition of heavier isotopes than groundwater.

The relationship between ^{18}O and ^{2}H composition in freshwater wetlands can be calculated by applying the Global Meteoric Water Line (GMWL) (Liescheidt, 2012). Slight deviation of sampled groundwater from the Local Meteoric Water Line (LMWL) suggest that some evaporation of rainfall had occurred prior to or during infiltration (Sikdar and Sahu, 2009). The GMWL is normally expressed by the following equation (Mekiso, 2011).

$$\delta^{2}H = 8 \times \delta^{18}O + 10$$

The delta (δ) notation typically represents the stable isotope compositions of $^{2}H$and^{18}O. It is defined in units of parts per thousand (‰ or per mil) from the Vienna Standard Mean Ocean Water (VSMOW) (Liescheidt, 2012).

Therefore, the study aims to characterise wetland hydrology in the three sub-catchments of Khalong-la-Lithunya. Specifically, the study i) determines the hydro-period of the wetland and ii) determines ground and surface water interactions in the wetland.

2.2 Material and Methods

2.2.1 Study description

The study was undertaken at Khalong-la-Lithunya palustrine wetland that is located at an altitude of 3100 – 3175m 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 geology of this area is recognized as the Lesotho formation with compact and amygdaloidal tholeiitic basalt and it falls within the Afroalpine Grassland zone dominated by grasses (Schmitz and Rooyani, 1987; Mating, 2012). The soils are classified as Moroke series (local name) or *Lithic Cryoborolls* (USDA) or *Dystric Mollic Cryosols* (WRB) along the hillslopes and Oxbow Series (local name) or *Hydric Cryohemists* (USDA) or *Reductaquic Histic Cryosols* (WRB) which dominate the wetlands (MCA-L, 2012). This wetland forms part of the sub-catchment that makes up the main quaternary catchment that acts as headwater of Motete River. The temperature for Khalong-la-Lithunya ranges from 7.6 – 22.4°C. The recorded mean annual rainfall for this area ranges between 1000 and 3000mm (Olaleye *et al*., 2014).

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. The piezometers were installed on transects that traverse the wetland in order to characterise the water level depths across the wetland. The current study used the same piezometers to record water levels and to collect water samples. 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 3280hacters (ha) while the restored part is about 1332hacters (ha) (Olaleye *et al*., 2014).This area is used for grazing by cattle posts owners.

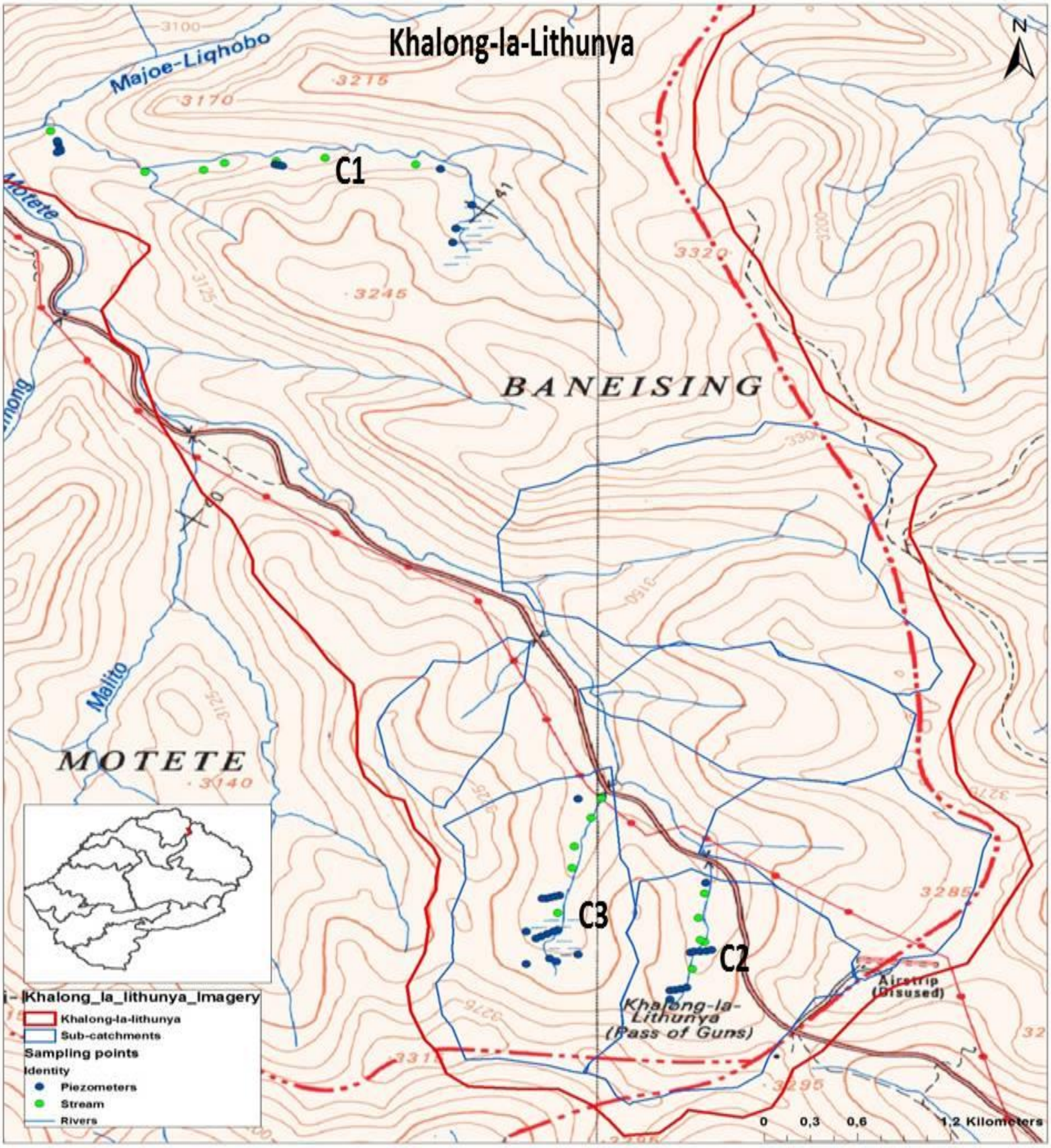


Figure 1: The location of the study area on the Lesotho map and a plot of sampling points in the sub-catchments1, 2 and 3, represented here in as C1, C2 and C3, respectively.

The objectives of the study were achieved in three approaches. The first approach was to monitor water levels in piezometers once a month 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 (Table 1) 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. The sampling points from the three sub-catchments (C1, C2 and C3) are indicated in Figure 1.

Table 1: Average values of soil properties at depth 0 to 90cm of the three sub-catchments of Khalong-la-Lithunya

Soil properties	Sub-catchment 1	Sub-catchment 2	Sub-catchment 3
SOC (%)	31.4	10.9	30.4
Av- P (mg/kg)	1.50	0.46	7.21
Av-N (mg/kg)	3.11	2.39	2.97
pHw	4.74	5.27	5.24
Na (Meq/100g)	2.43	0.07	3.87
K (Meq/100g)	0.92	1.65	3.19
Ca (Meq/100g)	9.80	9.95	5.13
BD (g/cm^3)	0.57	1.00	0.8
Porosity	0.78	0.61	0.69
Moisture Content	159	-	-
SAND %	67.9	64.8	58.3
CLAY%	15.7	13.4	18.7
SILT%	16.5	21.8	23.0
SILT / CLAY	1.15	1.86	1.25

2.2.2 Determination of the hydro-period of the Khalong-la-Lithunya wetland

The hydro-period of the Khalong-la-Lithunya wetland was determined using water levels. The water levels data recorded once a month by the MCA-L for the years 2010, 2011, 2012 and 2013 obtained from the Department of Water Affairs were used. In the current study, further water levels were manually recorded on monthly intervals from October 2015 to March 2016 from the same piezometers previously installed by MCA-L. The water levels were measured using acoustic water level indicator. The recorded water levels were expressed in meters and calculated using the equation described by Hoy (2012) and Troyer (2013) as:

H*ydraulic head = distance from top of casing to ground - distance from top of casing to the depth of water.*

Water levels data recorded in the current study and previous data from MCA-L were used to construct hydrographs. The influence of rainfall on water levels was studied by utilising monthly rainfall obtained from the nearest weather stations where 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).

Soil profiles were dug along transects next to piezometers installed in the three sub-catchments as indicated in Figure 1 and a detailed soil profile description as per USDA-NRCS (2010) was done. Core samples were taken at depths of 0-15, 15-30, 30-45, 45-60, 60-75 and 75-90cm per profile where possible for each catchment for determination of bulk density and porosity. Soil bulk density was estimated using the core method.

$$\rho_b = \frac{M\mathrm{ds}}{Vs}$$

Soil porosity was derived from the relationship between bulk and particle densities:

$$f = 1 - (\rho_b/\rho_s)$$

Where; f, ρ_b and ρ_s represent soil porosity, bulk and particle densities, respectively. Particle density is constant and equals to 2.65g/cm^3.

2.2.3 Determination of surface and ground water interaction in the Khalong-la-Lithunya wetland

Surface and ground water interaction in the wetland was determined using water stable isotopes. Water samples for rainfall and ground water were collected from installed rainfall collectors and piezometers respectively, and surface water samples were collected along the wetland stream (Figure 1). Eighteen (18) stream water samples were taken each time sampling was done. In piezometers the number of samples collected depended on the number of piezometers that had water during each sampling while with rainfall three composite samples from each sub-catchment were collected. The water samples were bottled in polyethylene plastic bottles which were tightly closed, stored in insulated cooler containing ice-packs and transported to the laboratory and stored in a refrigerator at 4^{o}C until they were analysed. Water stable isotope (^{18}O and ^{2}H) composition was determined from rainfall, surface and ground water samples collected in December 2015. Water samples were analysed for hydrogen and oxygen stable isotopes at the Environmental Isotope Group (EIG) of iThemba Laboratories, South Africa. Water isotopic ratios analysed were D/H (^{2}H/^{1}H) and ^{18}O/^{16}O. The stable isotope analysis was done using a Thermo Delta V mass spectrometer connected to a Gasbench. The analytical precision was estimated at 0.2‰ for O and 0.8‰ for H. Analytical results are presented in the common delta-notation (δ) which is expressed in units of parts per thousand (‰ or per mil) relative to a known standard. In this case Vienna standard mean ocean water (VSMOW) for δ^{18}O and δD as described by Mekiso (2011) is presented as follows:

$$\delta = (R_{sample}/R_{standard} - 1) * 1000$$

Where *R* denotes the ratio of the heavy to light isotope and it applies to both D/H (^{2}H/^{1}H) and ^{18}O/^{16}O. The relationship between ^{2}H and ^{18}O was plotted against the Global Meteoric Water Line (GMWL) which is considered as a world reference standard (Sanchez-Murillo *et al*., 2015) represented by the following equation according to Craig (1961):

$$\delta D = 8.0 * \delta^{18}O + 10‰$$

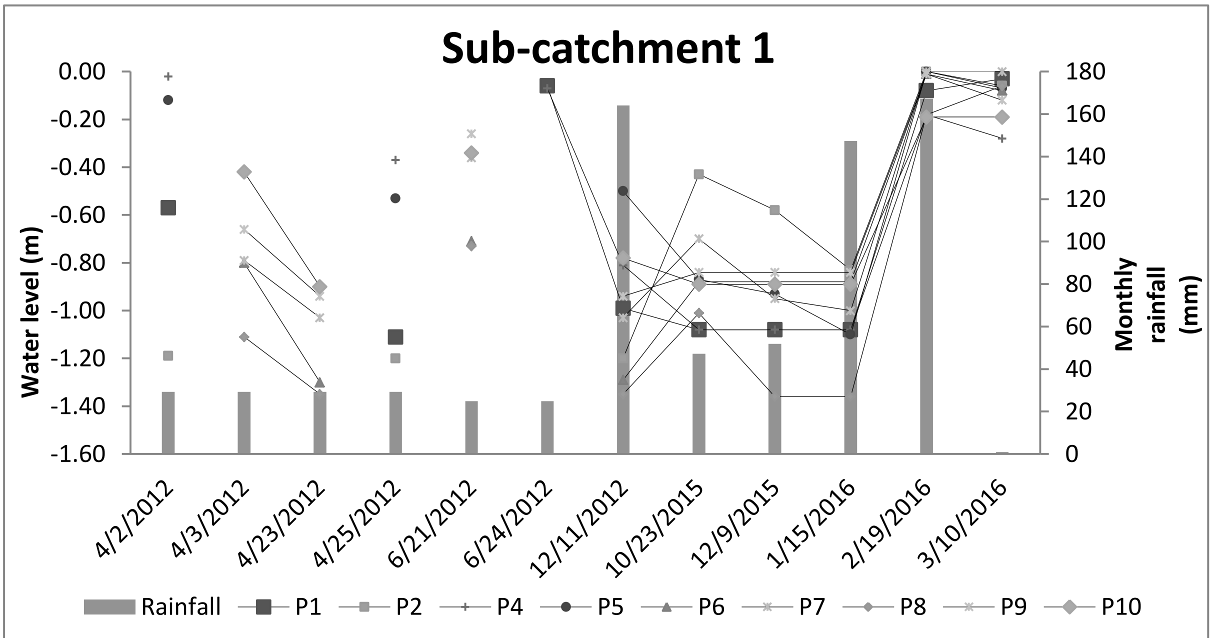
2.2.4 Analysis of hydro-period and surface – ground water interactions

Frequency analysis of piezometer water levels and exploration of variation in stable isotopes from different sampling points were done using SPSS (version 24). A paired T-test was done to explore the variation in stable isotopes. The explored variation was used to estimate the interaction between surface and ground water. Linear regression model was used to determine relationship between δ^{2}H and δ^{18}O stable isotopes and compared it with global meteoric water line (GMWL).

2.3 Results and Discussion

2.3.1 Monthly water level changes in sampled piezometers for the three sub-catchments

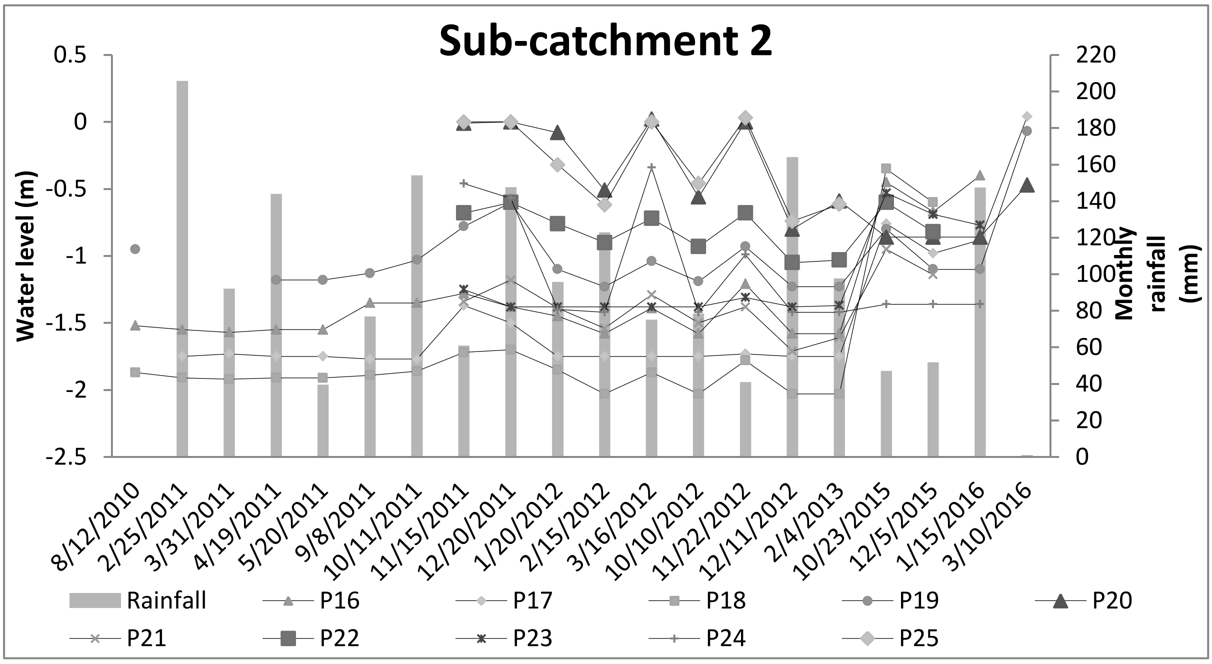
Figure 2 presents the water levels in piezometers for sub-catchment 1 recorded monthly from April 2012 to March 2016. However, not all months were recorded during this period. Water levels were lower than 0.4m in October 2015 to January 2016. In January water levels did not rise despite the amount of rainfall (147.4mm) received. There was however, a distinct rise in water levels in all sampled piezometers in February 2016 when 167.00mm rainfall amount was received. The delayed response of the water level in piezometers to rainfall received indicates the delayed ground water recharge in January. In March low amount of rainfall was received, however, water levels did not fall. This could be the effect of sub-surface recharge.



P1, P2, P3, (etc) – they are different piezometers

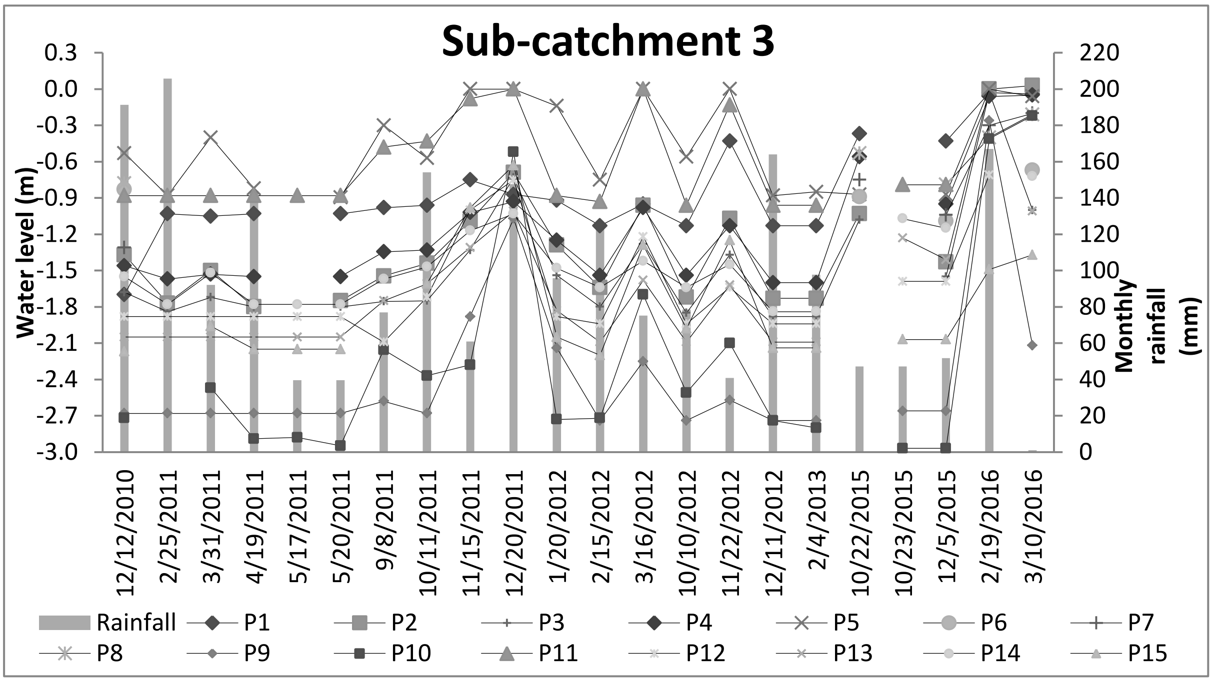
Figure 2: Sub-catchment 1 piezometer water levels and monthly rainfall from April 2012 to March 2016

Figures 3 and 4 display the observed piezometer water levels and rainfall for sub-catchments 2 and 3 respectively measured over a period from August 2010 to March 2016, however, some data are missing and therefore there are gaps on the plotted hydrographs. Considerable amount of rainfall has been received during summer (November to January) and autumn (February to March) in all years and little rainfall fell during winter and spring (May to October). However, hydrographs showed delayed response to summer rainfall and more response in autumn. During October 2015 to March 2016 similar response on the hydrographs to that of sub-catchment 1 was observed where water levels did not rise to the surface regardless of rainfall received. However, high levels of ponding were observed in February 2015. In March, the high water levels were also observed after the rain had stopped. This indicates the presence of the sub-surface flow that feeds the wetland (Troyer, 2013; Poh, 2013).



P16, P17, P18, (etc) – they are different piezometers

Figure 3: Sub-catchment 2 piezometer water levels and monthly rainfall from August 2010 to March 2016



P1, P2, P3, (etc) – they are different piezometers

Figure 4: Sub-catchment 3 piezometer water levels and monthly rainfall from December 2010 to March 2016

The hydro-period ranged from 40% of inundation (water level ranges between 0 and -0.30m), in sub-catchment 1 from October 2015 and March 2016, to 3.7% in sub-catchment 2 (Table 2). Sub-catchment 2 had the lowest hydro-period with only 3.7% of the times that the water was within -0.30m depth from the surface. Both sub-catchments 2 and 3 showed some evidence of surface ponding. The two catchments also show lower hydro-period for the longer monitoring period of August 2010 to April 2013, where percentage inundated time for sub-catchments 2 and 3 were 6.1 and 5.0%, respectively. Sub-catchment 1 also had a hydro-period of 14.7% for the period from April to December 2012 (Table 3).

Table 2: Number of occurrences that the water levels in piezometers were above, within and below the -0.30m depth in the three sub-catchments from October, 2015 to March, 2016.

Water level classes	Sub-catchment 1		Sub-catchment 2		Sub-catchment 3	
	Frequency	%	Frequency	%	Frequency	%
>0.0m	0	0	1	3.7	1	1.9
0.0 to -0.30m	18	40	1	3.7	13	24.1
<-0.30m	27	60	25	92.6	40	74.1
Total	45	100	27	100	54	100

Table 3: Number of occurrences that the water levels in piezometers were above, within and below the -0.30m depth in the three sub-catchments previously monitored by MCA-L from August, 2010 to April, 2013.

Water level classes	Sub-catchment 1		Sub-catchment 2		Sub-catchment 3	
	Frequency	%	Frequency	%	Frequency	%
>0.0m	0	0	2	1.7	0	0
0.0 to -0.30m	5	14.7	7	6.1	10	5.0
<-0.30m	29	85.3	106	92.2	189	95.0
Total	34	100	115	100	199	100

The overall hydro-period of the wetland was estimated to be 11.4%, and does not satisfy the hydrologic criteria which demands for at least 50% hydro-period of the sampled time. The reason might be that the wetland does not store enough water to keep it inundated for a longer time. The results are comparable to the results obtained by Poh (2013) whom observed a shorter hydro-period due to a shallow groundwater table. The results, however, conflict with the observations of Foster (2007), where a semi-annual (180 days each year) hydro-period was obtained.

The observed average soil bulk density for the three sub-catchments ranged from 0.57 to 1.00g/cm^3 with sub-catchment 2 having the highest bulk density (Table 4). The estimated soil porosity was in the range 0.61 to 0.78. The bulk density was low in sub-catchment 1. Mapeshoane (2013) relates a low bulk density in wetlands to the development of peat in the top surface layer of mostly permanently wet soils. Dunne *et al*. (2010) observed a low bulk of $0.345 g/cm^3$ in deep marsh wetland and suggested that it was due to a longer saturation. However, the high bulk density in sub-catchment 2 ($1.00 g/cm^3$) 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). Matano *et al*. (2015) obtained a higher mean bulk density of $0.956 g/cm^3$ and was associated to livestock trampling effects. Lewis and Feit (2015) observed a higher bulk density in short hydro-period swamps depicted by a significant negative correlation coefficient (-0.88^{**}).

Table 4: Average soil bulk density and porosity for the three sub-catchments

Sub-catchments	No. of observations	Bulk density (g/cm^3)	Porosity
1	84	0.57	0.78
2	19	1.00	0.61
3	23	0.80	0.69

2.3.2 Variation of δ^2H and $\delta^{18}O$ in rainfall, stream and piezometers water for the three sub-catchments

Hydrogen and oxygen stable isotopes (δ^2H and $\delta^{18}O$) data of the three sub-catchments for stream and piezometer water are presented in Tables 5 and 6. The obtained rainfall was 64.0 and 10.28‰ (sub-catchment 1), 7.6 and 1.02‰ (sub-catchment 2), 8.0 and 0.42‰ (sub-catchment 3) for δ^2H and $\delta^{18}O$ respectively. Generally, the results on Table 5 show significantly depleted values in piezometers ($P<0.05$) than in streams water in all sub-catchments.

Table 5: The means of δ^2H and $\delta^{18}O$ and T-test results for stream and piezometers water in the three sub-catchments in December 2015.

Sub-catchments	Water source	*n*	Mean (δ^2H and $\delta^{18}O$‰)	Sig. level ($P<0.05$)
1	Stream	8	-2.850	0.02
	Piezometer	8	-11.153	
2	Stream	10	-2.913	0.02
	Piezometer	10	-10.663	
3	Stream	10	1.419	0.00
	Piezometer	10	-11.130	

Table 6: Summary statistics of hydrogen (δ^2H) and oxygen (δ^{18}O) isotopes values relative to VSMOW for water collected from different sources in the three sub-catchments in December 2015.

Sub-catchments	Water source	*n*	Minimum (‰)		Maximum (‰)		Mean (‰)		Std. Deviation	
			δ^2H	δ^{18}O	δ^2H	δ^{18}O	δ^2H	δ^{18}O	δ^2H	δ^{18}O
1	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	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	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

The results are similar to the previous results obtained by other researchers (e.g McGuire *et al*., 2002; Rodgers *et al*., 2005; Ozyurt *et al*., 2014; Tekleab *et al*., 2014). They all found reduced isotopes compositions in either spring, stream, lake and ground water when compared to precipitation. 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 (Tekleab *et al*., 2014; Schwerdtfeger *et al*., 2014).

The observed variation between groundwater and rainfall isotopic compositions demonstrates that the experienced rainfall during December 2015 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). Depleted values with low composition of δ^2H and δ^{18}O are encountered when it is wet during the high groundwater discharge rates while the enriched values appear when it is dry, during the low discharge rates (Ahmad *et al*., 2004).

Mean residence time (MRT) explains the retention duration of the wetland (Schwerdtfeger *et al*., 2014; Sanchez-Murillo *et al*., 2015). Normally short water residence times are indicated by seasonal isotopic enrichments in the water source (precipitation) and output (surface or ground water) (Gibson, 2001) and they depict short retention duration while longer residence times are indicated by seasonal isotopic depletions in the output (Rodgers *et al*. 2005).

Rodgers *et al*. (2005) discovered that, in comparison to precipitation; stream water ^{18}O was highly depleted, reflecting the influence of longer residence time from runoff sources with more stable ^{18}O. Ozyurt *et al*. (2014) also found much depleted^{18}O variations in spring when compared to variations in precipitation and this indicated longer MRTs. Therefore, the highly depleted groundwater and slightly depleted surface water values observed indicate the longer residence time of the wetland. Longer residence times depict a healthier wetland with a long duration of water retention (Gibson, 2001; Rodgers *et al*. 2005).

Figure 5 shows the relationship of isotopes composition to the global meteoric water line (GMWL). The stream water samples plotted to the right of the GMWL, indicating the enrichment of δ^2H and $\delta^{18}O$ as a result of evaporation (Mendoza-Sanchez *et* al., 2013; Tekleab *et al*., 2014; Felstead *et al*., 2015). On the other hand most groundwater samples plotted towards the lower left of the GMWL, indicating depletions of δ^2H and $\delta^{18}O$ (Kohfahl *et al*., 2008; Garvelmann *et al*., 2012). Furthermore, precipitation plotted to the upper right, demonstrating great evaporation enrichments. Evaporation during summer months may result in increased ^{18}O and ^2H in surface water and rainfall while an enrichment of these heavy isotopes in the sub-surface may occur in the uppermost part of the soil column (Garvelmann *et al*., 2012).

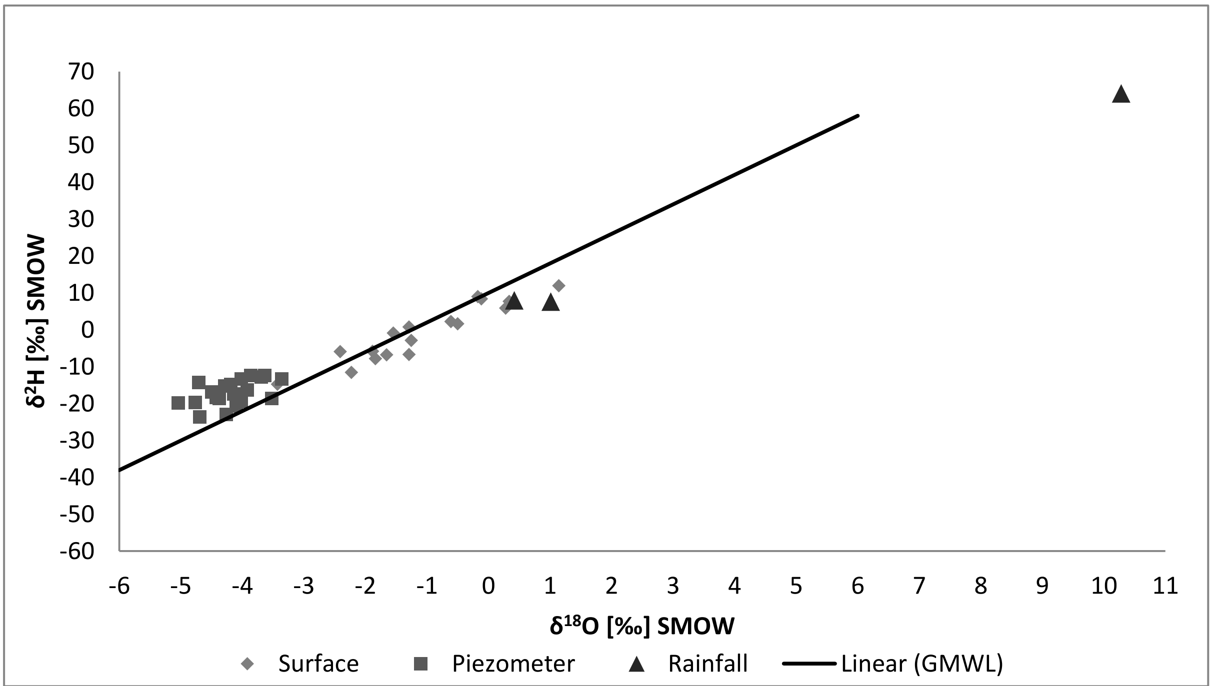


Figure 5: δ^2H and $\delta^{18}O$ data for water samples plotted alongside the global meteoric water line (GMWL)

2.4 Conclusion

The results show that sub-catchment 1 has longer hydro-period (40%) for the monitoring period of October 2015/March 2016. However, the longer monitoring period from 2010 to 2013, shows sub-catchment 2 to depict a slightly longer hydro-period (6.1%) than sub-catchment 3 (5.0%). The hydrographs also 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. This is also substantiated by the most enriched rainfall isotopes composition than depleted groundwater which shows that the experienced rainfall in December 2015 did not recharge the groundwater; however, the response was delayed until February. The average catchment hydro-period of the three sub-catchments is 11.4%. This is insufficient to meet the wetland hydrologic criterion which requires 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.

3. Assessment of water quality in streams and wetlands of Khalong-la-Lithunya, Lesotho.

3.1 Introduction

Water quality is defined differently by engineers, ecologists and hydrologists. Farrell-Poe (2000) defines water quality as a term used to describe the chemical, physical and biological characteristics of water for its suitability for a particular use. 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 in the best way (Mohamed and Zahir, 2013).

Wetlands are the most valuable components of the terrestrial ecosystems and essential part of ecology. Wetlands play important ecological roles such as water quality improvement, nutrient transformation and flood storages. A better water quality exists in those watersheds where wetlands are incorporated into the landscape (White and Fennessy 2005). They assimilate and transform pollutants and nutrient by acting as natural filters (sinks) ensuring that the water being discharged from the wetland to the next streams is of high quality (Johannesson *et al.*, 2015). However, during period of high flow wetlands can become a source of pollutants for adjacent water bodies (Rogers, 2006).

Water quality parameters that are important in wetlands include pH, electrical conductivity (EC), base cations, chemical oxygen demand (COD), biochemical oxygen demand (BOD), phosphorus (P) and nitrogen (N) (Chowdhury *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). The decomposition of the organic material in the form of dead plants and other aquatic life leads to depletion of the dissolved oxygen necessary for the living microorganisms in the water body which are responsible for the degradation of contaminants and pollutants (Hettiarchchi *et al*., 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 (Li *et al*., 2005; Ahmad, 2009; Yao *et al*., 2014). The COD values are ordinarily higher than the BOD values, because COD includes both non-biodegradable and the biodegradable material (Mohamed and Zahir, 2013).

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 (Najeeb *et* al., 2014; 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).

Several studies have studied wetland water quality to evaluate wetland functions and processes. These studies include; Najeeb *et al*. (2014) and Johannesson *et al.*(2015) who studied wetlands to quantify their function as sinks for particles and phosphorus lost from the catchments. The results obtained showed that there was accumulation or retention of phosphorus and particles in the wetland proven by the lower concentration that leaves the wetland compared to the higher concentration that entered the wetland. It was concluded that the wetlands worked well as particles and phosphorus sinks therefore improving water quality.

Rogers (2006) carried out a study to enumerate hydrologic and water quality characteristics of the wetland and observed that the wetland was primarily a phosphorus (P) sink for small storm events and a source for large events because small amounts of P moved in the wetland during small events while large amounts moved out during large events.

Microbes may play an important role in phosphorus removal in wetlands as mineralisers of organic phosphorus via biological mineralization and biochemical mineralization (Truu *et al.*, 2009; Sousa *et al.,* 2015). Microbial activity greatly dependents on the amount of dissolved oxygen which is directly influenced by BOD and COD of the water body and wetlands act very effectively as natural treatment units that support aquatic plants (macrophytes) which are responsible for the removal of COD, BOD and nutrients (Vergeles *et al*., 2015). Vergeles *et al*. (2015) assessed the treatment efficiency of the wetlands and observed a high removal efficiency of both COD and BOD by the wetland depicting a suitably functional wetland. Similarly, Verhoeven *et al*. (1999) obtained high removal rates of COD and BOD when testing the wastewater treatment by wetlands.

Westbrook *et al*.(2011) studied wetlands to determine whether spatial variations in wetland water quality could be attributed to permanence classes and it was found that total phosphorus, total dissolved nitrogen and dissolved organic carbon were high in seasonal than permanent wetlands, this is anticipated to be due to the pronounced periods of flooding and drying that affect seasonal wetlands.

Olaleye *et al*. (2014) results of the hydrochemistry from the installed piezometers in some parts of the Khalong-la-Lithunya showed that pH, EC, Ca, Mg, Na, K & NO_3-N were within the normal range stipulated by the WHO (2004), however, the study did not look at this variables in the adjacent streams and did not include other important water quality parameters such as BOD and COD, hence further studies on hydrochemistry were recommended. Therefore, the objective of this study is to evaluate the water quality of the Khalong-la-Lithunya wetland. Specifically this study aims to; (i) determine the temporal change in water chemistry (pH, EC, base cations (Na, Ca, K, and Mg), BOD, COD, PO_4 and NO_3) in the three sub-catchments of the Khalong-la-Lithunya wetland; (ii) determine water quality index in piezometers and streams within the wetland.

3.2 Material and Methods

3.2.1 Study description

The study was undertaken at Khalong-la-Lithunya palustrine wetland that is located at an altitude of 3100– 3175m 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 geology of this area is recognized as the Lesotho formation with compact and amygdaloidal tholeiitic basalt and it falls within the Afroalpine Grassland zone dominated by grasses (Schmitz and Rooyani, 1987; Mating, 2012). The soils are classified as Moroke series (local name) or *Lithic Cryoborolls* (USDA) or *Dystric Mollic Cryosols* (WRB) along the hillslopes and Oxbow Series (local name) or *Hydric Cryohemists* (USDA) or *Reductaquic Histic Cryosols* (WRB) which dominate the wetlands (MCA-L, 2012). This wetland forms part of the sub-catchment that makes up the main quaternary catchment that acts as headwater of Motete River. The temperature for Khalong-la-Lithunya ranges from 7.6 – 22.4°C. The recorded mean annual rainfall for this area ranges between 1000 and 3000mm (Olaleye *et al*., 2014).

3.2.2 Determination of spatial and temporal change in water quality of the three sub-catchments of Khalong-la-Lithunya

To assess the water quality of this wetland, water samples were collected along the streams flowing within each sub-catchment and from the installed piezometers to determine biological oxygen demand (BOD), chemical oxygen demand (COD), electrical conductivity, water pH, nitrates, phosphates and basic elements. The water samples were collected on monthly basis from October 2015 to March 2016. In streams, the samples were collected on positions adjacent to the wetland patches in order to determine the influence of the wetland. The samples were collected using a water grab sampler in the piezometers. Eighteen (18) stream water samples were taken each time of sampling while in piezometers the number of samples depended on the number of piezometers that had water during each sampling. The water samples were bottled in polyethylene plastic bottles which had been soaked in 10% nitric acid overnight and then rinsed with distilled water. After sampling the samples were preserved by storing in insulated cooler containing ice-packs and transported to the laboratory and stored in a refrigerator at 4^{o}C until the analyses were done.

In the laboratory pH and EC of each sample were measured using digital pH and electrical conductivity meters. The samples were divided into 3 replicates and analyzed for base cations (Na, Ca, K and Mg) by use of flame atomic absorption spectrophotometry (AAS). BOD was analyzed using a 5 - days BOD test while COD was determined by titration of the water samples with standardised ferrous ammonium sulphate solution. Phosphates and nitrates were measured calorimetrically using ascorbic acid and brucine sulfanilic acid methods, respectively. They were measured at wavelengths of 880 and 410nm, respectively.

3.2.3 Determination of water quality indices

The quality of water for wetlands ground water (piezometers) and streams within the wetlands was calculated using water quality index (WQI) for data with missing parameters (Hariharan *et al*., 2010; Srivastava and Kumar, 2014; Pathak *et al*., 2015). Water quality index is the rating that reflects the composite influence of different water quality parameters on the overall quality of water. It indicates quality with an index number which represents the overall water quality of the water for any intended use (Yogendra and Puttaiah, 2008; Gupta *et al*., 2012; Pathak *et al*., 2015). It was calculated using the following formula as given by Hariharan *et al*. (2010); Gupta *et al*. (2012); Srivastava and Kumar (2014):

$$WQI = \sum W_x Q_x / \sum W_x$$

Where: x = water quality parameters

W_x = weight factors of water parameters

Q_x = q-values of water parameters

The weighted factors are given in Table 6. The q-values are calculated from the concentration of used parameters. Water quality index was categorised in ranges according to arithmetic WQI method by Brown *et al*.(1972) also indicated in Hariharan *et al*. (2010); Chowdhury *et al*.(2012); Pathak *et al*.(2015) (Table 7).

Table 7: Weighted factors of water quality parameters (Srivastava and Kumar, 2013).

Parameters	Weighting Factors
pH	0.11
E.Coli	0.16
DO	0.17
Temperature	0.10
BOD	0.11
Nitrate	0.10
Phosphate	0.10
Turbidity	0.08
TDS	0.07

Table 8: Water quality ranges (Brown *et al*., 1972)

Index Ranges	Water Quality
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very poor
>100	Unsuitable

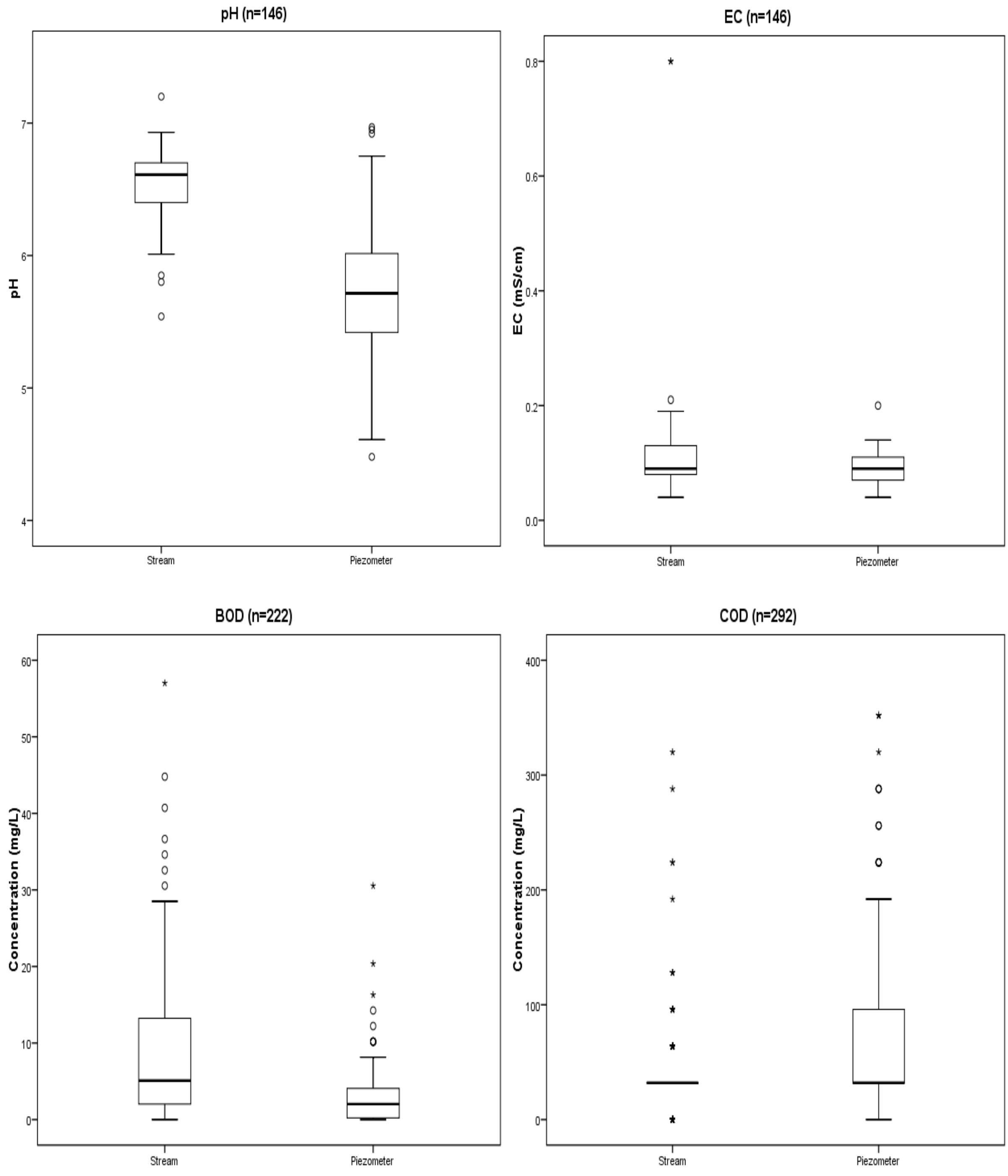
3.2.4 Analysis of water quality data

Statistical data distribution of stream and piezometers water quality parameters was explored using box and whisker plots. The means of water quality parameters for streams and piezometers were compared with WHO standards for streams. The relationship between the water quality parameters was estimated by using Pearson's correlation matrix and 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. The analyses were done using SPSS (version 24) and excel.

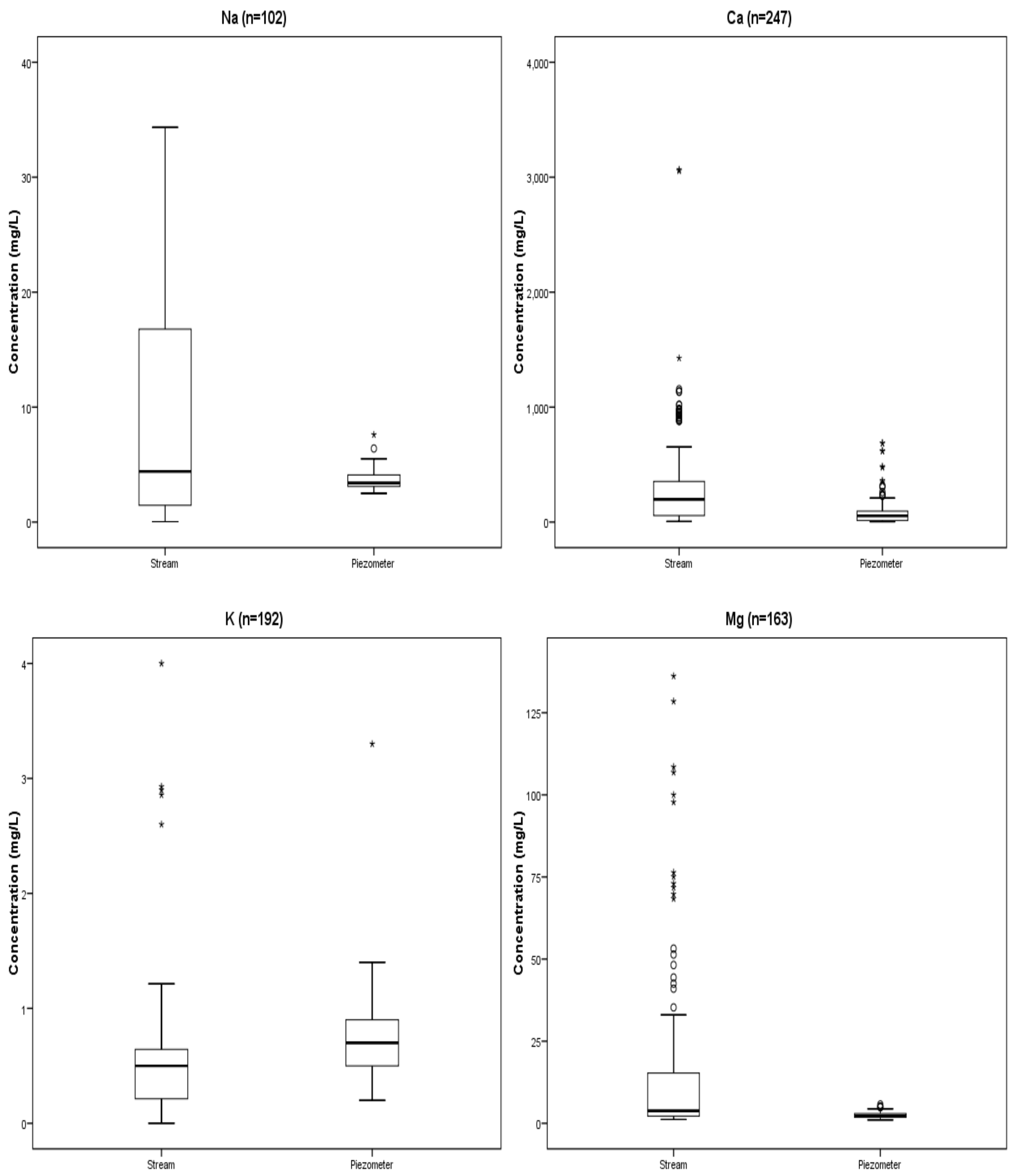
3.3 Results and Discussion

3.3.1 Range of selected water parameters in the streams and piezometers

The temporal and spatial data distributions for all measured parameters for all months in all sub-catchments are presented on the box and whisker plots (Figure 6). The boxplots show that the data of measured variables depart away from normality with skewness and suspected extreme values except for water pH, EC and potassium in piezometers as indicated by the median line which is in the middle of the box. However, Na in stream and phosphate in piezometers do not have suspected extreme values even though data are skewed. Skewness indicates that the intrinsic water quality is compromised due to unsymmetrical distribution of various water quality parameters in the study area.



pH (n=146)
pH
Stream
Piezometer
EC (n=146)
EC (mS/cm)
BOD (n=222)
Concentration (mg/L)
COD (n=292)



Na (n=102)
Ca (n=247)
K (n=192)
Mg (n=163)
Concentration (mg/L)
Stream
Piezometer
0
10
20
30
40
1,000
2,000
3,000
4,000
1
2
3
4
25
50
75
100
125

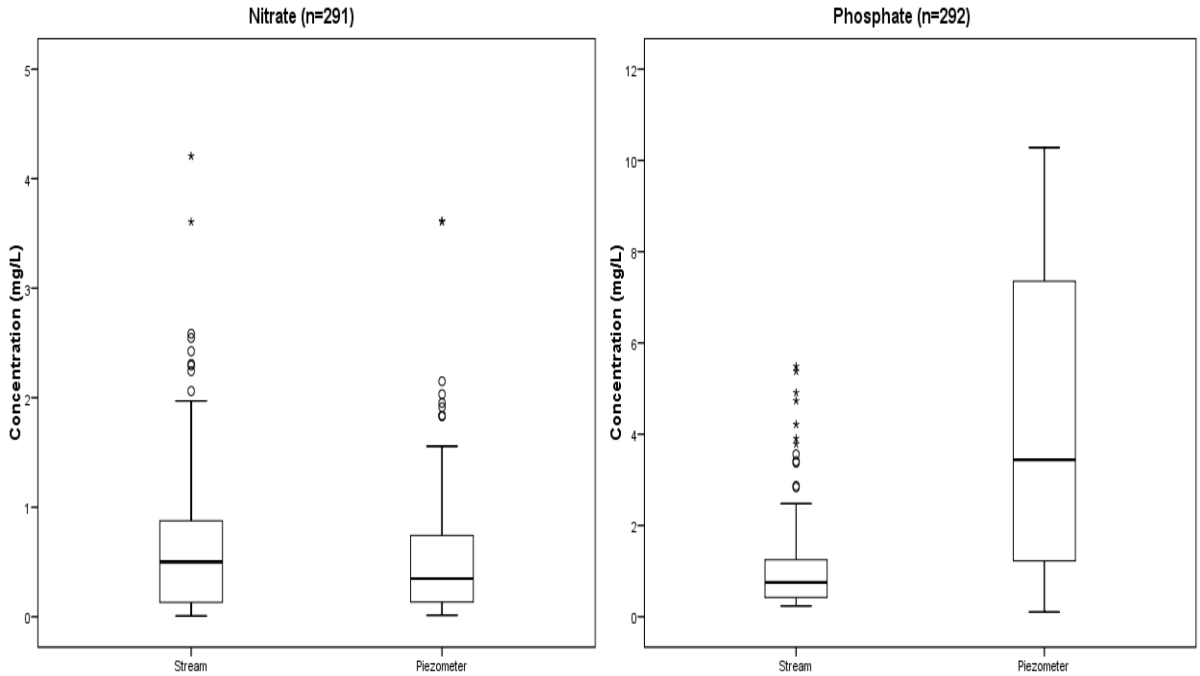


Figure 6: Box and whisker plots for water chemical properties for both stream and piezometer water samples

† Median is indicated by a thick line inside the box and shows normality or skewness of data.
‡ The lower edge of the box represents the 25th percentile while the cross bar at the end of the lower whisker represents the minimum, which is the lowest observed value. The upper edge of the box shows the 75th percentile and the cross bar at the end of the upper whisker shows the maximum value (the highest observed value).
††Suspected extreme values are indicated by circles and stars.

The water chemical parameters means for stream and piezometer were compared with the World Health Organisation (WHO) water standards (Table 9). Both the pH and EC are lower in piezometer than in streams. This might be due to high organic matter in the soil which is being degraded by the microbes producing high concentrations of dissolved carbon dioxide. This process results in lower pH in groundwater by increasing the carbonic acid concentration in the soil water. The pH in stream is within the acceptable limits of the WHO pH standard. The piezometer pH 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 and piezometer falls within the prescribed limit by WHO. Mating (2012) obtained pH and EC that ranged between 5.47 – 6.89 and 0.07 – 0.61dS/m respectively, in the streams of the same study area. Olaleye *et al*. (2014) however, found pH and EC ranging between 6.13 – 6.44 and 0.11 – 0.33mS/cm respectively, in the piezometers of the same study area. Ramsingh *et al*. (1998) reported a pH of 7.3 – 8.4 and EC of 7.0 – 9.8mS/m in the Katse Dam.

Table 9: Mean values for stream and piezometer's water chemical parameters and WHO standards (World Health Organization, 2004).

Variables	Units	Means		WHO standards
		Streams	Piezometers	
pH	pH units	6.525	5.700	6.5 – 8.5
EC	mS/cm	0.118	0.090	1.5
BOD	mg/L	9.027	3.633	5
COD	mg/L	42.051	80.471	10
Na	mg/L	13.266	3.758	200
Ca	mg/L	330.467	99.163	200
K	mg/L	0.554	0.754	12
Mg	mg/L	19.236	2.516	150
NO_3	mg/L	1.309	0.573	50
PO_4	mg/L	1.074	4.146	0.01–0.1

† EC-electrical conductivity, Na-sodium, Ca-calcium, K-potassium, Mg-magnesium, BOD-biochemical oxygen demand, COD-chemical oxygen demand, NO_3-nitrate, PO_4-phosphate

Biochemical oxygen demand (BOD) in streams (9.027mg/L) exceeds WHO standard (5mg/L) while that in piezometers (3.633mg/L) is within the limits. The COD in both stream (42.051mg/L) and piezometers (80.471mg/L) is beyond the WHO permissible limit (10mg/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 (Mohamed and Zahir, 2013). COD is higher than BOD because it includes both biodegradable and non-biodegradable material. Mohamed and Zahir, 2013 also obtained a higher COD that ranged between 25 to 95mg/L in groundwater.

All bases (Mg, K and Na) except Ca in streams are noticeably very low when compared with the cut off points of the WHO standards (Table 9). Mating (2012) and Olaleye *et al*. (2014) also observed markedly very low base cations over years at Khalong-la-Lithunya. The results of the base cations show higher concentrations in streams than in piezometers except for potassium which was slightly higher in piezometers. The higher concentration of base cations in stream than piezometer water reflects the exposure of stream water to great evaporation (Beutler, 2012; Poh, 2013). However, low concentration of base cations in the piezometers predicts the precipitation of these ions in the soil water or points to sorption of these ions to the surface of suspended particles in the ground water (Al-Charideh and Hasan, 2013). This might have also been brought about by the acidification effect due to an acidic pH (5.700) in piezometer water which leads to depletion of cations (Poh, 2013). High concentration of potassium in piezometer water may be ascribed to dissolution of potassium from the minerals (Singh *et al*., 2004; Poh, 2013).

Stream and piezometers nitrate levels are within WHO standard (50mg/L) and are relatively low (1.309 and 0.573mg/L) for stream and piezometers respectively. Nitrates are low in piezometers 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 (Verhoeven *et al*., 1999; Liescheidt, 2012; Mohamed and Zahir, 2013; Sirajudeen *et al*., 2014).

Phosphate means in both stream (1.074mg/L) and piezometers (4.146mg/L) are relatively higher than permissible WHO levels (0.1mg/L). High phosphates concentration in piezometers than in stream agrees with the phosphates results obtained by Olaleye *et al*. (2014) on the same study area. Olaleye *et al*. (2014) associated the high phosphate in piezometers to 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, however when the conditions turn into anaerobic as a result of flooding, iron (III) gets reduced to iron (II) leading to release of the phosphates into the sub-surface water, thus resulting in increased P concentration (Verhoeven *et al*., 1999). Phosphates retention may also be associated with hydraulic loading in wetlands (Johannesson *et al*., 2015).

3.3.2 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 q-values of the used parameters were determined from their concentrations (Yogendra and Puttaiah, 2008) and are given in Tables 10 and 11 for streams and piezometers respectively. 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 fall within the range 51–75.

Table 10: Concentration in streams, weighted factors and q-values of available water quality parameters

Parameters	Concentration	Wx	Qx	WxQx	WQI
pH	6.52	0.11	72	7.92	
BOD	9.03mg/L	0.11	36	3.96	
NO_3	0.67mg/L	0.10	95	9.5	
PO_4	1.07mg/L	0.10	37	3.7	
		∑Wx = 0.42	∑Qx = 240	∑WxQx = 25.08	59.71

† Wx – weighted factors
‡Qx – q-values

Table 11: Concentration in piezometers, weighted factors and q-values of available water quality parameters

Parameters	Concentration	Wx	Q-value	WxQx	WQI
pH	5.70	0.11	42	4.62	
BOD	3.63mg/L	0.11	62	6.82	
NO_3	0.57mg/L	0.10	96	9.6	
PO_4	4.15mg/L	0.10	15	1.5	
		∑Wx = 0.42	∑Qx = 215	∑WxQx = 22.54	53.67

† Wx – weighted factors
‡Qx – q-values

Wetlands are said to improve water quality through settlement of suspended solids, diffusion of dissolved nutrients into the sediment, mineralisation of the organic material, nutrient uptake by the micro-organisms and vegetation, microbial transformations as well as through physico-chemical adsorption and precipitation in the sediment to ensure that when water gets discharged from the wetland to the streams is of high quality (Noe and Hupp, 2007; Olaleye *et al*., 2014; Yu *et al*., 2015; Johannesson *et al*., 2015). The current observed higher WQI in streams than piezometers indicate additional source of pollutants from surface flow.

3.3.3 The relationship between water chemical parameters for stream and piezometers

There is a significant positive correlation ($P<0.05$) between stream pH and stream Na, Mg and NO_3 (Table 12). A positive correlation between pH and NO_3 relates to increased nitrification under high pH (Vymazal, 2007). Water pH in piezometers significantly correlates positively ($P<0.05$) with EC, and negatively ($P<0.01$) with piezometer NO_3 which indicates the susceptibility of NO_3 to leaching under relatively acidic conditions (Charkhabi and Sakizadeh, 2006). Water pH also correlates negatively with PO_4 ($P<0.05$) in piezometer which indicates phosphate retention under low pH. Stream EC has a significant positive correlation ($P<0.05$) with stream K.

There is a positive significant correlation between Na, and pH and EC at $P<0.05$, and Ca and BOD at $P<0.01$ in streams. In piezometers, Na significantly correlates positively ($P<0.01$) with all other base cations. However, Na in stream correlates negatively and significantly ($P<0.01$) with piezometer NO_3. Calcium (Ca) in streams is positively and significantly correlated with Mg in streams at $P<0.05$. Furthermore, Ca in piezometers correlates positively and significantly ($P<0.01$) with K and Mg, however, it significantly correlates ($P<0.01$) negatively with PO_4. There is an observed negative significant correlation between Ca in streams and pH, Na, Ca, BOD at $P<0.05$ and COD at $P<0.01$ in piezometers. Potassium in streams is significantly ($P<0.01$) correlated with PO_4 in stream. Moreover, it is significantly ($P<0.05$) correlated positively with BOD and NO_3 and negatively with pH and Ca. A positive correlation between potassium and BOD reflects the solubility of potassium under reduced conditions because high BOD means oxygen depletion (reduced conditions). There is a negative correlation which is significant between Mg in streams and PO_4 in both streams ($P<0.01$) and piezometers ($P<0.05$). Concentrated magnesium (Mg) displaces aluminium and iron from the soil surfaces leading to the release of phosphates (PO_4) (Vymazal, 2007).

Water BOD in piezometers has a significant positive correlation with COD in piezometers at $P<0.01$, however it correlates negatively with PO_4 in piezometers at significance level $P<0.05$. Stream BOD and COD in piezometers have a significant positive correlation at $P<0.05$. A positive significant correlation between BOD and COD relates to organic matter decomposition. While COD in piezometers correlates negatively at $P<0.05$ with PO_4 in piezometers, COD in streams correlates positively at $P<0.05$ with piezometer Ca and NO_3 and also correlates negatively with piezometer pH at $P<0.05$. Phosphate in streams significantly ($P<0.01$) correlates positively with NO_3 in piezometers while it significantly ($P<0.05$) correlates negatively with piezometer pH and Ca. The piezometer PO_4 is negatively correlated will all the parameters that it relates significantly with.

The principal component analysis (PCA), eigenvalues (Table 13) and the scree plot (Figure 7) indicate factors that affect water quality of the wetland (Singh *et al*., 2004; Kumar *et al*., 2010; Bhat *et al*., 2014). Three significant factors accounted for 52.56% of the variation in the data set. Factor 1 accounts for 27.99% of the total variance while Factor 2 explains 13.08% of the total variance. Factor 3 accounts for 11.48% of the variance (Table 13).

The factor loadings greater than 0.50 were considered to be the main sources of variability in each factor (Gbolo and Gerla, 2013). Factor 1 has positive loadings on Na, pH, Mg, BOD, NO_3^-, Ca and EC, however, Na, pH and Mg have highest loadings (>0.50) indicating that they are the most influencial factors that account for most variance brought by factor 1. This reflects that factor 1 originates 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). pH also affects the solubility of metals and activity of the micro-organisms (Gupta *et al*., 2012; Najeeb *et al*., 2014).

Table 12: Correlation between measured water chemical parameters in stream and piezometer water

	Stream										Piezometer									
	pH	EC	Na	Ca	K	Mg	BOD	COD	NO_3	PO_4	pH	EC	Na	Ca	K	Mg	BOD	COD	NO_3	PO_4
Stream																				
pH	1																			
EC	0.17	1																		
Na	0.36*	0.04	1																	
Ca	0.17	0.15	-0.07	1																
K	0.09	0.22*	-0.02	-0.01	1															
Mg	0.46*	0.12	0.06	0.21*	-0.18	1														
BOD	-0.20	-0.07	-0.13	-0.01	-0.12	-0.19	1													
COD	-0.03	0.02	0.08	0.03	0.16	0.00	0.03	1												
NO_3	0.27*	0.04	0.04	-0.03	-0.02	0.10	-0.09	0.05	1											
PO_4	-0.16	0.00	-0.08	0.05	0.30**	-0.33**	-0.08	0.09	-0.06	1										
Piezometer																				
pH	0.05	0.03	0.32*	-0.25*	-0.26*	0.27	-0.05	-0.28*	0.16	-0.27*	1									
EC	-0.11	-0.23	0.31*	-0.08	-0.14	0.07	-0.00	0.04	-0.09	-0.14	0.28*	1								
Na	-0.01	-0.17	-0.02	-0.26*	-0.22	-0.08	-0.15	-0.04	0.07	-0.23	0.14	0.14	1							
Ca	0.09	-0.09	0.27**	-0.21*	-0.21*	0.17	-0.07	0.23*	-0.05	-0.22*	0.15	0.14	0.51**	1						
K	0.13	-0.08	0.03	-0.13	-0.17	-0.03	-0.15	0.02	0.01	-0.24	0.20	0.06	0.77**	0.50**	1					
Mg	0.08	-0.12	-0.04	-0.22	-0.23	0.03	-0.01	0.06	-0.16	-0.15	0.27	0.00	0.34**	0.53**	0.06	1				
BOD	0.13	-0.01	0.31**	-0.20*	0.22*	0.13	0.04	-0.01	-0.16	0.08	0.10	0.06	0.08	0.10	0.16	-0.17	1			
COD	-0.02	-0.16	0.01	-0.30**	-0.02	-0.12	0.18*	0.07	-0.02	-0.08	0.02	-0.19	0.13	0.08	0.01	0.08	0.30**	1		
NO_3	0.05	0.09	-0.24**	0.17	0.19*	-0.09	0.12	0.17*	-0.01	0.32**	-0.36**	-0.21	0.04	-0.13	-0.02	-0.03	-0.07	0.00	1	
PO_4	-0.26*	0.02	-0.23*	0.06	-0.03	-0.22*	0.15	-0.08	-0.02	-0.04	-0.02	-0.07	0.06	-0.40**	-0.10	-0.08	-0.22*	-0.21*	0.05	1

*significant at 0.05 level; **Significant at 0.01 level

Table 13: Eigenvalues, percentage variance and cumulative percentage of the components

Components	Eigenvalue	% variance	% cumulative
1	2.799	27.99	27.99
2	1.308	13.08	41.08
3	1.148	11.48	52.56
4	0.998	9.94	62.49
5	0.902	9.02	71.52
6	0.813	8.13	79.64
7	0.740	7.40	87.05
8	0.594	5.94	92.99
9	0.411	4.11	97.10
10	0.290	2.90	100.00

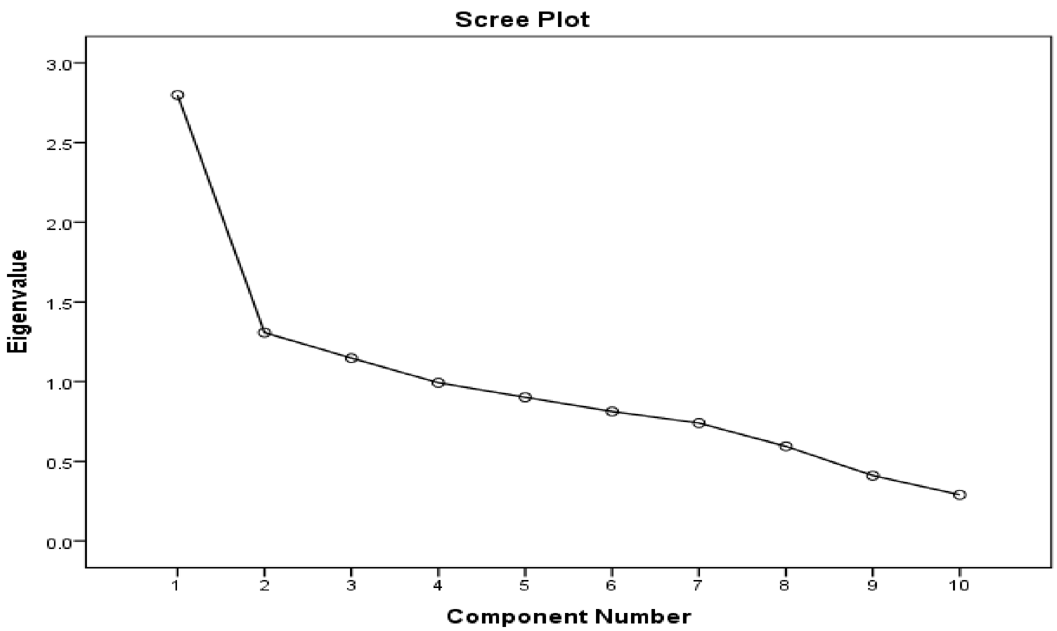


Figure 7: Scree plot of eigenvalues versus component numbers

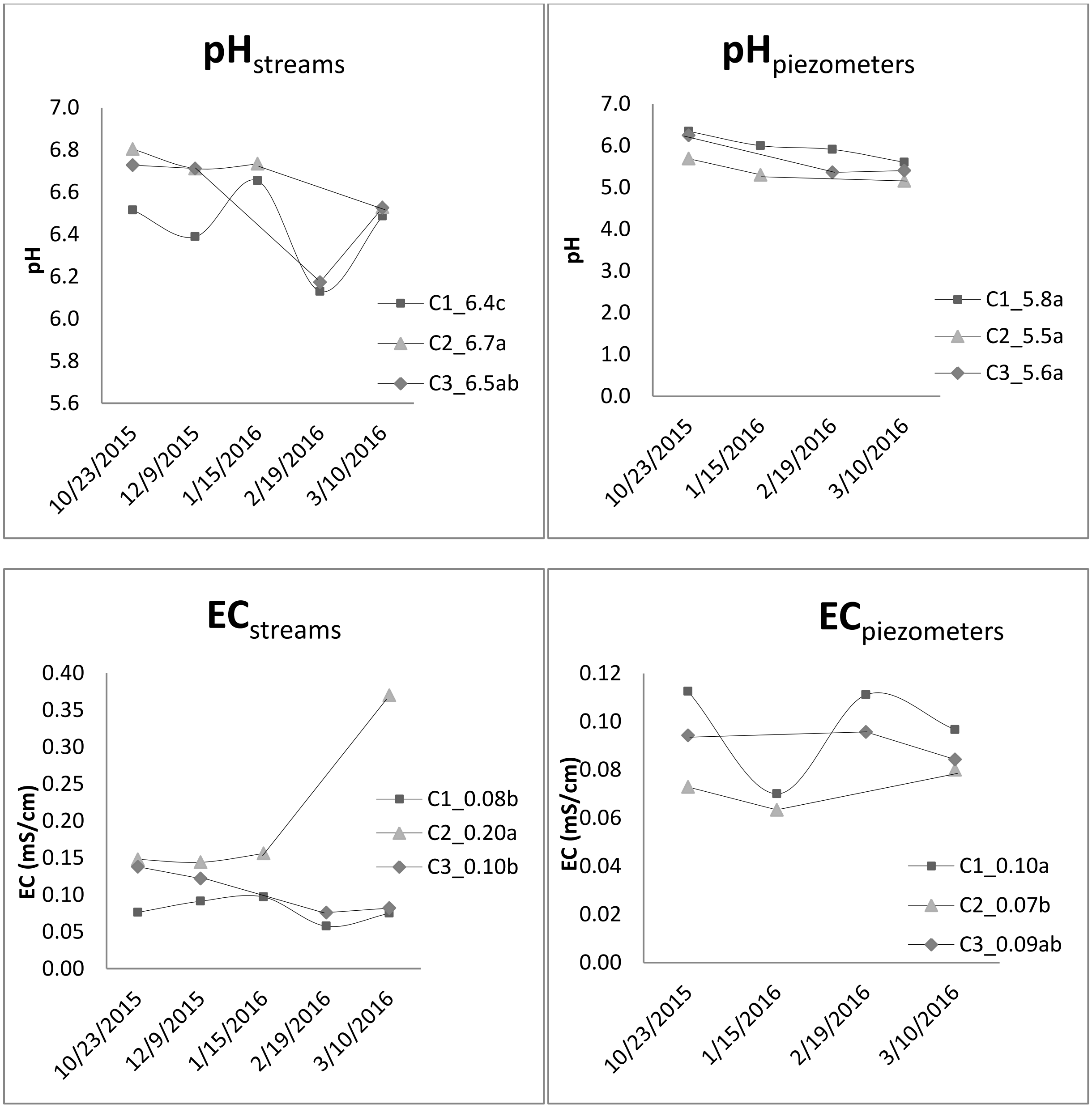
The second factor (Factor 2) has positive loadings on pH, COD, BOD, K and Ca, however, BOD shows the highest loading (>0.50). This factor points to high organic material and anthropogenic effects because of high BOD, it reflects that large organic matter component gets decomposed and during the process, oxygen is used up leading to anaerobic fermentation which produces ammonia and organic acids. Consequently, the hydrolysis of these acidic materials leads to a decrease in the pH of the water (Singh *et al*., 2004). The large organic material is assumed to be constituted by the dead plant material that resulted from the high NO_3 levels in streams (Table 9) leading to extensive growth and increased death of the plants. Factor 3 has high positive loadings on K, Ca and EC (>0.50) indicating 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; Beutler, 2012; Thompson, 2012; Al-Charideh and Hasan, 2013). Generally, the PCA indicates that the water quality of Khalong-la-Lithunya is greatly influenced by natural hydro-chemical processes, and to a less extends by; anthropogenic factors, soil constituents and the geology of the area.

Table 14: 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**

3.3.4 Temporal variation in water quality parameters

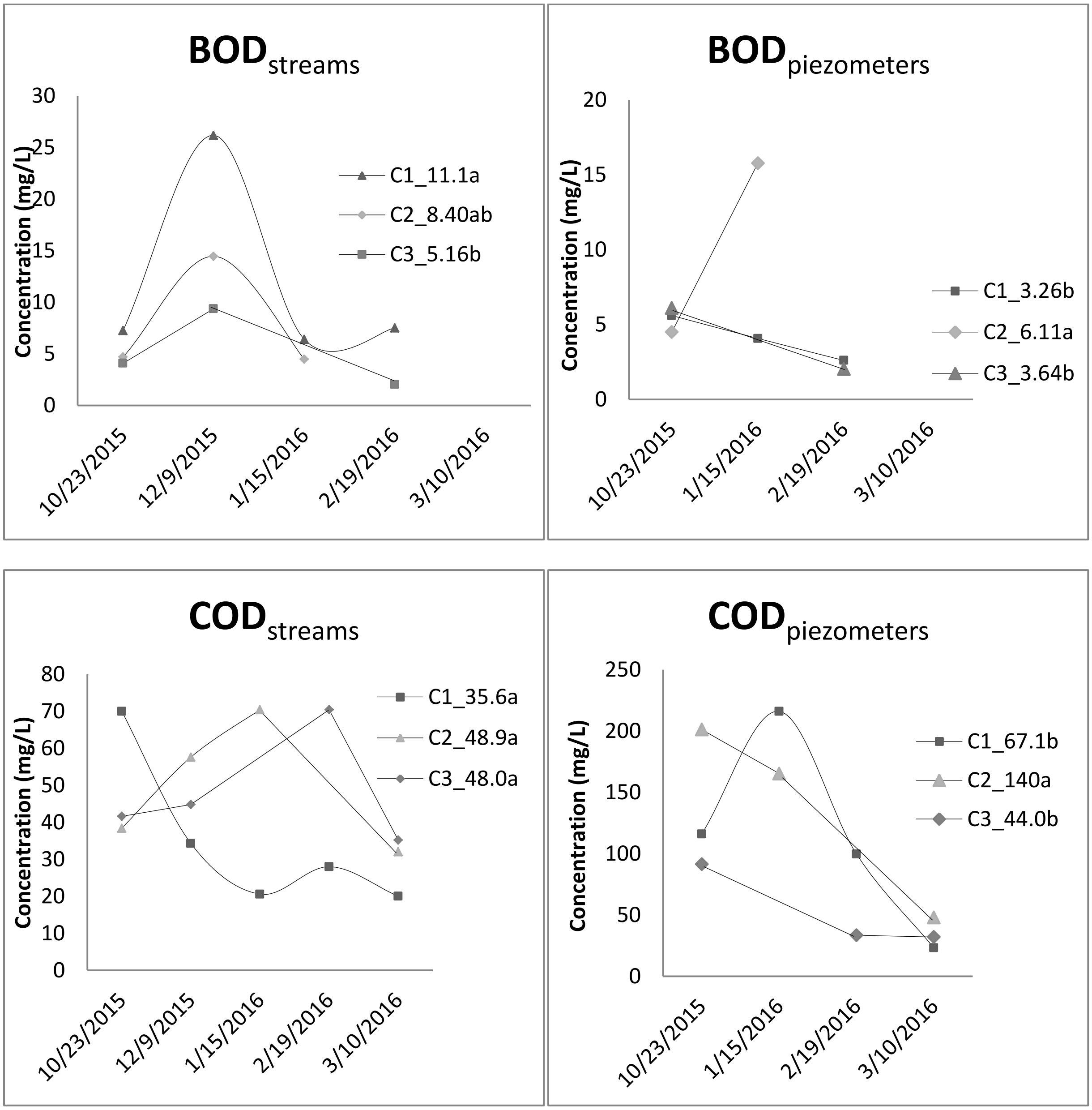
Figure 8 shows the temporal variation in pH and EC of both stream and piezometer water between the three studied sub-catchments of Khalong-la-Lithunya wetland. Water pH and EC were high in the streams of sub-catchment 2 (6.7 and 0.20mS/cm) throughout the season. They were observed as such during dry months (Figure 8) which could suggest that the water has been subjected to great evaporation. This concentrates the water with dissolved solids contributing to high EC (Mekiso, 2011). The low EC values during the wet conditions show the mixing with fresh water (Yuan *et al.*, 2011; Poh, 2013).



Means with the same letter are not significantly different at 5% level

Figure 8: Duncan mean test and monthly trend of pH and EC for stream and piezometers water samples of the three sub-catchments (C1, C2 and C3).

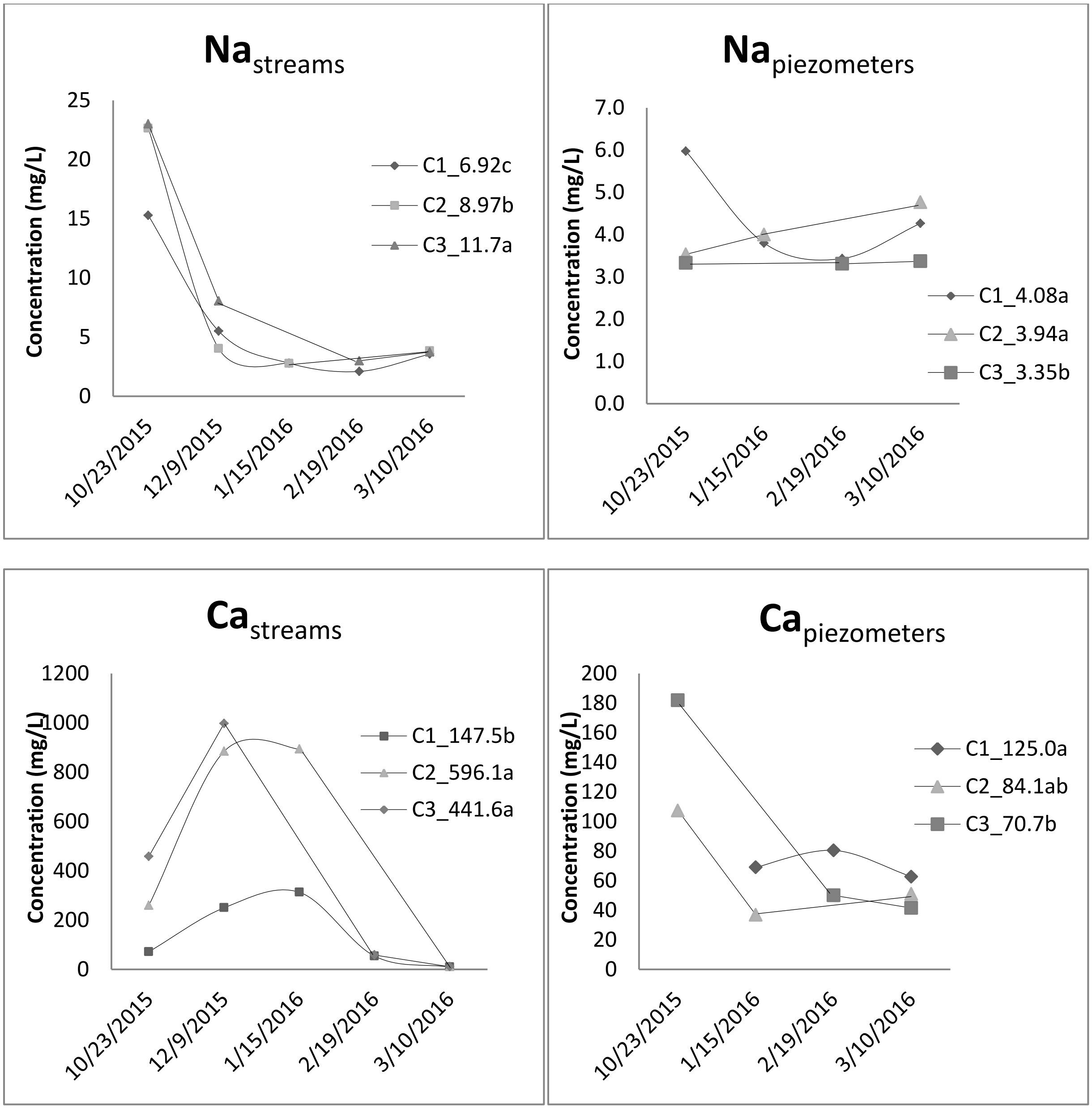
The BOD and COD gave inconsistent trends throughout the season; however their concentration was decreased at the end of the season (Figure 9). The BOD increased from the start of the season (October 2015) and decreased towards the end (February 2016) in streams with the highest mean in sub-catchment 1. In piezometers BOD decreased continually throughout the season except for sub-catchment 2. The COD in streams depicted a fluctuating trend during the season in sub-catchments 2 and 3 but decreased continually in piezometers for the same sub-catchments.



Means with the same letter are not significantly different at 5% level

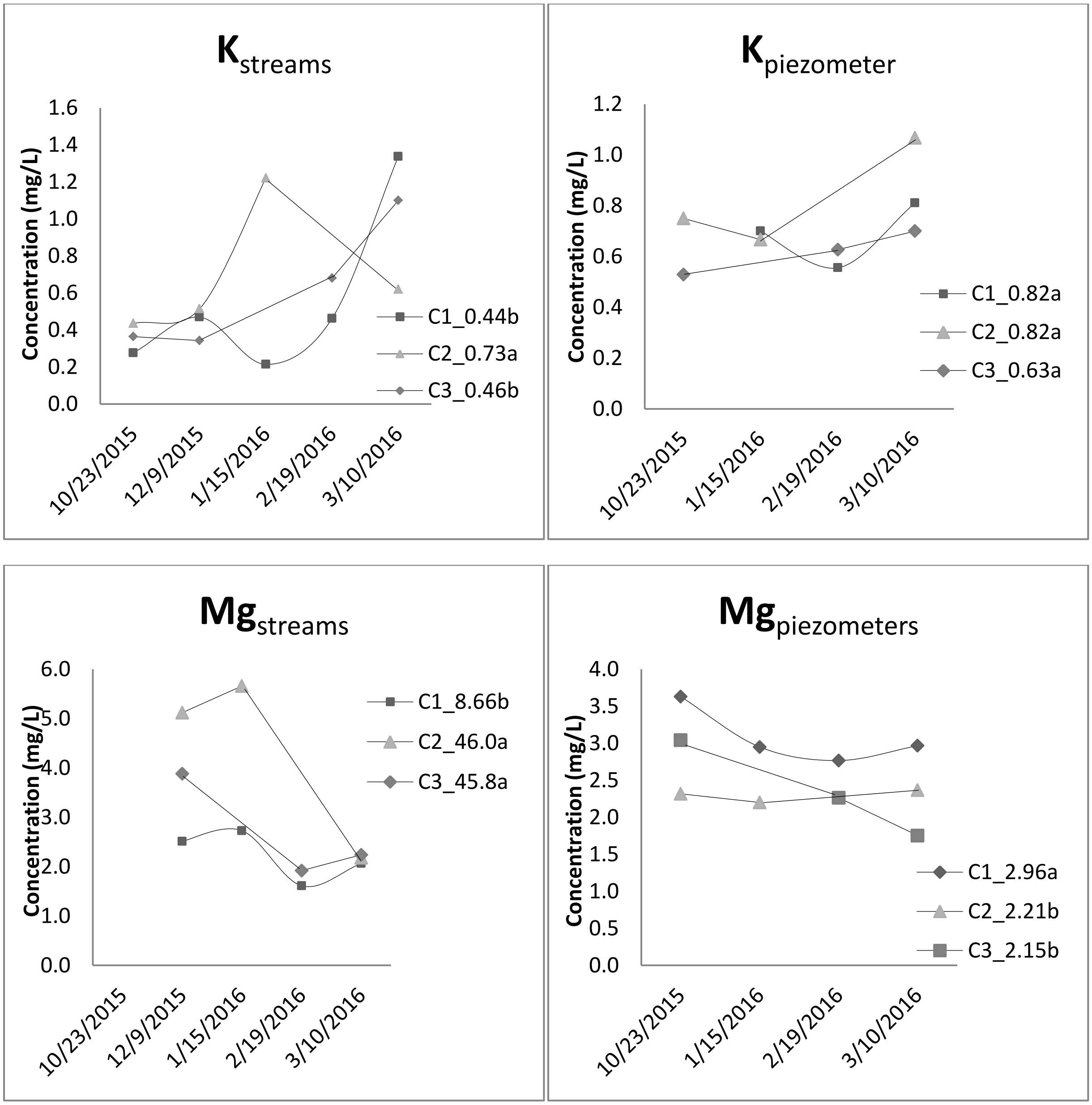
Figure 9: Duncan mean test and monthly concentration of BOD and COD for stream and piezometers water samples of the three sub-catchments (C1, C2 and C3).

All base cations in streams are higher in sub-catchment 2 than in other sub-catchments except Na which is significantly high in sub-catchment 3 (Figure 10). However, higher concentrations of base cations in piezometers were observed in sub-catchment 1. Similar to EC in Figure 8, all base cations show a decreasing trend from the highest values at the start of the season.



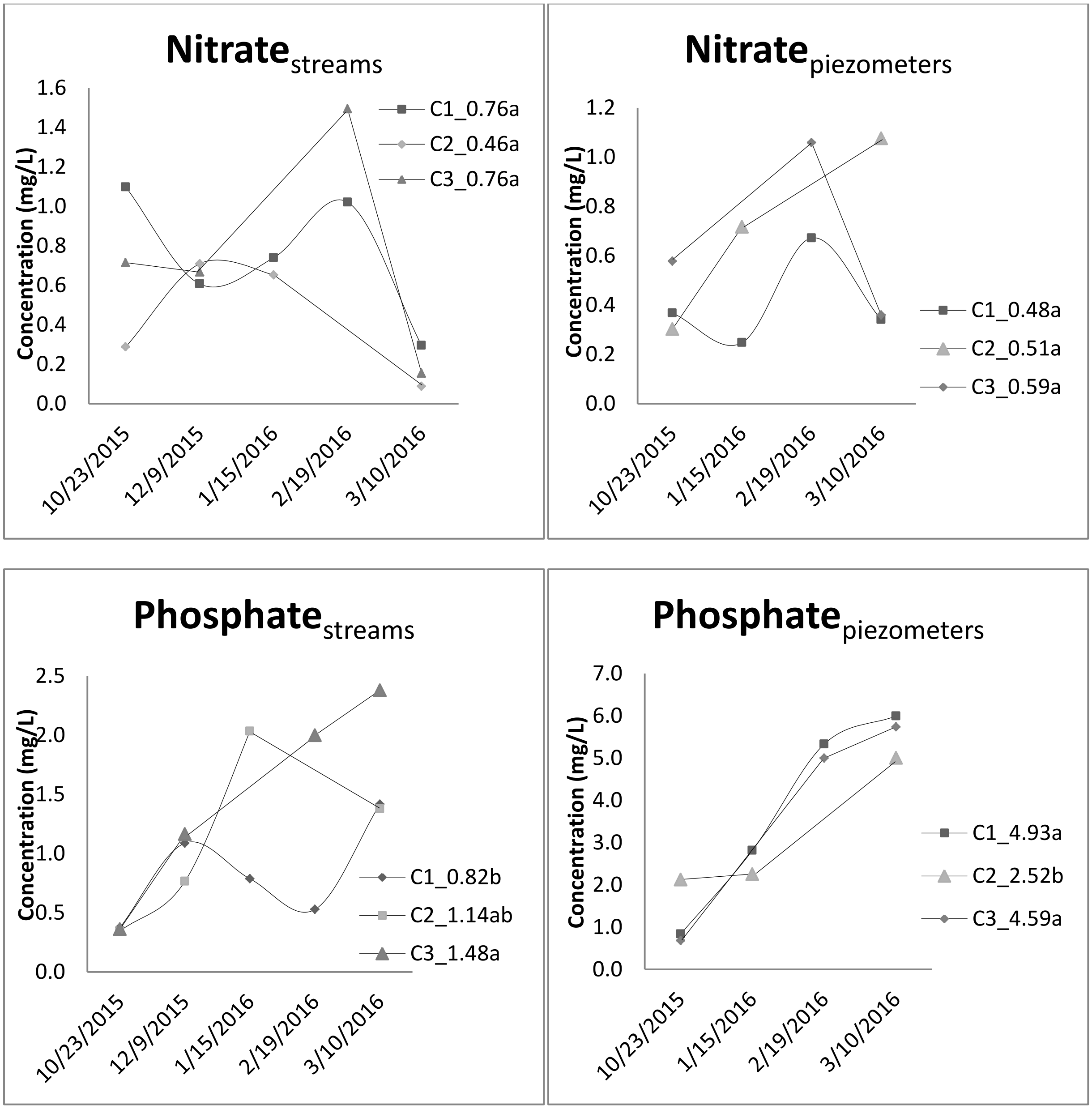
Means with the same letter are not significantly different at 5% level

Figure 10: Duncan mean test and monthly base cation's concentration for stream and piezometers water samples of the three sub-catchments (C1, C2 and C3).



Continuation of Figure 10: Duncan mean test and monthly base cation's concentration for stream and piezometers water samples of the three sub-catchments (C1, C2 and C3).

Nitrates also have a non-consistent trend throughout the season in streams while in piezometers sub-catchment 2 has a consistent increase. Phosphate was continually increasing with time in both stream and piezometer for all sub-catchments except for phosphate in streams of sub-catchments 1 and 2.



Means with the same letter are not significantly different at 5% level.

Figure 11: Duncan mean test and monthly concentration of nitrate and phosphate for streams and piezometers water samples of the three sub-catchments (C1, C2 and C3).

3.4 Conclusion

The most water quality parameters monitored over a period of 5 months from October 2015 to March 2016 (pH, EC, BOD, NO_3, Na, Ca and Mg) were higher in streams than in piezometers and were all within WHO permissible limits except Ca and BOD. Streams PO_4 and COD were also not within the WHO acceptable limits. In piezometers, K, COD and PO_4 were high and all were not within WHO standards except K. Water pH in piezometers was also lower than WHO set limits. The higher concentration of most parameters observed in streams water than in piezometers 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 are responsible for the variation in water quality are related to natural hydro-chemical processes (Na, Mg and pH) than the anthropogenic factors (BOD), as well as geology and soil constituents (K, Ca and EC). Na and Mg affect the EC and pH of water hence lower the water quality. BOD to a lesser extend indicates the organic loading from decomposing material. Sub-catchment 2 has most elevated concentrations of the chemical properties in the stream while sub-catchment 1 has high levels in piezometers. The monthly trend analysis demonstrates that most parameters have high concentration during dry conditions (October 2015 and December 2015).

Although, most of the chemical parameters are within the WHO permissible limits, the water quality index is poor. The poor index is attributed to ion exchange and anthropogenic factors such as organic pollution.

4. General discussion, conclusions and recommendations

4.1 Discussion

Generally, it was observed that, significant amount of rainfall has been received during summer and autumn in all years and little rainfall fell during winter and spring. However, hydrographs showed delayed response to summer rainfall and more response in autumn. The hydrographs that have water levels not responding to the amount of rainfall received and the depleted isotopes composition in piezometers when compared to rainfall illustrate the delayed groundwater response to rainfall. Consequently, this leads to a short overall hydro-period (11.4%) of the wetland because it does not satisfy the hydrologic criteria which demands for at least 50% inundation of the sampled time. The obtained results show that sub-catchments 2 and 3 mostly contributed to the short overall hydro-period. This could be because of the observed high bulk density in both sub-catchments although not statistically proven.

The observed high water levels after the rain had stopped and streams water that contains a proportion of groundwater isotopic composition confirm that there has been evidence of groundwater discharge or sub-surface flow that feeds the wetland during the dry periods maintaining the flow of the wetland stream. The isotopes of streams water plotted to the right of the global meteoric water line (GMWL) together with base cations and EC concentrations that were high in streams water reflect the evaporation effect on the streams water. This is also substantiated by the trend analysis that demonstrates high concentration of parameters during dry conditions (October and December 2015) when the evaporation rate is thought to be high. However, low concentrations of the water quality parameters during wet conditions show the influence of fresh water.

The poorer WQI and higher concentration of most parameters in streams than in piezometers indicate the additional source of pollutants from surface flow. The PCA demonstrates that the wetland water quality is influenced mostly by Na, pH and Mg that relate to hydro-chemical processes and to a less extend by organic pollution, soil and geology of the area. This is also supported by a significant positive correlation between pH, Na and Mg in streams on the correlation matrix which relates to the mechanism of basic ion exchange.

4.2 Conclusions

The study was carried out to assess the wetland condition by characterising wetland hydrology and water quality. The obtained short hydro-period (11.4%) indicates that the wetland is mostly ponded for a short period of time hence does not store enough water. The delayed response between groundwater and rainfall, and the observed groundwater discharge indicate a delayed positive interaction between surface and ground water. The poorer streams WQI may designate surface flow pollution and inefficient wetland filtration process. It is therefore concluded that these afore mentioned conditions could reflect an affected wetland ecological functioning.

4.3 Recommendations

In light of the above results and conclusions, it is recommended that; further consistent monitoring of water levels be done because that would give a better estimation of wetland hydro-period. Again, use of automated water level recorders is highly recommended because change in water levels could be recorded hourly which is not possible when using manual inspection. Manual inspection is also subjected to many obstacles such as severe weather conditions. Seasonal examination of water stable isotopes would help indicate the seasonal interactions between surface and ground water, identify the wetland water source and estimate the exact mean residence time of the wetland. A continuous measuring of water quality would indicate the change in water quality parameters over time and show the influence brought by different seasons. The water quality of groundwater and isotopes could also be integrated to assess accurately the wetland residence time. The study on the influence of land use in each sub-catchment would give a better understanding of the wetland condition. Further research needs to be done to identify source of the surface flow pollution.

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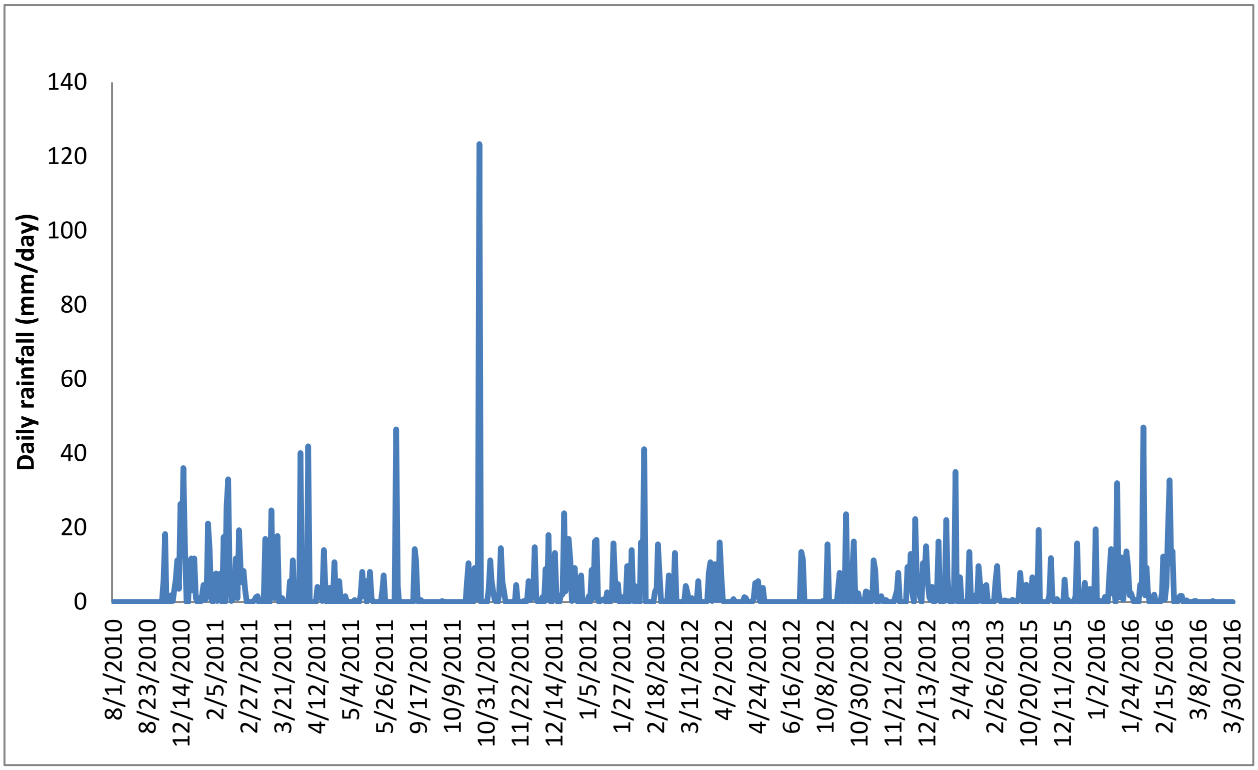
Appendices

Appendix A: Daily recorded rainfall for the sampled months from 2010 to 2016



Appendix B: Hydrogen (δ^2H) and Oxygen (δ^{18}O) isotopes values relative to VSMOW for water collected from different sources in the three sub-catchments in December, 2015.

Catchment/Location	Water source	δ^2H‰ SMOW	δ^{18}O‰ SMOW
Sub-catchment 1	Rainfall	**64.0**	**10.28**
	Stream1	5.9	0.28
	Stream 2	-14.8	-3.43
	Stream 3	-5.9	-2.41
	Stream 4	-0.9	-1.54
	Stream 5	-2.9	-1.25
	Stream 6	8.3	-0.11
	Stream 7	0.8	-1.29
	Average	**-1.3**	**-1.39**
	Piezometer m	-12.5	-3.87
	Piezometer d	-23.0	-4.26
	Piezometer 2	-18.7	-3.52
	Piezometer 5	-19.4	-4.02
	Average	**-18.4**	**-3.92**
Sub-catchment 2	Rainfall	**7.6**	**1.02**
	Stream 1	-5.9	-1.88

	Stream 2	-11.6	-2.23
	Stream 3	9.0	-0.17
	Stream 4	-6.8	-1.65
	Stream 5	-6.7	-1.29
	Average	**-4.4**	**-1.44**
	Piezometer r	-18.3	-4.42
	Piezometer m	-13.4	-4.01
	Piezometer d	-17.4	-4.14
	Piezometer 16	-23.6	-4.68
	Piezometer 17	-13.3	-3.36
	Piezometer 18	-16.9	-4.49
	Piezometer 21	-16.3	-3.92
	Piezometer 23	-19.7	-4.76
	Average	**-17.4**	**-4.22**
Sub-catchment 3	Rainfall	**8.0**	**0.42**
	Stream 1	11.9	1.15
	Stream 2	1.6	-0.50
	Stream 3	-7.9	-1.83
	Stream 4	7.7	0.34
	Stream 5	2.3	-0.60
	Average	**3.1**	**-0.29**
	Piezometer r	-15.2	-4.28
	Piezometer 1	-20.7	-4.09
	Piezometer 2	-14.9	-4.19
	Piezometer 3	-19.9	-5.04
	Piezometer 4	-18.6	-4.37
	Piezometer 7	-12.3	-3.63
	Piezometer 13	-12.8	-3.69
	Piezometer 14	-14.4	-4.70
	Average	**-16.1**	**-4.25**

Abbreviations; r, m and d represent piezometer at recharge, middle and discharge, respectively.

Appendix C: Summary statistics table for stream water quality parameters

Variables	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
pH	5.54	7.20	6.525	0.282
EC	0.04	0.80	0.118	0.118
BOD	0.00	57.01	9.027	10.531
COD	0.00	320.00	42.051	47.367
Na	0.03	300.00	13.266	37.763
Ca	5.95	3066.60	330.467	466.620
K	0.00	4.00	0.554	0.585
Mg	1.20	136.15	19.236	31.275
NO_3	0.01	100.00	1.309	7.986
PO_4	0.24	5.49	1.074	1.006

Appendix D: Summary statistics table for piezometer water quality parameters

Variables	Minimum	Maximum	Mean	Std. Deviation
pH	4.48	6.97	5.700	0.559
EC	0.04	0.20	0.090	0.027
BOD	0.00	30.54	3.633	4.695
COD	0.00	352.00	80.471	90.004
Na	2.50	7.60	3.758	0.941
Ca	2.21	686.80	99.163	142.946
K	0.20	3.30	0.754	0.417
Mg	1.00	5.70	2.516	1.023
NO_3	0.01	3.61	0.573	0.627
PO_4	0.11	10.28	4.146	3.220

Appendix E: Analysis of variance of stream water for the three sub-catchments

Variables	Source of Variance	Sum of Squares	Df	Mean Square	F-value	Significance level
pH	Between Catchments	0.223	2	0.111	6.428	0.10
	Within Catchments	0.260	15	0.017		
	Total	0.483	17			
EC	Between Catchments	0.050	2	0.025	10.051	0.002
	Within Catchments	0.038	15	0.003		
	Total	0.088	17			
BOD	Between Catchments	215.828	2	107.914	5.394	0.009
	Within Catchments	660.210	33	20.006		
	Total	876.037	35			
COD	Between Catchments	1485.68	2	742.840	1.216	0.309
	Within Catchments	20166.3	33	611.100		
	Total	21652.0	35			
Na	Between Catchments	141.689	2	70.844		
	Within Catchments	178.515	33	5.410	13.096	0.000
	Total	320.203	35			
Ca	Between Catchments	1345031.4	2	672515.7	10.749	0.000
	Within Catchments	2064686.1	33	62566.25		
	Total	3409717.5	35			
K	Between Catchments	0.593	2	0.297	3.802	0.033
	Within Catchments	2.574	33	0.078		
	Total	3.167	35			
Mg	Between Catchments	12672.461	2	6336.230	9.366	0.001
	Within Catchments	22326.118	33	676.549		
	Total	34998.578	35			
Nitrate	Between Catchments	0.639	2	0.319	2.852	0.0720
	Within Catchments	3.696	33	0.112		
	Total	4.335	35			
Phosphate	Between Catchments	2.648	2	1.324	8.074	0.001
	Within Catchments	5.411	33	0.164		
	Total	8.059	35			

Appendix F:Analysis of variance of piezometer water for the three sub-catchments

Variables	Source of Variance	Sum of Squares	Df	Mean Square	F-value	Significance level
pH	Between Catchments	0.564	2	0.282	1.438	0.254
	Within Catchments	5.493	28	0.196		
	Total	6.058	30			
EC	Between Catchments	0.004	2	0.002	6.592	0.005
	Within Catchments	0.010	28	0.000		
	Total	0.014	30			
BOD	Between Catchments	74.569	2	37.284	3.365	0.042
	Within Catchments	609.375	55	11.080		
	Total	683.944	57			
COD	Between Catchments	94926.85	2	47463.43	11.738	0.000
	Within Catchments	238572.4	59	4043.601		
	Total	333499.3	61			
Na	Between Catchments	3.478	2	1.739	4.815	0.016
	Within Catchments	10.111	28	0.361		
	Total	13.588	30			
Ca	Between Catchments	33829.87	2	16914.94	2.874	0.065
	Within Catchments	329637.7	56	5886.387		
	Total	363467.6	58			
K	Between Catchments	0.261	2	0.131	2.661	0.087
	Within Catchments	1.375	28	0.049		
	Total	1.637	30			
Mg	Between Catchments	3.991	2	1.995	4.704	0.017
	Within Catchments	11.877	28	0.424		
	Total	15.868	30			
Nitrate	Between Catchments	0.138	2	0.069	0.480	0.621
	Within Catchments	8.488	59	0.144		
	Total	8.626	61			
Phosphate	Between Catchments	59.029	2	29.515	5.349	0.007
	Within Catchments	325.527	59	5.517		
	Total	384.556	61			