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Full Length Research Paper

Assessment of heavy metals concentration in water, soil sediment and biological tissues of the lesser flamingos in four eastern rift valley lakes

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The term heavy metal refers to any metallic chemical element that has a relatively high density and is toxic at low concentrations. This study was conducted in four eastern Rift Valley lakes which included Lakes Oloidien, Crater, Elementaita and Nakuru, to determine the presence and levels of lead, arsenic, cadmium and chromium concentration in water, soil sediments and biological tissues of the Lesser Flamingos (Phoeniconaias minor) and compare with the set standards. As these lakes catchments fall directly within a combination of agricultural and industrial regions, the run-offs and the resulting effluents will make the waters highly prone to chemical contamination. The methodology involved collection of water samples (n=40), sediments samples (n=51) and the Lesser Flamingos (live n= 6; dead n=2) for qualitative and quantitative toxicological analysis. The analysis was done using Graphite Furnace Atomic Absorption Spectrophotometer (GFAAS) model-Specter AA-10 Varian. Lead and arsenic were found to be in high concentration in soil sediments in all four lakes while chromium and cadmium were in low concentration. Soil sediments analysed from the inflow of the Nakuru sewerage drain (1754±22.81 ppb) and rivers to Lake Nakuru (1129±107 ppb) had the highest mean ± SD lead concentration. Arsenic, cadmium, chromium and lead were also observed in bird tissues. Metals in the Lesser Flamingo tissues were below the toxicological levels that are reported in literature to be harmful, except lead which was above the level recommended by the US Environmental Protection Agency.

Key words: Heavy metals, lesser flamingo, environment.

INTRODUCTION

Kenya is located in Africa and lies along the equator. It has a number of lakes located in the Rift Valley region which are known to host a vast number of migratory birds during their stop over. Some of these lakes include

Elementaita, Nakuru, Oloidien and Crater all located in Nakuru County, Kenya. They host a significant number of water birds species which include Lesser Flamingo (Phoeniconaias minor).The Lesser Flamingo contributes significantly to ecotourism which, in turn, contributes substantially to the Kenya's Gross domestic Product (GDP). Tourism is regarded as the second largest sector of country's economy and is estimated at contributing about 10% of the GDP. It is Kenya's leading foreign exchange earner, generating around 654 million US dollars in 2007 (Udoto, 2012). Recently there have been massive die-offs of Lesser Flamingo population; the most recent occurred towards the end of 2013. These mass deaths have been attributed to a number of diverse causes that either relate to the availability of food for flamingos or having a negative impact directly on the flamingos. As these lakes catchments fall directly within a combination of agricultural and industrial regions, the run-offs and the resulting effluents makes the waters highly prone to chemical contamination. It is possible that the Lesser Flamingos (*Phoeniconaias minor*) can take in the metals as they feed in the lakes or drink water from the nearby rivers. It is therefore important to regularly monitor the levels of the heavy metals in the Kenyan Eastern Rift Valley lakes in order to safeguard the flamingos. However, the potential impacts of the agricultural and industrial pollutants on the health of birds in the lakes are not well documented. The lifespan of Lesser Flamingo is over 50 years and their bodies can accumulate heavy metals to a harmful level. It is therefore recommended that close monitoring on the levels of these metals should be done regularly in order to safeguard the birds' lives.

MATERIALS AND METHODS

Study area

The study was conducted in Nakuru County, northwest of the capital city Nairobi, Kenya (Figure 1), during the month of December, 2013. The samples were collected from Lakes Oloidien, Nakuru, Elementaita, Crater, rivers and sewage discharging to Lake Nakuru. The four lakes under study host a significant number of the Lesser Flamingos during their stop over.

Sample collection and laboratory analysis

Water sampling sites were chosen purposively depending on the discharge points into the lake and six further sites were done randomly at least 100 metres from discharge points. Water samples were collected in sterilised polyethylene plastic containers. About 300 mg of sediments was scooped from the lake and river bed and also packed separately in labelled sterile polyethylene plastic containers. Water sampling sites were chosen purposively depending on the discharge points into the lake and six further sites were done randomly at least 100 metres from discharge points. Birds sampling was done opportunistically. The birds were trapped from the lakes by making use of a noose carpet or those that were too weak were caught by hand. The noose carpet is a 1m x 1m grid covered in wire mesh onto which nylon nooses are fixed. The noose carpet was submerged in shallow water in the region the birds were feeding. The birds were released from the nooses and placed inside a cloth bag with suitable aeration. Birds that were found to be in very poor physical condition were euthanized by use of sodium thiopental, by injection directly into the heart. The birds were carried away from the lake shore where they were dissected on a disinfected plastic table and the tissues removed aseptically.

Five grams (5 g) of wet tissue from the flamingo organs/ tissue (liver, heart, kidney, lungs, bone and muscle) was individually digested with 20ml of concentrated nitric acid and complete digestion done by adding hydrogen peroxide followed by filtration. Two and a half grams of dry sediment was digested with 20ml concentrated nitric acid. Fifty millilitres of the water sample was digested with 5 ml of concentrated nitric acid and topped up with distilled water.Aliquots of filtrate was analyzed by Graphite Furnace Atomic Absorption Spectrophotometer (GFAAS) model-Specter AA-10 Varian.

Data obtained were analyzed using "Instat +" computer statistical package. Descriptive statistics; the mean, standard deviation, and two-way ANOVA was used to determined the significant difference ($p<0.05$) of statistical means of heavy metals in Lesser Flamingos, water and soil sediments samples.

RESULTS

The mean concentration of lead, chromium, cadmium and arsenic collected from water of the four lakes, rivers and sewage discharge in Nakuru County, Kenya are shown in Table 1. Lake Elementaita had the highest mean concentration of lead (14.24 ± 8.86 ppb) followed by Lake Nakuru (12 ± 14.24 ppb). There were no detectable levels of lead from Lake Oloidien and the Crater Lake. Rivers discharging to Lake Nakuru and sewage drain had the least lead concentrations. Chromium mean concentration from the highest to the lowest was; Lake Nakuru (5.25 ± 5.67 ppb) followed by Lake Elementaita (3.42 ± 4.16 ppb) and Crater Lake (0.21 ± 0.26 ppb). The concentration of arsenic was highest in Lake Oloidien with a mean of 11.37 ± 11.21 ppb and it was the only metal detected in Lake Oloidien water. Lake Nakuru had the lowest mean concentration of arsenic (2.34 ± 3.1 ppb). In general, it was observed that Lake Nakuru and Lake Elementaita had high concentrations of the four heavy metals.

All the metals under study were found in soil sediments of the four lakes except cadmium which was not

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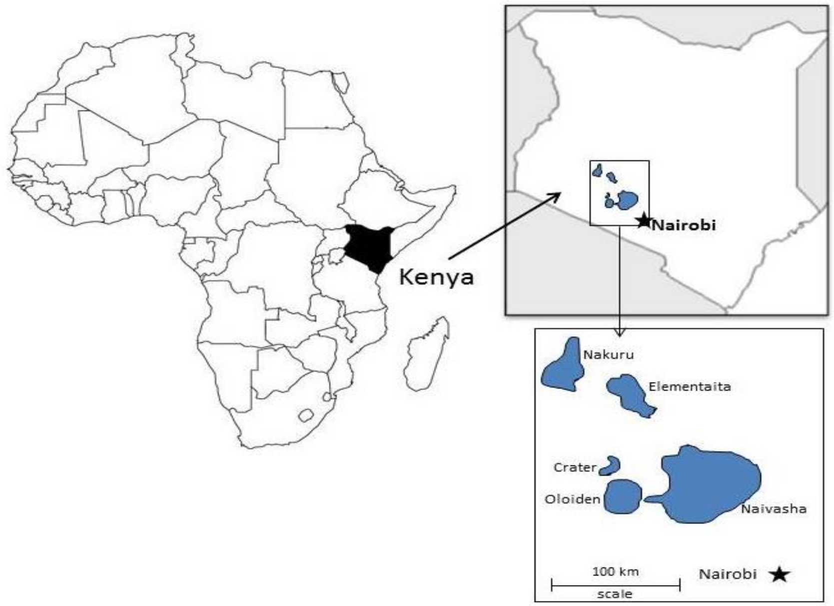

Figure 1. Location of Kenya in Africa and lakes Nakuru, Elementaita, Crater and Oloidien in Nakuru County, Kenya.

Table 1. Mean metal concentrations ± SD (ppb) in water and sediment from the four Rift Valley lakes in Nakuru County, Kenya.

Locality	metals in water					metals in sediment				
	N	Pb	Ca	Cr	As	N	Pb	Ca	Cr	As
Crater	4	ND	ND	0.21 ± 0.26	4.35 ± 3.81	6	212.5 ± 44.29	36.2 ± 39.7	136.4 ± 48.4	409.3 ± 243.9
Elementaita	8	14.24± 8.86	ND	3.42 ± 4.16	9.68 ± 3.36	12	567.3 ± 46.12	64.8 ± 40.47	64.85 ± 18.73	512 ± 66.96
Nakuru	12	12 ± 14.24	ND	5.25 ± 5.67	2.34 ± 3.1	15	430.1 ± 122.1	76.69 ± 48.31	57.85 ± 17.29	354.4 ± 294.9
Oloidien	4	ND	ND	ND	11.37 ± 11.21	6	273.7 ± 67.12	0.4673 ± 0.52	50.27 ± 3.98	265.5 ± 290.8
River Nakuru	8	1.2 ± 2.23	ND	18.55 ± 19.92	0.77 ± 1.36	9	1129 ± 107	82.88 ± 17.83	99.72 ± 24.38	198.4 ± 49.87
Sewage Nakuru	4	1.52 ± 1.76	ND	4.47 ± 0.96	0.50 ± 0.44	3	1754 ± 22.81	ND	91.3 ± 6.26	ND
Benchmark levels*		8.1	9.3	50	36		21000	1000	8100	6000

*Benchmark levels for water concentrations (µg/L) for Pb from US EPA (1999) and for Ca, Cr and As from US EPA (1987). For sediment benchmark levels (µg/kg): Pb and Cd from MacDonald (1993), Cr from Long et al. (1995), As from Persaud et al. (1993). ND not detected.

Table 2. Mean metal concentrations ±SD (ppb) in birds tissue samples collected from the four Rift Valley lakes in Nakuru County, Kenya.

	Muscle	bone	brain	heart	Kidney	liver	lungs
Lead * 25							
Crater Lake(n=2)	32±45.25	111.5±17.68	0.21±0.29	47±18.38	70.5±14.85	21.5±4.95	20.5±4.95
Oloidien(n=5)	4.94±9.61	162±31.14	2.94±1.6	7.17±12.28	7.74±13.13	17.1±9.15	13.6±8.08
Elementaita(n=1)	ND	100	ND	9	17	4.9	2.2
Nakuru	None	none	none	none	None	none	none
Cumulative mean	11.09±22.69	141.6±37.45	1.89±1.89	17.36±21.67	24.59±30.79	16.68±8.83	13.9±8.54
Cadmium *1450							
Crater (n=2)	ND	ND	ND	ND	62.7±1.27	27.3±15.98	ND
Oloidien(n=5)	ND	ND	ND	ND	37.46±47.32	64.96±28.72	ND
Elementaita(n=1)	ND	ND	ND	ND	71.8	78.9	ND
Nakuru	None	none	none	none	None	none	none
Cumulative mean	ND	ND	ND	ND	48.06±38.76	57.29±29.56	ND
Chromium*1000							
Crater (n=2)	0.82±0.97	10.65±8.98	10±8.49	10.16±8.29	27.4±4.38	8.08±4	7.3±3.11
Oloidien(n=5)	1.29 ±1.82	10.94±6.38	10.52±6.55	8.26±3.52	255.2±329	21.96±19.35	7.76±3.53
Elementaita(n=1)	1.1	11.9	12.6	9.3	23.7	21	5.94
Nakuru	None	none	none	none	None	none	none
Cumulative mean	1.15±1.44	10.99±5.91	10.65±5.96	8.87±4.2	169.3±276.1	18.37±16.02	7.42±2.98
Arsenic*2460							
Crater (n=2)	11.37±4.15	7.65±4.88	5.35±0.92	13.3±5.24	19.45±8.27	11.18±3.29	8.14±1.29
Oloidien(n=5)	9.65±2.75	7.23±1.23	5.17±2.97	10.02±1.99	17.67±2.78	19.18±6.29	14.7±2.90
Elementaita(n=1)	10.6	3.07	5.4	6.77	25.7	17.1	9.84
Nakuru	None	none	none	none	None	none	None
Cumulative mean	10.2±2.72	6.82±2.57	5.24±2.27	10.43±3.25	19.12±4.68	16.92±6.1	12.45±3.87

Key: ND – not detected, none- no sample collected. ***Benchmarkslevels for birds concentration µg/kg BW-day for Pb from Kendall and Scanlon (1982),Ca from White and Finley,(1978),Cr from Heseltine et al. (1985) and As from U.S. Fish and Wildlife Service,(1969).

detectable in sewage drain soil sediment in Lake Nakuru. Heart, lungs, brain, liver, kidney, bone and muscle tissues were sampled. All the metals were detected in tissues of Lesser Flamingo except cadmium which was detected only in the liver and kidney (Table 2)

DISCUSSION

Lake Oloidien had the highest levels of arsenic which could be as a result of wash off from the surrounding flower farms. It is also possible that the arsenic leaches from the volcanic soils to the water hence the high concentration. In general, it was observed that Lake Nakuru and Lake Elementaita had the highest levels of the four heavy metals. This suggests that the rivers flowing in and the sewage drain to Lake Nakuru contribute to the levels of these metals apart from those leaching naturally from the ground. Analysis of variance (ANOVA) for metal in water revealed that the mean concentration of all the metals varied significantly ($p<0.05$) with Lake Nakuru levels being significantly higher. There is much inflow from the rivers which flood the lake and this could be the possible cause of the higher variation in Lake Nakuru.

The levels of cadmium, chromium and arsenic in the four lakes under study were below the benchmark levels recommended by the US Environmental Protection Agency (Table 1) except for lead levels in Lake Elementaita (14.24 ± 8.86 ppb) and Lake Nakuru (12 ± 14.24 ppb).

Lead, cadmium, chromium and arsenic were found in soil sediments of the four lakes; however cadmium and arsenic were not detected in sewage drain to Lake Nakuru. Sewage drain and the rivers draining to Lake Nakuru had a high mean concentration of lead (1754

±22.81 ppb) and (1129 ± 107 ppb) respectively and they were the possible causes of lead detected in Lake Nakuru. Comparing the present average levels of chromium (57.85ppb) and lead (430.1ppb) detected in soil sediments in Lake Nakuru with the previous findings by Nelson et al. (1998), (average levels of chromium 67 ppb and lead 22 ppb) chromium current levels are slightly lower while lead levels for the current study are very high. The present higher average levels of lead in Lake Nakuru compared to the other lakes can be attributed to accumulation, since the lake has no out-flow but has many inflows. Another contributing factor could be due to increase in the number of industries and population which in turn increases effluent and sewage discharge respectively. The levels of all the metals under study were below the benchmark levels of the marine soil sediments (Table 1).

Heart, lungs, brain, liver, kidney, bone and muscle tissues were sampled. All the metals were detected in tissues of Lesser Flamingo except cadmium which was detected only in the liver and kidney (Table 2) which agrees with studies done by Schafer, *et al*.,(1999) that the liver and kidney accumulates cadmium. The highest mean concentration of cadmium was 58 µg/kg which is almost 40 times higher than what was found out by Kairu, 1996 (1.3 µg/kg) and Koeman et al., 1972 (1.35 µg/kg). This can be attributed to bioaccumulation since the Lesser Flamingo can live for about 50 years. The Lesser Flamingos are filter feeders,they feed through stiring up the lake sediments then filtering out their food and in the process can take in the metals in the lake sediments.There is also possibility that the Lesser Flamingos consumes the heavy metals from the rivers that are discharging to the lakes.

Conclusion

Metals were detected in water and soil sediments but they were below the benchmark levels except lead in Lake Elementaita and Lake Nakuru waters. Levels of lead were above the recommended in the birds tissues.

Conflict of interests

The author has not declared any conflict of interests.

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Full Length Research Paper

Temporal and spatial variability of rainfall distribution and evapotranspiration across altitudinal gradient in the Bilate River Watershed, Southern Ethiopia

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Rainfall and evapotranspiration are the two major climatic factors affecting agricultural production. This study examined the extent and nature of rainfall variability from measured data while estimation of evapotranspiration was made from recorded weather data. Analysis of rainfall variability is made by the rainfall anomaly index, coefficient of variance and precipitation concentration index. The FAO-56 reference ET (ETo) approach was used to determine the amount of evapotranspiration. Estimation of the onset, end of growing season and length of growing period was done using Instat software. The results show that mean annual rainfall of the upper (2307 m.a.s.l), middle (1772 m.a.s.l) and lower (1361 m.a.s.l) altitude zones of the watershed are in the order of 1100, 1070 and 785 mm with CV of 12, 15 and 17% respectively. There was a high temporal anomaly in rainfall between 1980 and 2013. The wettest years recorded Rainfall Anomaly Index of +5, +6 and +8 for stations in upper, middle and lower altitude zones respectively, where the driest year recorded value is -5 in all the stations. The average onset date of rainfall for the upper zone is April 3 ± 8 days, for the middle zone April 10 ± 10 days and for the lower zone is April 11 ± 11 days with CV of 23%, 26 and 29% respectively. The average end dates of the rainy season in the upper and middle zones are October 3 ± 5 days and September 25 ± 7 days with CV 5 and 7%. The main rainy season ends earlier in the lower zone; it is on July 12 ± 10 days with CV of 14%.

Key words: Variability, days of the year (DOY), onset, end date, length of growing period (LGP).

INTRODUCTION

Variability is a very important inherent characteristic of climate and it varies on all timescales. There has been much recent public and scientific interest in climate variability and change, and the possible role of human activity in observed climate change (Braganza et al., 2003). So far, most studies have focused on measuring

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the impacts of changes in climatic averages on different sectors (Kucharik and Serbin, 2008; Lobell and Burke, 2008; Lobell and Field, 2007; Tao et al., 2008; Rowhani et al., 2011). Global scale assessments of climate change impacts on livelihoods and economic factors are commonly based on averages, rather than on the analysis of the variability or extremes (Adams et al., 1990; Penalbaa and Vargasa, 2008). Observations, however, suggest that climate change impacts on society result primarily from extreme events and their variability (IPCC, 2007). This is because, in addition to changes in climate means, climate variability is expected to increase in some regions in the future, including the frequency and intensity of extreme events (IPCC, 2007). Some have proposed that changes in extremes will have a more adverse impact on crop production than changes in climate averages alone (Morton, 2007; Tubiello et al., 2007).

Climate variability can be described as a combination of some preferred spatial patterns. The most prominent of these are known as modes of climate variability, which affect weather and climate on many spatial and temporal scales. The best known and truly periodic climate variability mode is the seasonal cycle. Others are quasiperiodic or of wide spectrum temporal variability (Blunden et al., 2011).

Rainfall variability receives higher attention among other climatic elements especially in relation to agriculture. The variability in rainfall can be explained either temporally or spatially or both depending on the purpose needed (Song et al., 2014). A better understanding of the spatial and temporal variations of precipitation on different timescales and the adjustment of specific theoretical models like models that generate design storms and models that allows for the simulation of continuous time series at a point or spatially distributed are important for many applications (Vernieuwe et al., 2015). The resulting models will lead to a better management of a great variety of problems associated with variations in precipitation and will make it possible to improve statistical weather forecasts and climate monitoring (Penalbaa and Vargasa, 2008).

Characterizing and quantifying these variability is of fundamental importance not only for purposes of detection and attribution, but also for strategic approaches to adaptation and mitigation.

Precipitation distributions over tropical East Africa exhibit pronounced regional variations, and the seasonal cycle is complicated (Cook and Vizy, 2012). In most regions, there are two peak rainfall seasons that are nominally associated with solar heating maxima in the equinox seasons, Sea Surface Temperature forcing, and teleconnections to the West African and Indian monsoon systems are among the other important factors influencing the timing and intensity of seasonal rainfall (Cook and Vizy, 2013). Topography is another factor that determines spatial distribution regardless of the impact of the equinox (Hession and Moore, 2011).

Rainfall in tropical East Africa, within about 15° of the equator, is often delivered during two seasons, which are governed by the seasonal oscillation of Intertropical convergence zone (ITCZ). As a result, one rainy period occurs during boreal spring, known as the spring rain ‘‘*Belg*’’ in Ethiopia. A second rainy period occurs in the boreal fall over much of the region, is known as the summer rain ‘‘*Keremt*’’ (Cook and Vizy, 2013).

Rainfall and evapotranispiration are two major climatic factors affecting agricultural production (Tilahun, 2006), and agricultural water resources face two major problems. One is the lack of available water supply in rain-fed agriculture, and the loss of available water through evapotranispiration (Wriedt et al., 2009; Derbile, 2013; Mou et al., 2014).

Evapotranspiration (ET) is an important hydrological process and its estimation is needed for many applications in diverse disciplines such as agriculture, hydrology, and meteorology (Suleiman et al., 2008) but usually the estimation of ET needs measurements of many weather variables such as atmospheric pressure, wind speed, air temperature, net radiation and relative humidity, but these weather variables are not easily obtainable from practical measurements in weather stations (Ishak et al., 2010) as the most prevailing weather stations in Ethiopia are class III meteorological stations that can collect only air temperature and rainfall and class IV stations that can collect only rainfall.

Potential Evapotranspiration (PET) is defined as the maximum ability to evaporate under the assumption of a well-watered surface. Accurate and timely estimates of PET are essential for agricultural and water resource planning as well as for understanding the impacts of climate variability on terrestrial systems (Kim and Hogue, 2008) and Reference Evapotranspiration (ETo) is the evapotranispiration from the reference surface, which is a hypothetical grass reference crop with an assumed height of 0.12 m, a fixed surface resistance of 70 S/m, and an albedo of 0.23, and closely resembles an extensive surface of green, well-watered grass of uniform height, actively growing and completely shading the ground (Allen et al., 1998). The quantity ETo can be considered to be an upper limit of actual ET.

The Food and Agriculture Organization (FAO) adopted and modified (as FAO 56) the Penman–Monteith (PM) equation as the standard ETo estimation method (Allen et al., 1998). FAO-56 has been accepted worldwide as a good ETo estimator compared with other methods (McVicar et al., 2005; Sumner and Jacobs, 2005).

This study was conducted to statistically analyse the temporal variation in monthly and annual rainfall and determine reference evapotranspiration ETo using FAO *ETo calculator* (Raes, 2009) for *Hosana, Alaba Kulito* and *Bilate* meteorological stations representing upper, middle and lower altitude zones of the Bilate watershed respectively. Then, to determine the average onset, end

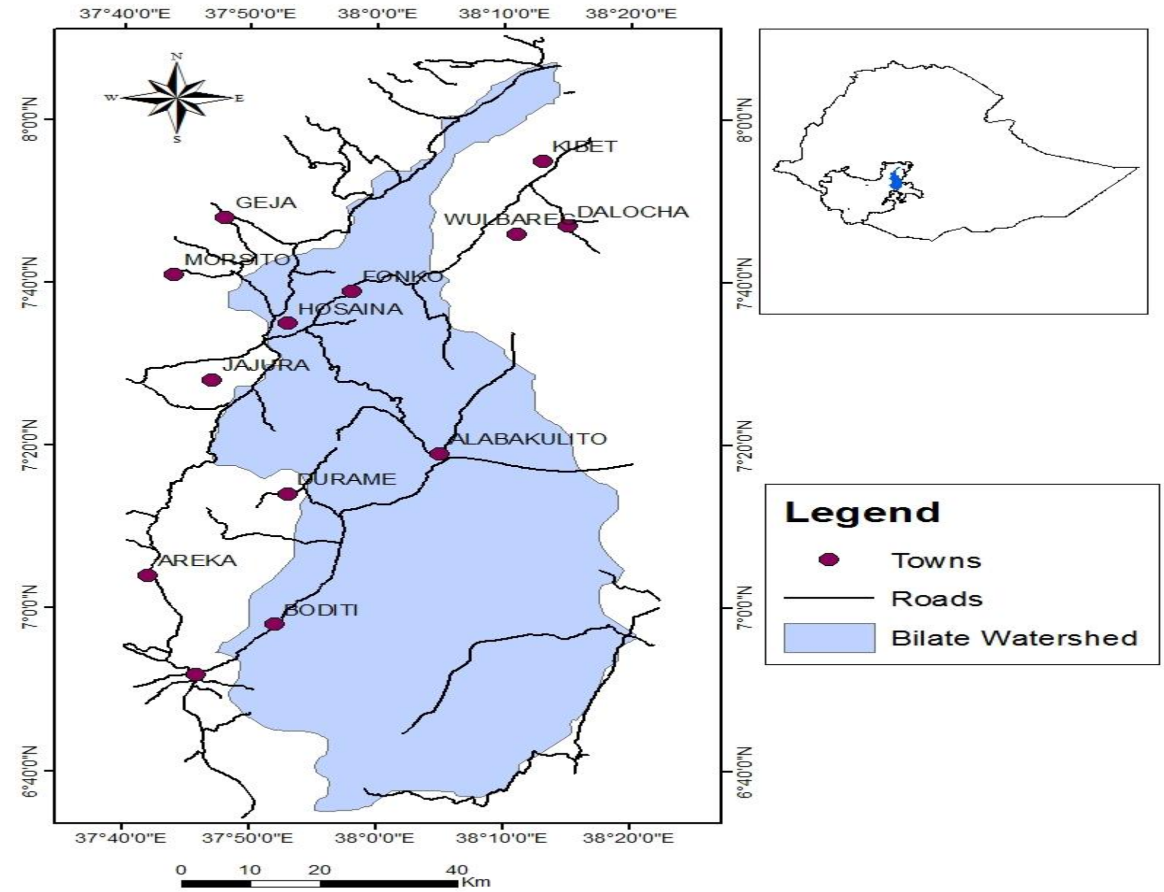

Figure 1. Location map of the Bilate River Watershed.

date and length of growing period for areas in the watershed and finally compare the monthly rainfall and evapotranspiration at different exceedance probability levels for stations in the watershed.

MATERIALS AND METHODS

Study area description

This study was conducted in the Bilate River Watershed. Bilate River is one of the inland rivers of Ethiopia that drains the northern watershed of the Lake Abaya-Chamo drainage basin which forms part of the Main Ethiopian Rift and in turn is part of an active rift system of the Great Rift Valley in Africa. The Bilate River watershed (BRW) covers an area of about 5625 km^2 and is located in the southern Ethiopian Rift Valley and partly in the Western Ethiopian Highlands. The altitude of the watershed ranges from 1300 at Lake Abaya to 3050 m above sea level at Mt. Ambaricho (Figure 1).

The population distribution of the watershed has two characteristics. The first one is maximum rural population density in the upper and middle course areas of the western part of the basin, while the second is the eastern part that is dominantly known for agro-pastoralism and relatively sparse population distribution. As discussed above, parts of the areas under Bilate watershed are known for their high density of population. This may be related to the suitable agro-climatic condition, soil type and availability of water resources. In these areas maximum rural population density is the highest in Ethiopia, which exceeds 500 persons/km^2 (CSA, 2013).

The ethnic and cultural distribution within the watershed is highly diversified. There are more than eight ethnic groups dwelling within the watershed. Their contribution to the environment depends also on their cultural agricultural and land management practices. For example, the ethnic groups living near the mouth of the Bilate River or northern part of Lake Abaya are more of agro-pastoralists. On the other hand the people living in the western part of the watershed are known for their intensive and mixed farming culture.

Data source

Time series rainfall data of the stations in the study watershed were obtained from the Ethiopian National Meteorological Agency (NMA). For the time period of Jan/01/1980 to Dec/31/2013, rainfall stations with an amount of daily data above 75% were selected. From around 18 available stations inside and around the watershed, 11 stations satisfied the criteria. The selected stations with their mean annual value and the percent of daily missing rainfall data for the 30 years period under study is summarized in Table 1.

The recent 30 years records of daily rainfall, maximum and minimum temperature data which used to show the spatial and temporal variability of rainfall and temperature in the BRW is obtained from Ethiopian National Meteorological Agency. For the sake of data management and analysis comparison was made

Table 1. Rainfall stations in the Bilate River Watershed.

S/N	Station name	Longitude (E)	Latitude (N)	Altitude (m)	Missing daily %	Mean annual rainfall (mm)
1	Alaba Kulito	38° 05' 38.00"	7° 18' 38.00"	1772	0.74	1025
2	Angacha	37° 51' 26.00"	7° 20' 25.99"	2317	17.82	1223
3	Bilate	38° 05' 0.00"	6° 49' 0.00"	1361	6.03	781
4	Boditi	37° 57' 18.00"	6° 57' 13.00"	2043	1.97	1154
5	Durame	37° 57' 0.00"	7° 11' 59.99"	2000	5.16	1031
6	Fonko	37° 58' 4.99"	7° 38' 31.99"	2246	9.17	1093
7	Hosana	37° 51' 14.00"	7° 34' 1.99"	2307	3.74	1100
8	Imdiber	37° 56' 10.00"	8° 07' 5.99"	2082	8.19	1068
9	Mayokote	37° 51' 11.00"	6° 53' 8.99"	2121	22.29	1173
10	Shone	37° 57' 9.99"	7° 00' 0.99"	1959	1.72	1353
11	Wulbareg	38° 07' 13.00"	7° 44' 11.00"	1992	3.69	1131

Table 2. Summary of selected meteorological stations.

Station name	Longitude (E)	Latitude (N)	Altitude (m.a.s.l)	Missing %
		Maximum and minimum temperature		
Hosana	37° 51' 14.00"	7° 34' 1.99"	2307	17.79
Bilate	38° 05' 0.00"	6° 49' 0.00"	1361	14.86
Alaba Kulito	38° 05' 38.00"	7° 18' 38.00"	1772	6.16
Angacha	37° 51' 26.00"	7° 20' 25.99"	2317	23.02
Wulbareg	38° 07' 13.00"	7° 44' 11.00"	1992	14.71
Boditi	37° 57' 18.00"	6° 57' 13.00"	2043	1.95
		Rainfall		
Alaba Kulito	38° 05' 38.00"	7° 18' 38.00"	1772	0.74
Angacha	37° 51' 26.00"	7° 20' 25.99"	2317	17.82
Bilate	38° 05' 0.00"	6° 49' 0.00"	1361	6.03
Boditi	37° 57' 18.00"	6° 57' 13.00"	2043	1.97
Durame	37° 57' 0.00"	7° 11' 59.99"	2000	5.16
Fonko	37° 58' 4.99"	7° 38' 31.99"	2246	9.17
Hosana	37° 51' 14.00"	7° 34' 1.99"	2307	3.74
Imdiber	37° 56' 10.00"	8° 07' 5.99"	2082	8.19
Mayokote	37° 51' 11.00"	6° 53' 8.99"	2121	22.29
Shone	37° 57' 9.99"	7° 00' 0.99"	1959	1.72
Wulbareg	38° 07' 13.00"	7° 44' 11.00"	1992	3.69

among selected meteorological stations, but only few meteorological stations have continuous datasets of the total timeframe (Table 2).

The appropriate daily rainfall, minimum and maximum temperature data was arranged by the day of a year (DOY) entry format. Data quality control was done by careful inspection of completeness, spatial and temporal consistence of the records in the study area. The missing values of daily data were calculated and simulated by using INSTAT +v.3.36 first and second order Markov-chain simulation models (Stern et al., 2006). A Markov-based random model was established to generate simulated time series of daily precipitation, and the simulated statistic parameters demonstrated good consistency with their observational equivalents (Yuguo et al., 2010). The inbuilt Markov chain model of InStat software performs the simulation of the missing data in two steps. First, it determines the probability of dry and wet weather from the input climate data of the recorded dates, the model depicts rainfall or no rainfall dates. If there is rainfall, then it comes to the second step which is simulating the precipitation amounts.

Analytical methods

Rainfall data of daily records for 30 years (1984 to 2013) of three weather stations were used for these analyses. Hosana, Alaba Kulito and Bilate weather stations were selected to represent the upper watershed, the mid watershed and the lower watershed respectively. The selection is also based on the completeness of the daily data and the stations reside totally inside the watershed. Seasonal rainfall variability was analysed for onset, end date and Length of Growing period (LGP). Other statistical parameters like the mean, standard deviation and coefficient of variation were also determined.

To determine the onset, end date and LGP the definition from Stern et al. (2006) was used. By this definition, a day with accumulated rainfall amount of 20 mm in three consecutive days and not followed by greater than 9 days of dry spell length within 30 days from the planting day is defined as the onset date.

The end of the growing season is determined by the amount of water which is stored in the soil and accessible to the crop after the rain stops. For this study the end of the rainy season was defined as any day when the soil water reaches zero with the assumption of a fixed average evapotranispiration of 5 mm per day and 80 mm/meter of soil water holding capacity (Stern et al., 2006; Hoefsloot, 2009). By using this definition the built-in Instat statistical software version 3.36 was used for the analysis and on the way LGP was determined by taking the difference between the end date and the onset. The count of wet and dry days was made with the 3 mm rainfall threshold for the agricultural water management purpose (Abiy et al., 2014).

The coefficient of variance (CV) statistics were used to test the level of mean variations of seasonal rainfall, CV is defined as the ratio of standard deviation to mean in percent, where mean and standard deviation are estimated from rainfall data.

$$CV = \frac{S.d}{\bar{X}} * 100 \quad (1)$$

Where: CV = coefficient of variation; S.d = standard deviation; $\bar{X}$=Mean of rainfall (mm).

NMSA (1996) used CV to classify degree of variability of rainfall as less when (CV<20%), moderate when (CV from 20-30%) and highly variable for values of (CV>30%).

To describe annual rainfall variability, the (Van-Rooy, 1965) rainfall anomaly index (RAI), which has been modified to account for non-normality is calculated as follows:

1. for positive anomalies:

$$RAI = \frac{1}{3}\left[\frac{RF-M_{RF}}{M_{H10}-M_{RF}}\right] \quad (2)$$

2. For negative anomalies:

$$RAI = -\frac{1}{3}\left[\frac{RF-M_{RF}}{M_{L10}-M_{RF}}\right] \quad (3)$$

Where: RAI stands for the annual rainfall anomaly index, RF is the actual rainfall for a given year, M_{RF} is mean for the total length of record; M_{H10} is the mean of the 10 highest values of rainfall on record, and M_{L10} is the mean of the 10 lowest values of rainfall on record. The RAI of Van Rooy has been shown to be very effective index of to compute seasonal variability for both positive and negative anomalies (Tilahun, 2006; Kisaka et al., 2015).

To study monthly variability of rainfall in the BRW Precipitation Concentration Index (PCI) was used. PCI is described as:

$$PCI = 100X \left[\frac{\sum Pi^2}{(\sum P_i)^2}\right] \quad (4)$$

Where: Pi is the rainfall amount of the i^{th} month, and $\sum Pi$ is Summation over the 12 months.

PCI values of less than 10 indicate uniform monthly distribution of rainfall, PCI values between 11 and 20 shows high concentration and values more than 21 shows a very high concentration in the distribution of rainfall (Taye and Zewdu, 2012).

The FAO-56 reference ET (ETo) approach (Allen et al., 1998) was used to determine the amount of evapotranispiration in the study area because it would provide the best estimate of ET under various climatic conditions (Suleiman et al., 2008). The ETo Calculator software Version 3.1, is used to calculate the reference ET. The reference evapotranspiration from meteorological data is assessed in the ETo calculator software by means of the FAO Penman-Monteith (FAO-56) equation and all the assumptions made during ETo calculation were discussed in Dirk (2009):

$$ETo = \frac{0.408\,\Delta\,(Rn-G) + \gamma\,\frac{900}{T+273}\,\mu_2\,(e_s - e_a)}{\Delta + \gamma(1 + 0.34\,\mu_2)} \quad (5)$$

where R_n is the net radiation (MJ m^2/day), G the soil heat flux (MJ m^2/day), T the mean daily air temp (°C), u_2 the mean daily wind speed at 2 m height (m/s), e_s - e_a the saturation vapor pressure deficit (kPa), Δ the slope of the vapor pressure–temperature curve (kPa /°C), and γ the psychometric constant (kPa/ °C).

Aridity index (AI) was computed by using the UNESCO aridity index (Rodier, 1985) as follows:

$$AI = \frac{P}{ET_o} \quad (6)$$

Where P is the mean annual rainfall and ETo is the mean annual reference evapotranispiration. UNESCO adopted a classification for degrees of aridity as follows: AI < 0.05 is hyper-arid zone, 0.05 < AI < 0.20 is an arid zone, 0.20 < AI < 0.50 is a semi-arid zone, 0.5 < AI < 0.65 is a Dry sub-humid zone and AI > 0.65 is humid (Rodier, 1985).

RESULTS AND DISCUSSION

Trend of annual and seasonal rainfall

The recent 30 years mean annual rainfall in the BRW ranges between 721 and 1353 mm which shows large spatial variability with a maximum rain fall of as large as 1.87 times the minimum rainfall. Areas that belong to the part of the Western Ethiopian Highlands show higher rainfall on annual base while the part of the watershed that belongs to the Ethiopian rift valley shows lower rainfall. Based on the interpolation method used, the mean annual rainfall of the period 1984 to 2013 is estimated to be 1121 mm.

The statistical trend results for the time series of rainfall observed at three stations is presented in Table 3. The table shows a non-significant trend at 95% confidence level in all the stations. Although it is non-significant at 95% confidence level at Hosana, the "*Belg"* season can be explained to significantly decreasing (p = 0.05). The variability in rainfall in the watershed can be shown by the trend variation of the annual rainfall with decreasing trend in Hosana station (3.43 mm/year) to increasing trend in Bilate station (4.76 mm/year). As depicted in Table 3, there was a decreasing trend during *Belg* season in Hosana area of the watershed. In Alaba Kulito and Bilate area there is increasing trend both in the *belg* and *Kiremit* seasons, which are known to be the wettest part of the year. But in all the causes the trend is not significant at 95% confidence level.

Table 3. Total Annual and seasonal precipitation trends of three selected stations.

Stations	Mean (mm)	SD (mm)	Slope (mm/year)	Significance (P value)
Seasons				
Hosana				
Annual	1100.2	128.20	-3.43	0.12
Bega	120.25	51.38	-0.64	0.28
Belg	407.71	95.98	-4.00	0.05
Kiremt	572.28	67.37	1.20	0.68
5 years mean	1042.86	183.14		0.50
10 years mean	1064.34	147.35		0.30
15 years mean	1086.95	133.03		0.12
Alaba Kulito				
Annual	1069.96	156.55	0.35	0.60
Bega	173.6	71.76	-1.36	0.11
Belg	391.83	88.08	1.49	0.85
Kiremt	505.19	86.14	0.22	0.70
5 years mean	1123.92	170.83		0.89
10 years mean	1086.16	141.93		0.86
15 years mean	1066.69	136.33		0.88
Bilate				
Annual	785.11	133.45	4.76	0.90
Bega	168.13	47.62	1.01	0.85
Belg	289.4	60.48	0.04	0.41
Kiremt	327.57	91.31	3.71	0.96
5 years mean	907.84	229.70		0.59
10 years mean	823.52	190.74		0.95
15 years mean	816	165.37		0.81

There was a high temporal anomaly in rainfall between 1984 and 2013. It is shown in Figure 2 that none of the stations depicted years with persistent near average rainfall with RAI = 0. In Bilate the wettest year recorded in 2000 (RAI = +5) and in 2010 (RAI = +4). In Alaba Kulito the highest positive anomalies recorded in 1984 (RAI = +6), 1998 (RAI = +4) and 2012 (RAI = +5). The three wettest years of Hosana are 1984 (RAI = +8), 2007(RAI = +4) and 2011 (RAI = +5). Hosana station has more number of years (seven out of 30 years) with average annual rainfall amount (RAI = 0) and the three driest years in Hosana were recorded in 1990 (RAI = -5), 2010 (RAI = -4) and 2012 (RAI = -5).

A 30 year time-series analysis of the rainfall dataset (Table 3 and Figure 2) showed more frequent rainfall anomalies in the BRW. The results of rainfall analysis for anomalies show that, the BRW is characterised by periodic fluctuation of the dry and wet years. Even if, it is not in consecutive years Hosana station has seven out of 30 years with average annual rainfall amount (RAI = 0), otherwise the results of Rainfall Anomaly Index (RAI) depicted that in all the stations there is no persistent trend showing near average rainfall with RAI = 0. Relatively, being an area having near average rainfall Hosana area also experienced a very dry years in 1990(RAI = -5), 2010 (RAI = -4) and 2012 (RAI = -5). In contrast Bilate area, driest of all stations, also experienced wettest years recorded in 2000 (RAI = +5) and in 2010 (RAI = +4). The variability in rainfall in the watershed can also be explained by the trend variation of the annual rainfall with decreasing trend in annual rainfall in Hosana with the average amount of decrease over the last 30 years is 3.43 mm every year whereas the increasing trend in Bilate station is an average 4.76 mm rainfall every year. Clearly, the trend analysis results depend on the study period chosen. That means if the time period were changed or extended, a different conclusion may be drawn. This result of increasing trend in rainfall in Bilate and decreasing trend in rainfall in Hosana with all the anomalies shown in the watershed is in agreement with the previous studies of Abiy et al. (2014). Generally, the mean annual rainfall increases moving to southwest and with an increasing elevation, ranging from 781 mm at Bilate up to 1100 mm at Hosana.

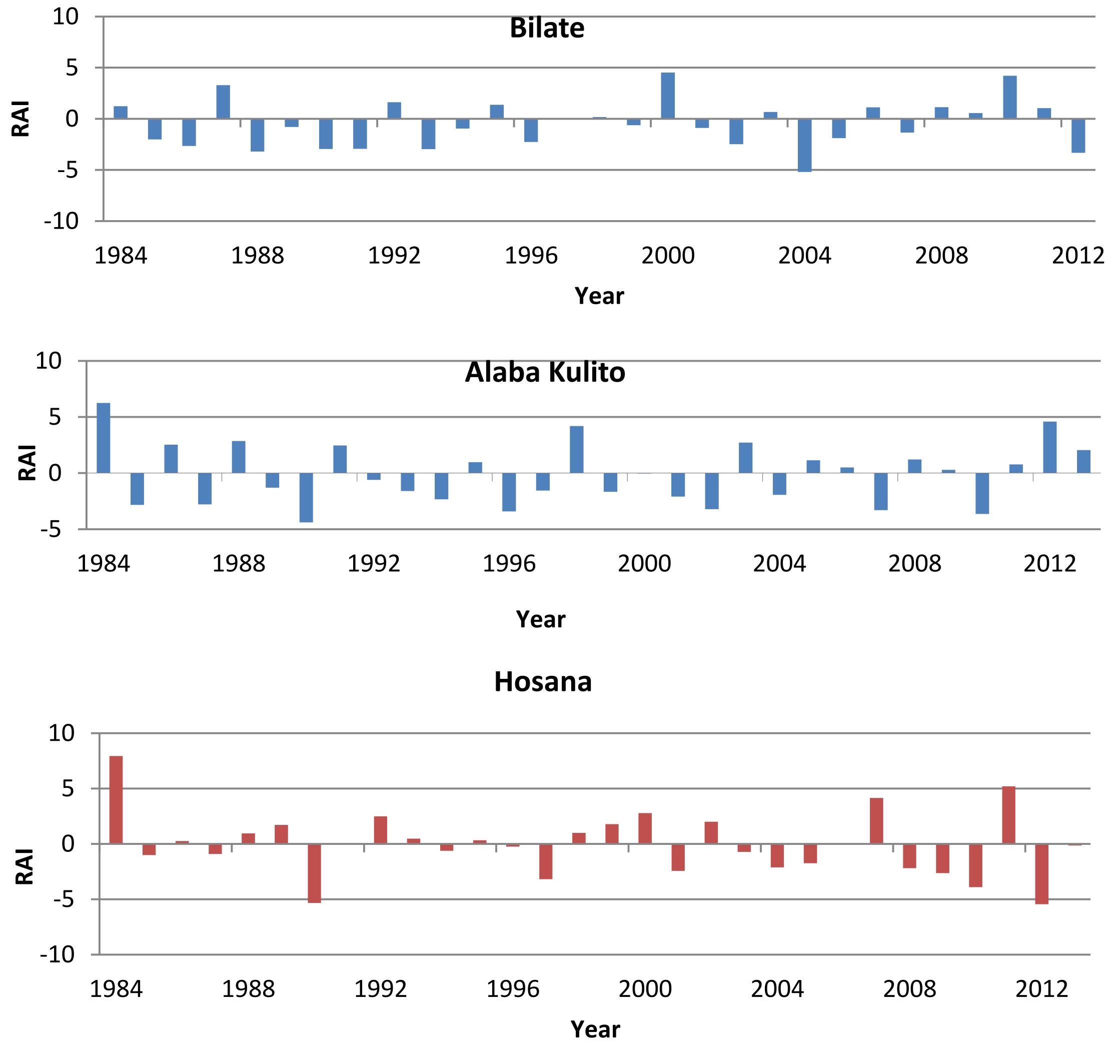

Figure 2. Rainfall anomaly index for the study period in three selected stations.

This is also in agreement with Kassa (2015).

Monthly variations in rainfall amounts and number of rainy days

The results in Table 4 showed that rainfall amounts received in the long rainy season (belg-kirmt) from March to September were highly variable in Alaba Kulito and Bilate all with CV > 0.3. The CV in Rainfall Amounts (CV-RA) was higher in Months of March and October in all the three stations. For Hosana March (CV-RA = 0.44) and October (CV-RA = 0.56), for Alaba Kulito and Bilate both March (CV-RA = 0.47) and October (CV-RA = 0.47).

Variability in number of rainy days (CV-RD) is also higher for the two mentioned months. For Hosana station March CV-RD = 0.39 and Oct. CV-RD = 0.53, in Alaba Kulito the CV-RD of March and October was 0.41 and 0.52 respectively. The Bilate station an exception to have the highest CV-RD in months of June (CV-RD = 0.42) and July (CV-RD = 0.41) unlike other stations.

There is high variability in the amount of rainfall in a given month and the number of raining days in that month in all the stations of the watershed. Bilate station is an exception to have the highest variation in the number of rainy days to have in months of June (CV-RD = 0.42) and July (CV-RD = 0.41), otherwise the highest CV-RD happened in March and October in other stations. The onset month (March) and end month (October) showed higher variability in rainfall amounts and the number of rainy days compared to mid seasonal months. This result shows that the main problem of the watershed was not the total amount of annual rainfall. The fluctuation of onset dates and end dates of the farming period or more specifically delay of the starting dates and early cessation of rain relative to the average dates of the past. Lower values of CV-RD shows that the variation in rainy days is more or less consistent compared to variations in the

Table 4. Variability in rainfall amount and number of rainy days.

Hosana	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
RA (mm)	85.0	131.0	145.0	135.0	144.0	150.0	144.0	50.0
CV-RA	0.44	0.43	0.33	0.23	0.28	0.19	0.37	0.56
RD	8.0	10.0	12.0	11.0	13.0	14.0	12.0	4.0
CV-RD	0.39	0.39	0.22	0.21	0.23	0.18	0.29	0.53
Alaba Kulito								
RA (mm)	60.0	93.0	106.0	97.0	83.0	74.0	72.0	67.0
CV-RA	0.47	0.32	0.34	0.51	0.46	0.39	0.38	0.47
RD	7.0	9.0	9.0	9.0	9.0	12.0	9.0	5.0
CV-RD	0.41	0.34	0.24	0.33	0.29	0.25	0.26	0.52
Bilate								
RA (mm)	60.0	93.0	106.0	97.0	83.0	74.0	72.0	67.0
CV-RA	0.47	0.32	0.34	0.51	0.46	0.39	0.38	0.47
RD	6.0	8.0	9.0	8.0	7.0	7.0	7.0	7.0
CV-RD	0.39	0.32	0.3	0.42	0.41	0.3	0.34	0.36

Table 5. Annual and seasonal mean of rainfall (mm), standard deviation (mm), Coefficient of variation (%) and Precipitation Concentration Index (PCI %).

Station	Annual			*Kiremt*			*Belg*			*Bega*			PCI %
	Mean	CV	SD	Mean	CV	SD	Mean	CV	SD	Mean	CV	SD	
Alaba Kulito	1070	15	157	505	17	86	392	22	88	173	41	71	10
Boditi	1197	14	173	556	20	109	455	24	108	185	28	53	10.38
Bilate	785	17	133	328	28	91	289	21	60	168	28	48	9.67
Hosana	1100	12	128	572	12	67	408	24	96	120	43	51	11.05
Wulbareg	1202	15	179	687	18	123	417	25	103	98	58	56	11.87

monthly rainfall amounts and the higher variability in the onset and end of rainy season is known to affect the cropping calendar of rain-fed agriculture (Kisaka et al., 2015).

Variability of rainfall amount and monthly contributions

From Table 5, the recent 30 years mean annual rainfall of Hosana, AlabaKulito and Bilate is found to be 1100, 1070 and 785 mm with CV of 12, 15 and 17%, respectively. The mean *Kiremt* and *Belg* rainfall for Hosana is 572 and 408 mm with SD of 67 and 96 mm. The CV is higher for Hosana and Alaba Kulito in *belg* season than the annual. As the *belg* rainfall is very important, for crops like maize and sorghum which are known for their longer growing period, higher variability in the *belg* rainfall will hinder the agricultural production of the area.

As shown in Table 6 half of the year from April to September contributed 77% to the annual rainfall in Hosana station, for which *belg* contributed 37% and *Kiremt* contributed 52%. The monthly contribution January, February and March is 3, 4 and 8% which is very low compared to August (14%). The annual rainfall CV in all stations is below 20% which is said to be less (NMSA, 1996) but the CV of *belg* season, which is known to be main maize growing season for the area, is higher than the annual amount. Similarly at Alaba Kulito 36.64% of annual rainfall was occurred in *belg*, while 47.2% of the annual rainfall occurred in *kiremt.* The Precipitation Concentration Index (PCI) is 11.05, 10 and 9.67% in Hosana, Alaba Kulito and Bilate Stations respectively.

The Precipitation Concentration Index (PCI) of all the stations is near or above the threshold value of PCI = 10% for uniform rainfall distribution throughout a year. March, April and May (MAM) contribute 33% of annual rainfall in the Bilate station which shows that MAM is, relatively the main growing season in the lowland areas (NMSA, 1996).

Onset, end and length of growing period

The computation of onset, end and LGP is done by following the days of year (DOY) entry format for a year

Table 6. Mean monthly amount and percentage contribution of rainfall for selected stations.

Station	Jan	Feb	mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean monthly rainfall (mm)												
Hosana	29	47	85	131	145	135	144	150	144	50	25	17
Alaba Kulito	36	52	93	118	128	118	118	150	120	74	37	26
Bilate	27	30	60	93	106	97	83	74	72	67	42	33
Percent contribution to annual (%)												
Hosana	3	4	8	12	13	12	13	14	13	5	2	2
AlabaKulito	3	5	9	11	12	11	11	14	11	7	3	2
Bilate	3	4	8	12	14	12	11	9	9	8	5	4

Table 7. Onset, end and length of growing period (LGP) in three selected stations.

Station		Hosana	Alaba Kulito	Bilate
Onset	Max	127	158	158
	Min	51	53	43
	Mean	94	101	102
	CI	94 ± 8	101 ± 10	102 ± 11
	SD	22	26	29
	CV	0.23	0.26	0.29
End	Max	302	311	254
	Min	247	245	149
	Mean	277	269	194
	CI	277 ± 5	269 ± 7	194 ± 10
	SD	15	19	28
	CV	0.05	0.07	0.14
LGP	Max	229	252	150
	Min	131	87	29
	Mean	183	168	92
	CI	183 ± 10	168 ± 13	92 ± 13
	SD	26	34	35
	CV	0.14	0.2	0.38

Onset and End measured in DOY, LGP measured in number of days, CI stands for Confidence interval at $\alpha = 0.05$.

beginning in January and ending in December and using daily rainfall data of 30 (1984 - 2013) years for three rainfall stations. The results in Table 7 showed that the average onset date of rainfall for Hosana is 94 ± 8 DOY (April 3), for Alaba Kulito 101 ± 10 DOY (April 10) and for Bilate is 102 ± 11 DOY (April 11) with CV of 23, 26 and 29% respectively. The average end dates of the rainy season in Hosana and Alaba Kulito are October 3 (277 ± 5 DOY) and September 25 (269 ± 7 DOY) with CV 5 and 7%. The main rainy season ends earlier in Bilate, it is on July 12 (194 ± 10 DOY) with CV 14%. The length of growing period (LGP) in Hosana varies from 131 to 229 days with 30 years mean value of 183 ± 10 days, CV 14% and SD of 26 days. The result of LGP for Alaba Kulito varies from 87 days to 252 days with mean value of 168 days, CV 20% and SD of 34 days.

The box plot in Figure 3 shows that the LGP is very variable in all the three stations, but it is highly variable (from 29 - 150 days) in Bilate station with CV of 38% and SD of 35 days. Ethiopia is known to have three distinct seasons. The first is the “Belg” Season (February, March, April and May) which is the main growing season for most of the long duration crops like maize and sorghum (NMSA, 1996; Abiye et al., 2014), the second is “Kiremet” Season (June, July, August and September) which is responsible for up to 57% of annual rainfall in the study area and the third is the “Bega” Season (October, November, December and January) which is usually a dry season known to be non-growing season. From the above discussion it is clear that the long rainy season (Belg - Kiremt) runes from February to September and the computation of onset, end and LGP is done within

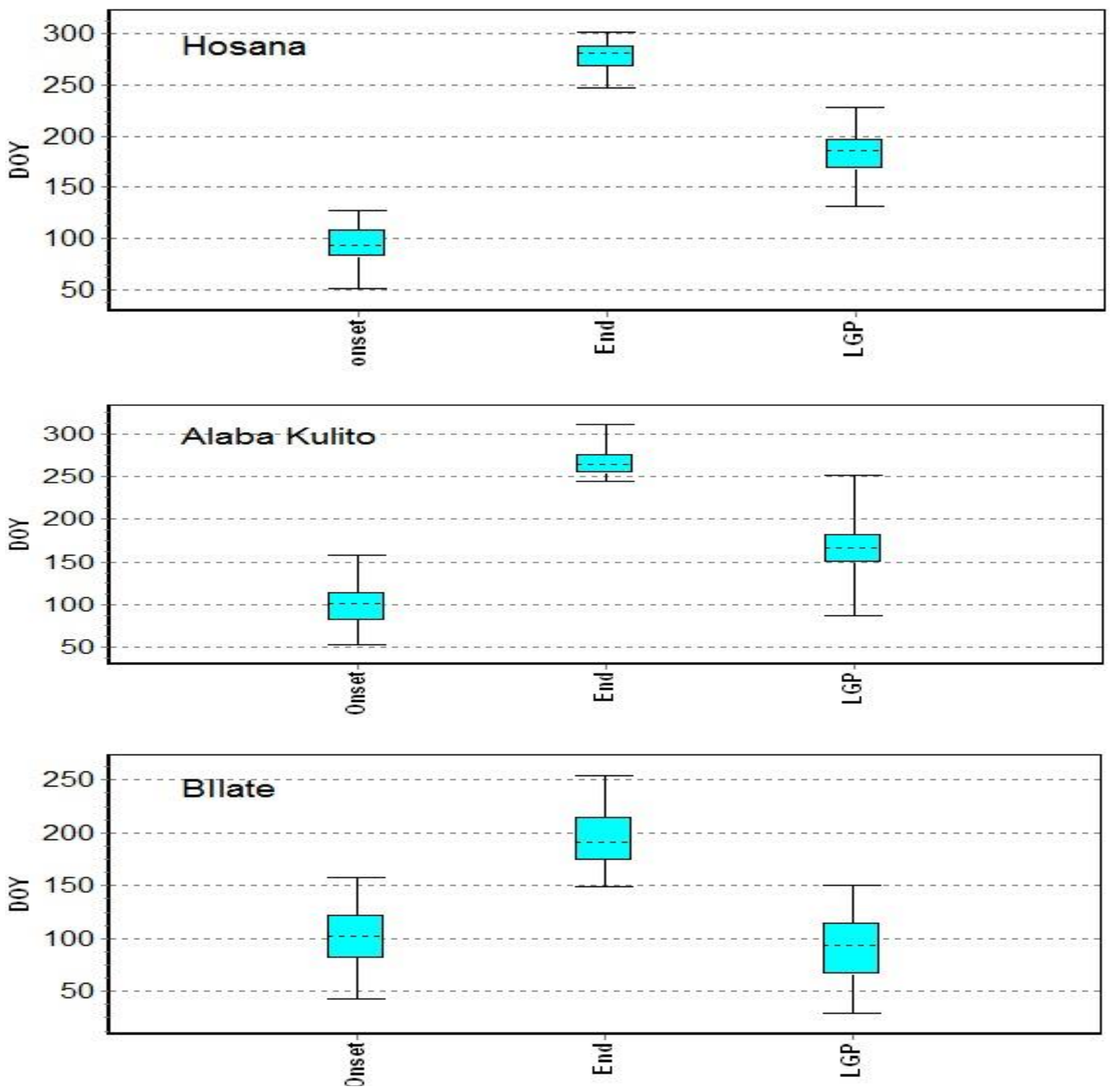

Figure 3. Box plot graph of onset, end and LGP in three stations. The upper and lower tip of the whiskers shows the maximum and the minimum values, the upper and lower sides of the box represent 75th and 25th percentile and the dot line inside the box indicates the median dates.

these months by following the days of year (DOY) entry format for a year beginning in January and ending in December and using daily rainfall data of 30 (1984 - 2013) years for three rainfall stations.

As shown in Table 7 there is no big difference in the mean on set date of rainfall in the watershed with the first and second week of April is the average on set date of rainfall in all the stations. But the average end date and so the LGP is different from station to station in the watershed. Based on the 30 years result, the mean end date of the rainy season in Hosana, Alaba Kulito and Bilate station was October 3, September 25 and July 12 respectively, giving the stations mean the Length of Growing Period of 183, 168 and 98 days respectively and this results are in agreement with the findings of Abiyet al. (2014).

Analysis and comparison of evapotranspiration

As shown in Figure 4, in Hosana station the mean monthly rainfall exceed the evapotranispiration for months from April to September and there is water deficit in the area for the rest of the year. Hosana, with 30 years mean Aridity Index (AI) of 0.8 is classified as a humid zone even though there is water deficit for half of the year. In Alaba Kulito, an area with 30 years mean AI = 0.6 (Dry sub-humid zone) the evapotranispiration values exceed the rainfall amount for most of the months except July and August. As shown in Figure 4, in Bilate area, the evapotranispiration values exceed the rainfall amount for all of the months, showing that rain fed agriculture is not feasible. The AI of Bilate area is 0.43, so that the area is classified as semi-arid zone according to UNFCCC

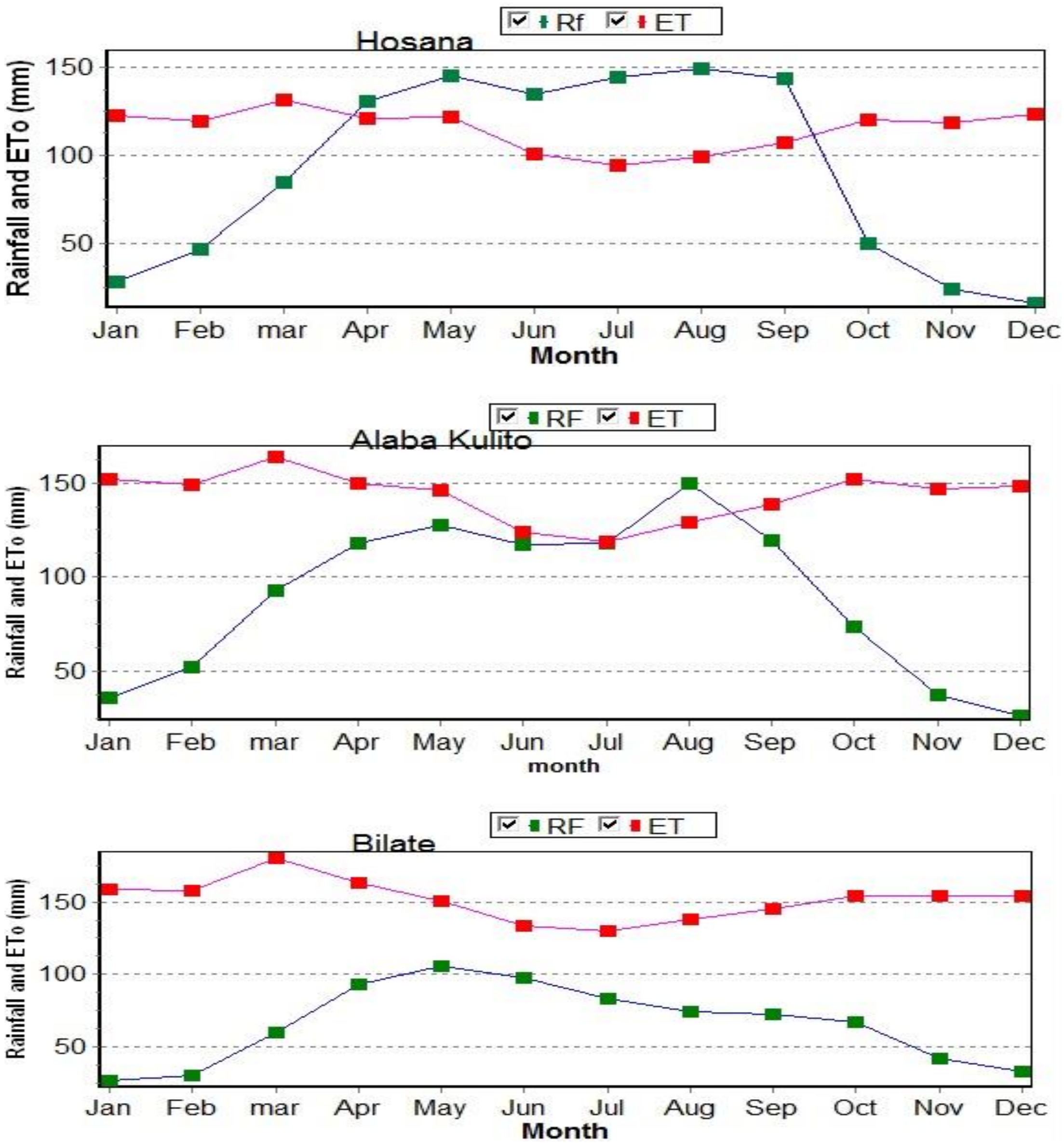

Figure 4. Comparison of monthly rainfall and reference evapotranspiration.

(Rodier, 1985).

The relationship between 20, 50 and 80% exceedance levels of monthly rainfall representing wet, normal and dry years respectively and the reference crop evapotranspiration of 20, 50 and 80% exceedance levels is shown in Figure 5 for three selected station. For Hosana station the rainfall expected in normal year is less than the reference crop evapotranisipiration for half of months of the year. In a wet year (20%RF) two more months with expected rainfall higher than the reference crop evapotranisipiration at 20, 50 and 80% will be added. Furthermore, the monthly 80% dependable reference evapotranisipiration is in the range of ± 31 mm of the monthly mean value, which shows that there is a probability of the reference evapotranisipiration exceeds the mean monthly rainfall leaving the area with deficiency of crop water.

Similarly, in Alaba Kulito station in a normal and dry years (50 and 20% RF) rainfall is less than the reference crop evapotranisipiration throughout the year. In Bilate station only 20% RF in wet years exceeds the reference evapotranisipiration in couple of months giving the area a slight chance of rain-fed agriculture with mean Length of Growing period (LGP) less than 90 days.

For all the stations monthly reference evapotranisipiration was computed and compared with the monthly mean rainfall. This helps to determine the period with moisture deficit and times when the need for

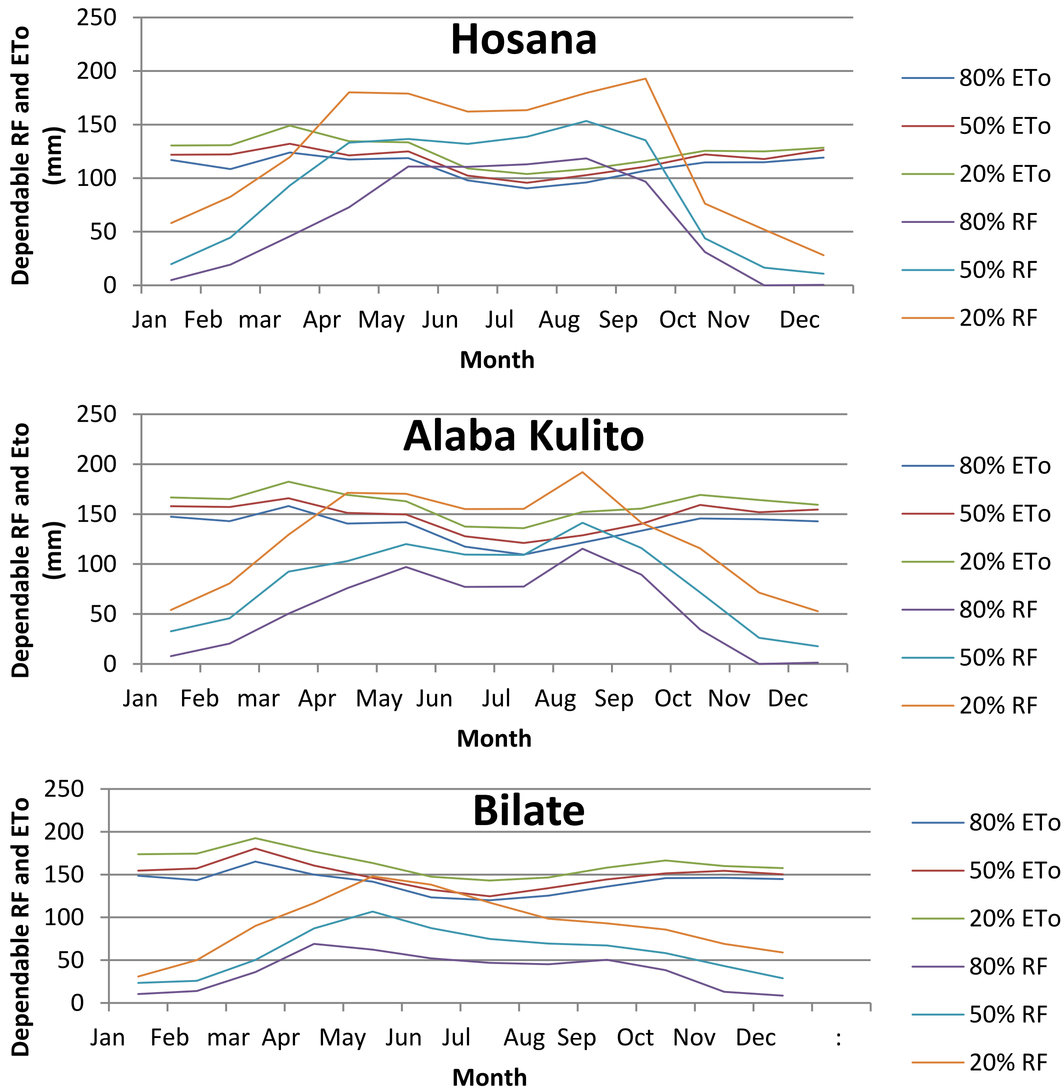

Figure 5. Monthly rainfall and evapotranspiration at three exceedance probability levels for selected three stations.

water from other sources is high and the farmers cannot depend only on rain for their agricultural production. As shown in Figure 4, in Hosana station the mean monthly rainfall exceed the evapotranispiration for months from April to September and there is water deficit in the area for the rest of the year. In Alaba Kulito, an area with 30 years mean AI = 0.6 (Dry sub-humid zone) the evapotranispiration values exceed the rainfall amount for most of the months except July and August. As shown in Figure 4, in Bilate area, the evapotranispiration values exceed the rainfall amount for all of the months, showing that rain fed agriculture is not feasible but only 20% RF in wet years exceeds the reference evapotranispiration (Figure 5) in couple of months giving the area a slight chance of rain-fed agriculture with mean Length of Growing period (LGP) less than 90 days, otherwise the area is having rainfall below the threshold of rain-fed agriculture of 250 mm (Aghajani, 2007). The Aridity Index (AI) of Bilate area for the last 30 years is 0.43, so that the area is classified as semi-arid zone according to UNFCCC (Rodier, 1985).

Conclusion

In this study rainfall variability including the onset, end and length of growing period with the number of raining days and over all statistical parameters was analysed. The reference evapotranispiration (ETo) was also determined from other directly measured climatic variables and compared with the annual and seasonal rainfall trend as this is the determining factors of planning and management of water resources and agricultural practices. Rainfall is the major climatic parameter that needs to be analysed for its statistical characteristics in order to conduct successful rainfed agriculture, while evapotranspiration is another factor that can be estimated from other climatic parameters. The result showed that, there was a considerable spatial variation of rainfall and temperature over Bilate watershed. The annual total rainfall of the watershed varies from a little over 780 mm in Bilate station to over 1350 mm in Shone station. From the different rainfall features considered in the study, onset and end dates of rainfall and so the Length of growing period was also found to considerably variable. The main climatic problem of all the stations for their rainfed agriculture is a Pseudo onset of the rain, days with limited amount of rainfall that are followed by dry spell of more than 9 days within a month time. From the comparison of rainfall and evapotranispiration mean values for the last 30 years, it has been seen that the areas in upper and mid part of the watershed experience a water deficit from 6 to 9 months of the year, while area in the lower part of the watershed experience moisture deficit throughout the year which necessities supplementing the rainfed agriculture with other sources of water for irrigation. The Impact of large-scale climate anomalies, such as ENSO on the main growing period (Belg and Kiremt seasons) of the BRW needs to be addressed by further research.

Conflict of Interests

The authors have not declared any conflict of interests.

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Physicochemical and bacteriological quality assessment of the Bambui community drinking water in the North West Region of Cameroon

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In order to ascertain water quality for human consumption, physical and chemical parameters, together with faecal forms of bacteria were evaluated in the drinking water resources of the Bambui community in the North West region of Cameroon. This study was necessitated by the occasional presence of suspended particles in the water and typhoid cases recorded in the Bambui community. Samples of tap water collected from Niba, Atunui and Tubah quarters in the town of Bambui were analyzed for physical, chemical and bacteriological characteristics using standard methods. Results obtained indicated that the water samples were contaminated to different extents by bacteria and heavy metals due to lack of disinfection, uncontrolled defecation, pipe leakages and the use of fungicides for agricultural activities. All the samples contained the faecal forms of bacteria. The level of water pollution increased in the order Nibah<Atunui<Tubah when compared with World Health Organization standards. A highly significant difference ($p < 0.05$) was recorded for pH, N-NO_3, N-NH_4, SO_4^{2-}, Fe, Zn and Ca contents of the water samples between the months of December 2013 and April 2014. Significant positive and negative correlations were recorded between some physical, chemical and bacteriological variables of the samples with the sulphate content of the water samples being highly significantly and negatively correlated ($r = -1.000$, $p < 0.01$) with all the bacteria (entero-bacteria, *Escherichia coli*, *Streptococcus, Salmonella* and *Proteus)* content of the samples. The results presented therefore attest that the Bambui Community drinking water needs appropriate attention from water authorities in particular and the community in general. The public is informed that although the water has no odour and looks clean, it contains infectious bacteria and thus should be treated by chlorination or boiling before use.

Key words: Water resources, bacteria, health, contamination, disinfection and maintenance.

INTRODUCTION

The importance of environmental quality in general, water quality assessment and treatment in particular cannot be overemphasized, given its enormous impact on human health and economic status of the population. The quality of drinking water has a powerful impact on public health and therefore, the effective monitoring and comprehensive assessment of public drinking water systems are crucial to protect the wellbeing of the public and to allow the implementation of a preventive approach to manage drinking water quality (Li et al., 2009). To manage water resources in a meaningful and effective manner, development should be seen as an integrated and continuous process for sustainability and poverty reduction (Nyambod and Nazmul, 2010).

Most of the mortality associated with water related diseases especially in developing countries is due directly or indirectly to infectious agents which infect man through ingesting pathogenic bacteria, viruses or parasites (protozoans and helminthes) in water polluted by human or animal faeces or urine. Diseases in this category include cholera (*Cholera vibrio*), shigellosis (dysentery caused by *Shigella* species), typhoid (*Samonella typhi*), paratyphoid (*Samonella paratyphi*), diarrhea (*Escherichia coli*), hepatitis (Hepatitis virus) and poliomyelitis (Polio virus). Some are associated with scarcity of water for personal hygiene (bathing, hand washing), laundry and cleaning of cooking utensils. In this category of diseases are scabies, yaws, skin ulcers, conjunctivitis, and trachoma. It has also been estimated that over two million people all over the world, die of cholera per year; the majority of which are children under the age of five (Obasohan et al., 2010; Zamxaka et al., 2004).

The source(s) of drinking water for any community is very essential. Three sources of water have been identified to include: rainwater, groundwater (wells, boreholes and springs) and surface water (rivers, lakes, streams and oceans). Amongst these sources, surface waters are the most exposed and consequently require careful monitoring and treatment. Rainwater essentially supplements the other sources (www.WHO.int, 2014). Ibanga (2015) carried out a study in which he assessed the sanitary conditions in an Urban Community in Nigeria and found that tap water was the major source of water which was stored using closed containers and disinfected by boiling. The industrial units located in the cities, agricultural practices and the indiscriminate disposal of domestic and industrial wastes are the sources of surface water and ground water pollution. Armand et al. (2012) in a study which modelled households' decision to purify water before drinking, accorded particular attention to the possible simultaneity of the choice of the drinking water source and the decision to purify or not water before drinking it, in order to get reliable results. They found that the correlation between the choice of the water source and the adoption of a purification method was positive and strongly significant. The need to determine the physical-chemical parameters, in drinking water sources is urgent in Cameroon since some sources may have a reasonably good chemical quality but for exceptions related to the occurrence of lead contamination as in the Northern part of the country (Sabrina et al., 2013). The quality of a particular stream or river is seriously correlated with the nature of activities in its surroundings thus it was mentioned that the good status of a stream named Nga and its great taxonomic richness could be linked to the relatively non perturbed state of its river basin and to the characteristics of streams found at the source of this basin which is a non-mountainous forest zone with no anthropogenic activities, where vegetation is known to be very dense (Foto et al., 2013).

Parameters such as appearance, taste, odour, and colour amongst others are of primordial importance and are recommended for minimum monitoring of community water supplies. These parameters equally establish the hygienic state of water and the risk (if any) of water borne infections. The provision of drinking water that is not only safe but also acceptable in appearance is of high priority. Water that is aesthetically unacceptable will undermine the confidence of consumers, will lead to complaints and more importantly, could lead to the use of water from sources that are less safe (WHO, 1997). The appearance of water is usually determined by observation with the eyes while taste like odour originates from natural inorganic and organic chemical contamination and biological sources or processes such as aquatic microorganisms or from contamination by synthetic chemicals or from corrosion, as a result of problems with the treatment of water e.g. chlorination. Taste may also develop during storage and distribution resulting from microbial activity. Tastes caused by disinfectants are best controlled through careful operation of the disinfection process and pre-treatment to remove precursors. Odour affects the quality of drinking water. It is usually measured by the threshold odour number (TON), which corresponds to the dilution factor necessary before the odour is perceived. A TON of 1, for example is indicative that the water possesses characteristics comparable to odour from water (Evangelou, 1998). In drinking water, colour may be used as an index of large quantities of organic chemicals from plants and soil organic matter (Evangelou, 1998). Metals such as copper, manganese and iron can also induce colour. The appearance of colour in water is caused by the absorption of certain wavelengths of light by coloured substances dissolved in water often referred to as true colour (real colour) and by the scattering of light by suspended particles, otherwise known as apparent colour. In clear water, true and

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apparent colours are the same and this equally holds for water with low turbidity. Changes in colour from that normally seen can provide warning of possible quality changes or maintenance issues and should be investigated (Payment et al., 1991).

Ideally, drinking water should not contain bacteria or micro-organisms known to be pathogenic, that is, capable of causing disease or any bacteria indicative of faecal pollution. The detection of bacteria such as *E. coli* and faecal *coliform* provides definite evidence of faecal pollution and are measured as indicators of more harmful bacteria. Other *coliform* and *streptococci*, some of which infect the upper respiratory tract can cause diseases for example, *S. pyrogenes*, which causes scarlet fever and sore throats can also be detected (Franciska et al., 2005). Studies reveal that drinking water is highly vulnerable to bacterial contamination. Water contamination may be due to leakage of pipes, cross contamination with waste water, short distance between water supply network and sewage supply lines, construction of septic tanks near wells and drinking water supplies, run off, infiltration of waste amongst others. Microbial parameters can be very useful in providing information throughout the drinking water production process, including catchment survey, source water characterisation, treatment efficiency and examination of the distribution system.

The Bambui Community water sometimes appears coloured with suspended particles and is not chlorinated. These result in so many people suffering from typhoid infection. In order to enhance the availability of safe drinking water to the Bambui Community by proposing good water quality practices such as treatment or purification and general sanitation, this study was necessitated.

Generally, this study was aimed at investigating the extent of contamination of the Bambui Community water by examining some parameters that determine water quality. Specifically, this study evaluated physical and chemical parameters such as the temperature, suspended and dissolved solids, chloride (Cl^-), nitrate (NO_3^-), sulphate (SO_4^{2}) and phosphate (PO_4^{3-}) ions in the water, the presence and concentrations of essential mineral elements and some heavy metals such as sodium, potassium, magnesium, calcium, iron, zinc, lead, and chromium in water, the presence and numbers of various bacterial forms such as *E. coli, Enterobacteria*, *Streptococci, Salmonella* and *Proteus* species in the water and finally recommendations made from the results obtained.

MATERIALS AND METHODS

Sampling sites

Samples were collected from three locations: Nibah, Atunui and Tubah quarters in the Bambui Community located in Mezam division of the North West Region of Cameroon. All these samples were tap water from three different sources harnessed by the community. The location of the sampling points is as shown in Figure 1.

A total of six water samples were collected from Bambui Community tap water in two different seasons. The first set was in the month of December 2013 (end of rainy season) and the second set took place in the month of April 2014 (beginning of the rainy season). The samples were collected in clean polythene bottles of 1500 ml capacity. Plastic bottles were preferred to glass bottles because glass bottles can absorb metals and will cause inaccuracy in analysis (Reeve, 2002). Each water sample was used to rinse the apparatus before collecting the required sample volume. The collection was effected very early in the morning before sunrise and the samples packaged in a carton with labels on them. The early collection was to prevent sunlight from falling on them and causing a reaction. Transportation to the laboratories in the University of Dschang where the analyses were conducted was done on the same day for preservation purposes.

Laboratory analysis

Organoleptic and physico-chemical analysis

Organoleptic parameters were determined using the human senses. The appearance of the samples was determined by observing with the eyes. The characteristics of interest included the perceptible colour of the water, state of floating of the particles and speed of flow. Odour was described by making use of the sense of smell either as being offensive or smelling. pH was measured electrochemically using a pH meter. Water turbidity was measured using a turbidimeter (DRT, 100B, MF scientific, Inc.) by allowing a beam of light to be projected towards the tube in which the samples were contained. Turbidity is measured in nephelometric turbidity units (NTU). Electrical conductivity was measured using a conductimeter and recorded in µS/cm. Chloride content was measured using argentometric method (silver nitrate titration). Total nitrogen exists in three forms, namely: Nitrate-Nitrogen (NO_3-N), Ammonium-Nitrogen (NH_4^+- N) and Organic-Nitrogen (by-products from living organism). Ammonium–Nitrogen was determined by Kjeildahl's distillation method. Nitrate-Nitrogen was determined by Raleigh Atomic Absorption Spectrophotometry because Nitrate-Nitrogen is very unstable and volatile. The bicarbonates were determined by acid-base titration. The determination of the concentrations of Ca, Mg, K, Na Zn, Cr, Pb and Fe were done using Atomic Absorption Spectrophotometry.

Bacteriological analysis

Multi tube fermentation technique (most probable technique of diluted sample) and membrane filter technique were used (Cheesbrough, 1984).

Multi tube fermentation method

Glassware was sterilized in an oven at 160°C for 1 h. This was followed by the preparation of bacteria logical media as per the manufacturer's procedure and sterilized by autoclaving at 12°C for 15 min. The working bench of the laboratory was also sterilized prior to and after analyses. The Bunsen burner was kept burning to maintain an aseptic laboratory environment. To isolate the bacteria, 1.0 ml of each sample was added to 5.0 ml of broth, mixed and

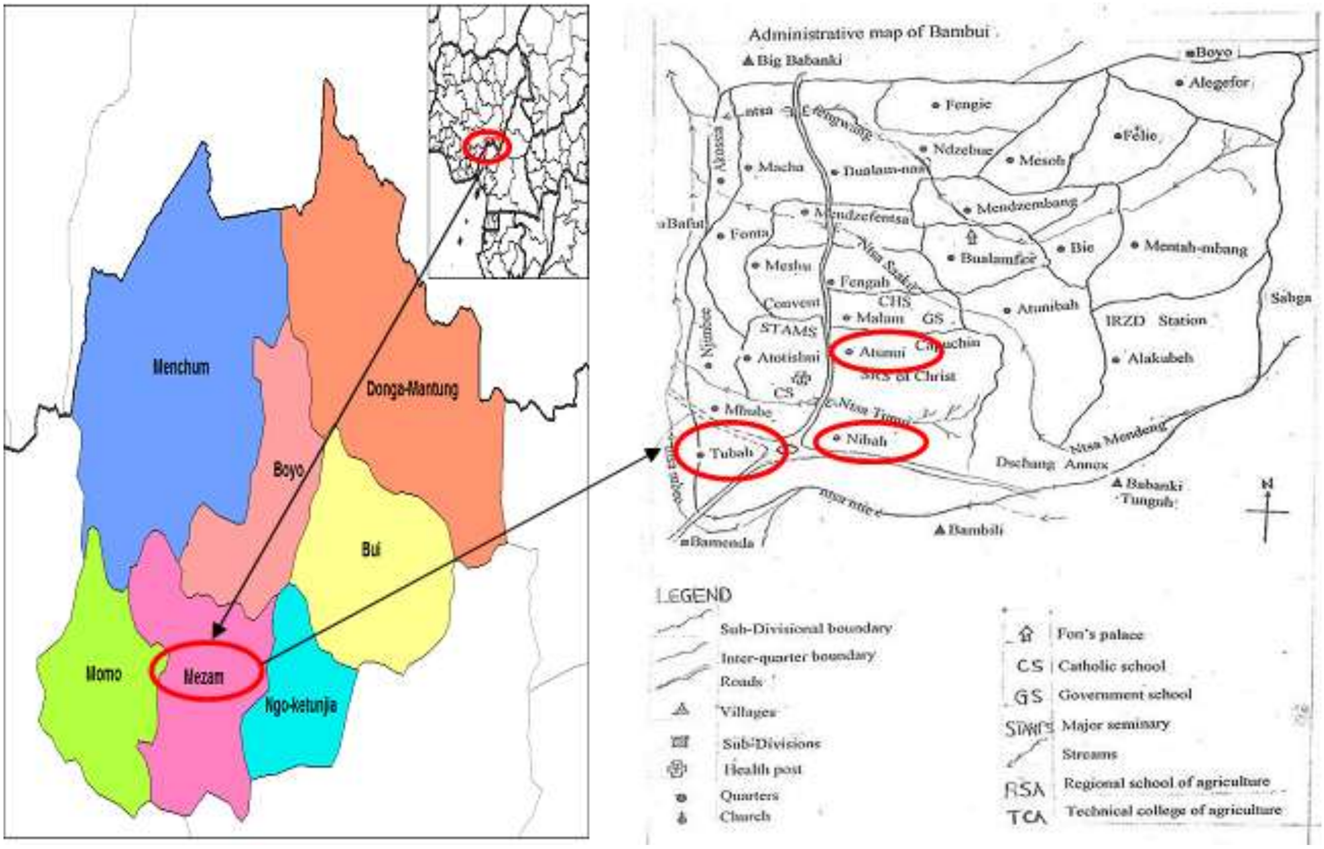

Figure 1. Location of the sampling site and sampling points.

incubated overnight at 44°C. A loopful of the inoculated broth was then sub-cultured into a well dried agar and eventually streaked to obtain bacteria colonies. Plates were then incubated throughout the night. Plates were read the following day under the microscope and pure cultures obtained after identifying the colonies.

Membrane filter method

The plates were read under the microscope. The parameters determined on each colony isolated on the plates included predominance, colour, shape, size, odour and consistency. To identify under the microscope, smears of each colony were made, allowed to dry and then stained using Gram staining techniques into Gram positive and Gram negative bacteria as well as *cocci* and *bacilli*. Motility test was conducted to detect the motility of the bacteria. The use of API profile index kit was equally used for rapid identification. API profile index kits are plastic strips containing twenty micro tubes with dehydrated substrates capable of detecting biochemical characteristics of bacteria. The tests substrates were inoculated with the pure culture of bacteria suspended in sterile physiological saline. The test results were converted to 7 digits for enterobacteria, 9 digits for Gram negative and thereafter, the names of the bacteria were identified with the aid of the kit.

Statistical analysis

Student test (t-test) was used to compare the results obtained for each parameter in December and April. Correlation analyses were also performed between some selected water physico-chemical parameters and bacteria content of the water samples. Student test and correlation analyses were performed using SPSS Version 19 and GenStat 9th Edition.

RESULTS AND DISCUSSION

Samples analysed were labelled A (Nibah), B (Atunui) and C (Tubah). The results presented in Tables 1, 2, 3, 4 and 5 are those obtained in the months of December 2013 and April 2014 for the organoleptic, physical, chemical (illustrating anions, cations and their hydrochemical facies, and finally heavy metals) and bacteriological analysis, respectively. Each parameter was discussed in relation to guidelines for drinking water quality limits by World Health Organisation (WHO) and the United States Environmental Protection Agency (EPA).

The samples were clean and clear except for sample A which initially was not clear with brownish debris and sample C which was clear with tiny dark debris. This could have resulted from rainfall that washed pollutants from the air into the water sources. Interestingly, all the samples were colourless and odourless. Ideally, safe drinking water should be clean and clear, as well as

Table 1. Results of organoleptic parameters.

Sample	Appearance		Colour		Odour	
	December	**April**	**December**	**April**	**December**	**April**
A	Not clear with many brown debris	Clean and clear	Colourless	colourless	Odourless	Odourless
B	Clean and clear	Clean and clear	Colourless	colourless	Odourless	Odourless
C	Clean and clear	Clear with tiny dark debris	Colourless	colourless	Odourless	Odourless
WHO	Clean and clear	-	-	-	-	-

Table 2. Results of physical analysis.

Sample	pH		Electrical conductivity(µs/cm)		Turbidity(NTU)	
	December	**April**	**December**	**April**	**December**	**April**
A	6.0	7.3	70	70	0.67	0.30
B	6.0	7.0	56	60	0.05	0.10
C	6.1	7.5	61	90	0.89	1.80
WHO	6.5-8.5		2000		0.1-5	

colourless and odourless. Samples A and C were therefore mildly polluted.

The pH of all the samples ranged from 6.0 to 7.5 with sample C having the highest pH value and sample B the lowest. WHO pH limit range is 6.5 to 8.5. Thus, the pH of the samples fell within the limit in April 2014 and out of it in December 2013. A highly significant difference ($p < 0.01$) was recorded between the pH values in December and April. Within a tolerance level, the pH values do not therefore indicate any form of pollution. The electrical conductivity levels of all the samples ranged from 56 to 90 µS/cm compared to the WHO limit of 2000 µS/cm. These values were quite low and within limits indicating that there were very little dissolved solids. Therefore, there was no contamination from dissolved solids**.** The turbidity values of all the samples ranged from 0.05 to 1.8 NTU compared to the WHO limit of ≤5 and so, the values were within limits. This implies that the amount of suspended solids was quite small. For this reason, there was no pollution resulting from suspended solids. Also, no significant differences were recorded in the electrical conductivities and turbidity of the samples between the months of December and April.

The concentration of $N\text{-}NO_3$ in the samples ranged from 0.001 to 4.48 mg/L which when compared with the WHO limit of 50 mg/L fell well below and so the water was free of nitrate contamination. Again, the concentration of $N\text{-}NH_4$ ranged from 0.006 to 9.52 mg/L for the samples. The limit prescribed by WHO is 1.5 mg/L. A significant difference ($p < 0.05$) was recorded in the $N\text{-}NO_3$ and $N\text{-}NH_4$ content of the samples in December and April. All the $N\text{-}NH_4$ content in December fell below the limit whereas the values for all the samples taken in April were above the limit with that of sample C being the highest (9.52 mg/L) and A the lowest (5.3 mg/L). This implies that the three water sources were heavily contaminated with ammonium nitrogen in April. High values of $N\text{-}NH_4$ recorded throughout the study period may have resulted from pollution with animal or human organic matter washed by the first rains into water bodies and could indicate on one hand, high mineralization of water, and on the other hand, an increase in organic matter loads, thus indicating poor water quality. This can be resolved through biological nitrification or oxidation. These results conform to those of Foto et al. (2006) working in the urban streams of the Mfoundi river basin where very high values of $N\text{-}NH_4$ (3.2 to 27.2 mg/L) and PO_4^{3-} (1.83 to 12.7 mg/L) ions were obtained but are different from those of Foto et al. (2013) who had very low values. The level of chlorine in the six samples collected was non-detectable. This is explained by the fact that chlorine is not used to disinfect the water sources. So, there was no chloride contamination. The sulphate levels of all samples were very low (ranging from 0.043 to 0.17 mg/L) comparable to the WHO and EPA value of 250 mg/L. A highly significant difference ($p < 0.01$) was recorded in the sulphate content of the samples in December and April, showing a high fluctuation between the seasons. The phosphorus levels of all samples ranged from 0.2314 to 3.4088 mg/L and fell below the WHO limit of ≤5 mg/L. There was therefore no phosphorus contamination. All the samples had a bicarbonate range of 48.8 to 78.08 mg/L which is well below the WHO and EPA value of 1000 mg/L. Thus, no contamination resulted from bicarbonate. Anion concentrations are illustrated on a bar chart on Figure 2.

Table 3. Results of chemical analysis.

Sample	$N\text{-}NO_3$ (mg/L)		$N\text{-}NH_4$ (mg/L)		Cl (mg/L)		SO_4^{2-} (%)		P (mg/L)		HCO_3^- (mg/L)		Fe (mg/L)	
	Dec	April	Dec	April	Dec	April	Dec	April	Dec	April	Dec	April	Dec	April
A	0.001	2.520	0.040	5.320	nd		0.043	0.164	0.2314	1.5239	73.20	61.00	12.5	2.35
B	0.002	3.640	0.026	7.280	nd		0.072	0.180	0.2314	3.4088	73.20	48.80	13.83	2.94
C	0.014	4.480	0.006	9.520	nd		0.072	0.197	0.3751	0.2673	73.20	78.08	16.16	1.71
WHO limits	50		1.5		250		250		≤ 5		1000		0.3	

Sample	Pb (mg/L)		Zn (mg/L)		Cr (mg/L)		Ca (mg/L)		Mg (mg/L)		K (mg/L)		Na (mg/L)	
	Dec	April	Dec	April	Dec	April	Dec	April	Dec	April	Dec	April	Dec	April
A	1.65	2.16	0.14	3.26	1.75	1.83	0.27	8.31	8.29	8.48	nd	1.00	12	106
B	3.00	2.23	0.81	3.07	2.25	2.06	0.20	8.26	nd	1.43	nd	1.54	12	117
C	3.40	1.84	1.14	2.63	5.5	2.06	0.11	8.58	nd	1.33	nd	1.09	18	254
WHO	0.05		3.0		0.05		200		150		20		20	
EPA	0.05		5.0		-		-		-		-		-	

Dec = December; nd = non detectable.

Table 4. Results of bacteriological analysis for most probable number.

Volume of sample in each bottle	50 ml		10 ml		1 ml		Most Probable Number of coliforms in 100 ml of the original water			
Number of bottles used	1		5		5		Mean count		Category	
	Dec	April	Dec	April	Dec	April	Dec	April	Dec	April
A	1	1	4	1	4	0	35	3	C	B
B	1	1	3	1	1	2	11	7	C	B
C	1	1	3	5	1	3	11	90	C	D

Category C = High risk unacceptable, B = Low risk acceptable and D = grossly polluted. WHO standard is category A which is acceptable and unpolluted with bacteria and with the MPN per 100 ml of water sample being zero. Dec = December.

Table 5. Results of bacteriological analysis for specific microbes isolated (colony forming unit/me).

Sample	Enterobacteria		Esch-coli		Streptococcus		Salmonella		Proteus	
	Dec	April	Dec	April	Dec	April	Dec	April	Dec	April
A	1000	20	600	10	500	50	30	00	20	00
B	30	30	20	20	50	50	00	00	00	05
C	20	200	20	150	50	200	00	10	00	10

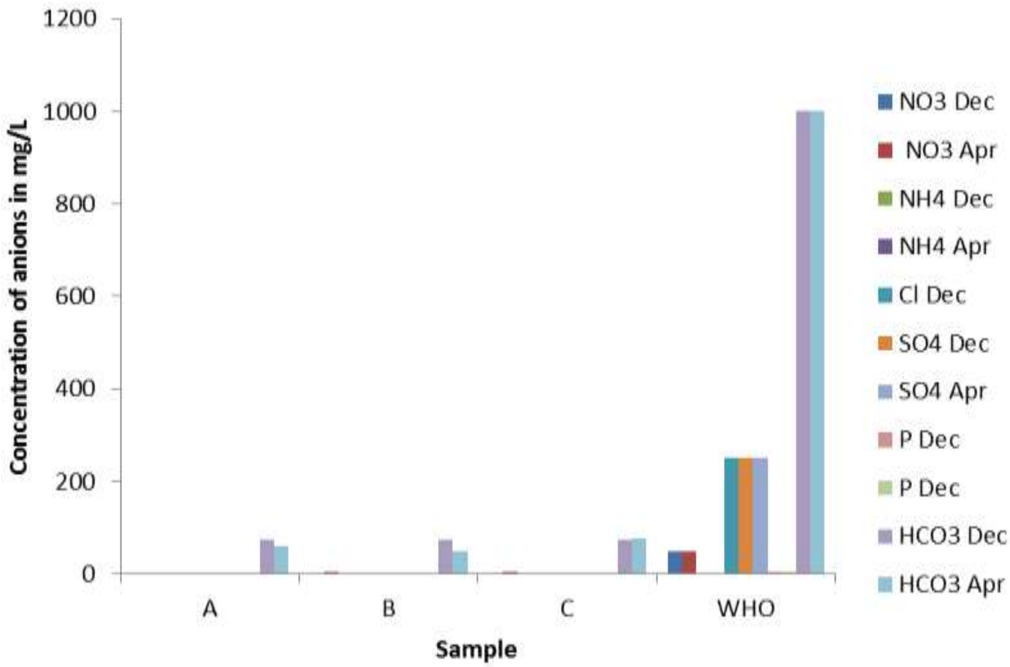

Figure 2. Anion concentration for each sample.

Calcium and magnesium levels of all the samples ranged from 0.11 to 8.58 mg/L and 1.33 to 8.48 mg/L, respectively. These values were well below the WHO limit of 200 mg/L for calcium and 150 mg/L for magnesium. Thus, no contamination by calcium and magnesium was observed and consequently, the water is soft. A significant difference ($p < 0.05$) was recorded in the calcium content of the samples in December and April. Sodium and potassium levels ranged from 12 to 254 mg/L and 1 to 1.54 mg/L, respectively compared to the WHO limit of 20 mg/L for both sodium and potassium. However, potassium levels fell within limit whereas sodium levels far exceeded the limit on average. Therefore, there is sodium contamination for all the samples with sample C being the highest and sample A the least. The value for sample C is 185 mg/L on average which is very close to 200 mg/L considered high; though, this is only much risky to hypertensive patients.

Hydrochemical facies of cations and anions in samples

The concentrations of major ionic and cationic constituents of the water samples were plotted on a Piper trilinear diagram (Piper, 1953) to determine the water types as shown in Figure 3. Diamond shaped field between the two triangles is used to represent the composition of water with respect to both cations and anions. The classification for cations and anions facies, in terms of major ion percentages and water types, is according to the domain in which they occur on the diagram segments. The points for both the cations and anions are plotted on the appropriate triangle diagrams. The plot of chemical data on the diamond shaped trilinear diagram (Figure 3) reveals that the majority of the water samples fall in the Na, Ca, Mg facies and HCO_3^- facies.

The classification diagram for anion and cation facies in the form of major-ion percentages is as follows: magnesium type-A, No dominant type-B, calcium type-C, sodium and potassium type-D, sulphate type-E, chloride type-F, and bicarbonate type-G. Zone H represents chlorides, sulphates, calcium and magnesium, while zone I represents sodium and potassium chlorides or sodium sulphate. Zone J represents sodium hydrogen carbonates and potassium hydrogen carbonate while zone K represents calcium hydrogen carbonates and magnesium hydrogen carbonate.

The levels of chromium in the water samples ranged from 1.75 to 5.5 mg/L. This fell above the WHO limit of 0.05 mg/L. The highest value was found for sample C and the lowest for sample A. This means that the water was polluted with chromium as indicated by the results for December and April. Chromium is found to be carcinogenic. This may have resulted from the use of fungicides, pigments and paints. The levels of lead in all the samples ranged from 1.65 to 3.4 mg/L compared to the WHO limit of 0.05 mg/L. Thus, there was heavy

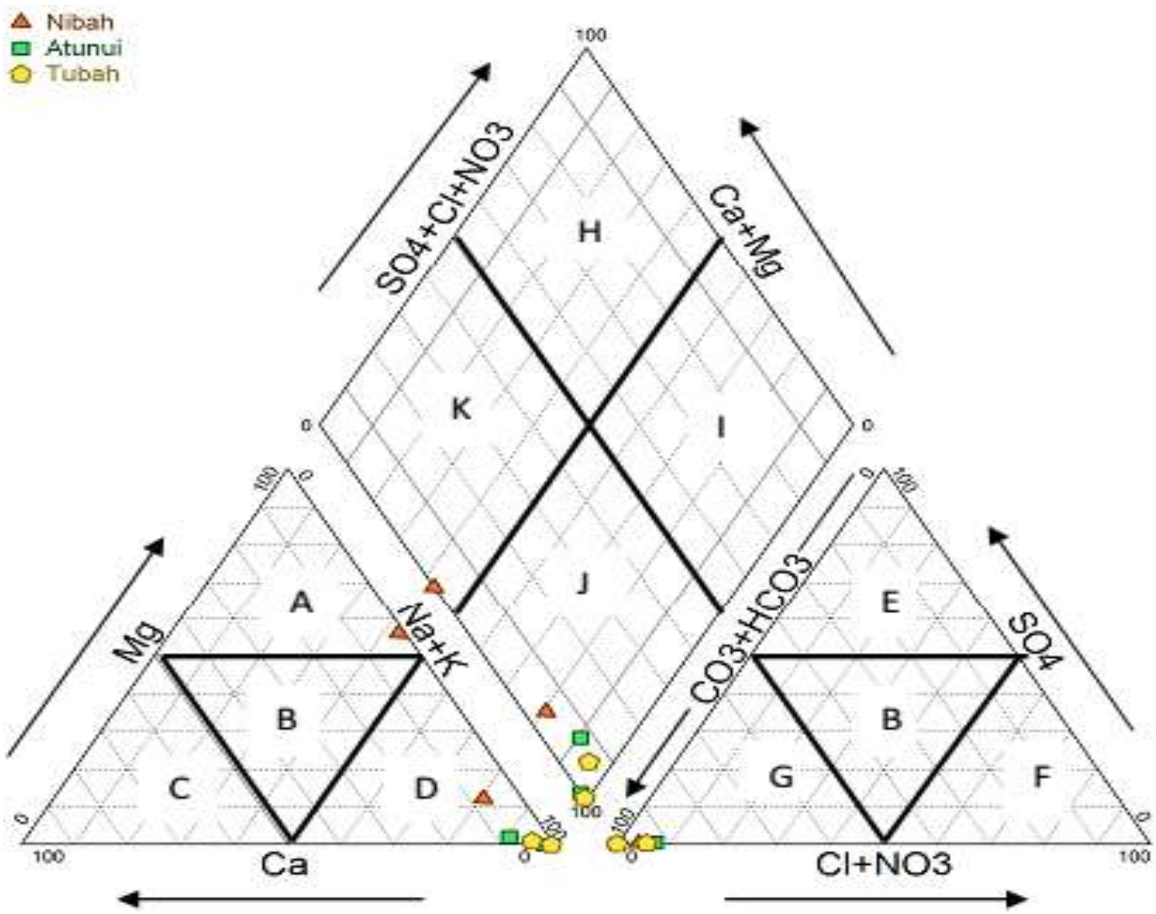

Figure 3. Piper Trilinear Diagram.

may have resulted from lead acid batteries usage, use of electronic equipment or plumbing activities. Lead is damaging to the nervous system. This equally leads to delays in physical and mental development in children. The levels of iron for the samples ranged from 1.71 to 16.16 mg/L comparable with 0.3 mg/L value for WHO limit. This was the highest for sample C and the lowest for sample A. On the average, the values are far higher than those prescribed by WHO. This implies heavy contamination of the water sources with iron for the two months. However, this is not very risky given the so many uses of iron in the human system. The zinc levels for all samples ranged between 0.14 and 3.26 mg/L compared to 3 and 5 mg/L for WHO and EPA limit, respectively. On the average therefore, the values were within the limit; thus, there was no pollution by zinc. A significant difference ($p < 0.05$) was recorded in the iron and zinc content of the samples in December and April, showing a high fluctuation between the seasons. Heavy metal concentrations are illustrated on a bar chart as shown in Figure 4.

The average Most Probable Number count of the samples ranged from 9 to 50.5 with sample C recording the highest and sample B the lowest. In addition, all the samples contained total faecal coliforms, namely enterobacteria, *E. coli*, *Streptococcus, Salmonella* and *Proteus* with the first three predominating and the last two almost absent. This presence of high numbers of feacal coliforms and feacal streptococci is worrying, knowing that feacal coliforms and feacal streptococci are used as an indication of feacal contamination and reflect the risk of pathogens presence in the water (Franciska et al., 2005). Sample A recorded the highest number of all the bacteria forms, seconded by sample C. The heavy presence of the faecal forms of bacteria is as a result of the presence of either animal or human faeces or both or the presence of organic matter in the water indicating faecal pollution. Ideally, and following the WHO recommendations, there should be no bacteria available per 100 ml of the water sample. These data are illustrated on a bar chart as shown in Figure 5.

There are many factors which influence groundwater and surface water quality; among other things, the type of pollution source(s), the nature of the ground and many

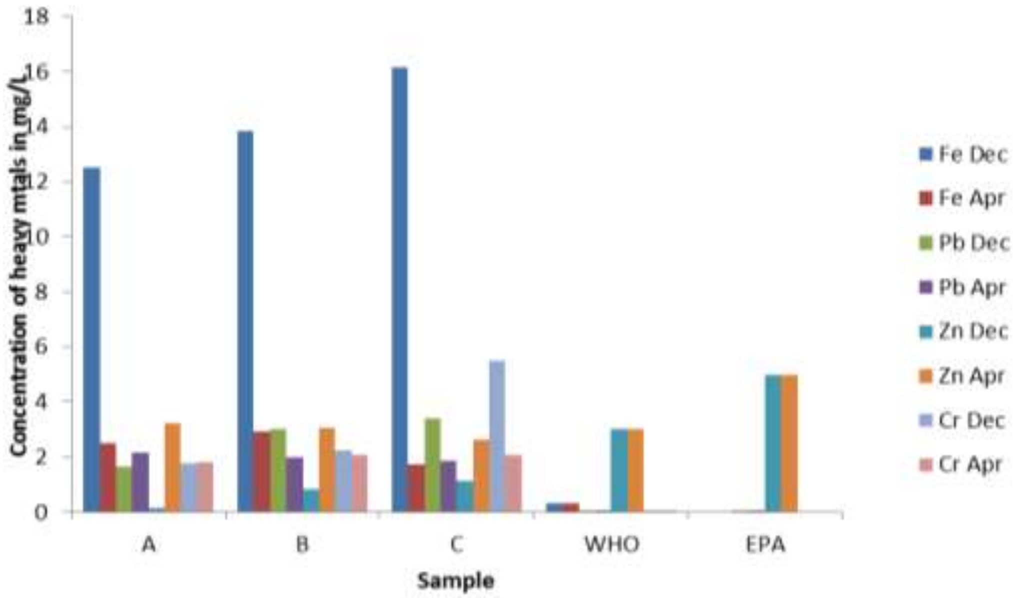

Figure 4. Heavy metal concentration for the samples.

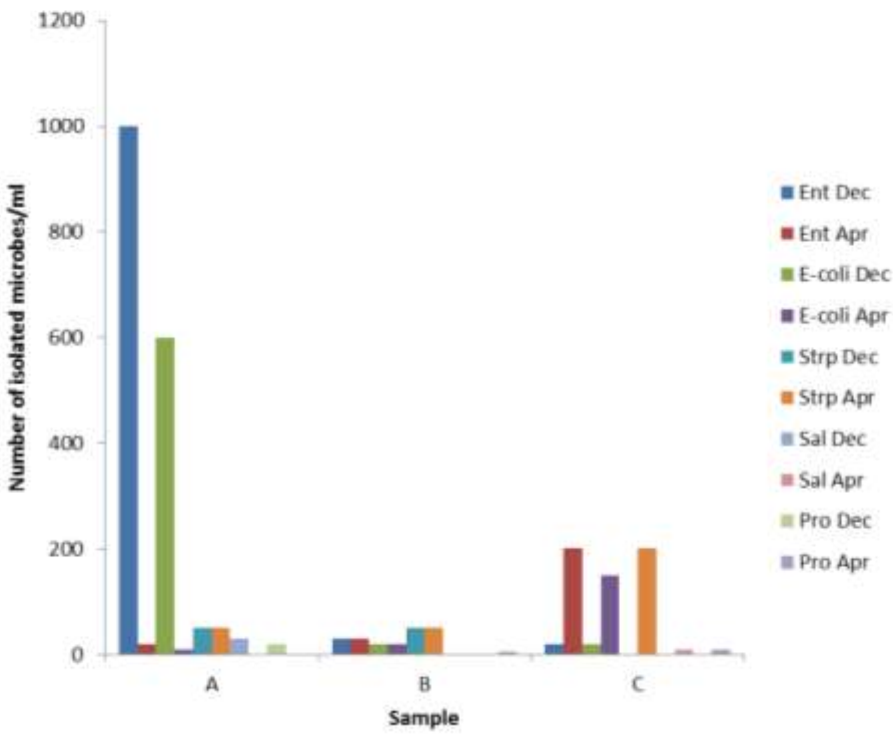

Figure 5. Number of microbes isolated per sample.

anthropogenic influences. The same conclusion was drawn by Barnes and Gordon (2004), Djuikom et al. (2011) in developing methods that will allow identifying the source of the feacal contamination.

Significant positive and negative correlations were recorded between some physical, chemical and bacteriological variables. pH was found to be highly significantly and positively correlated with the $N\text{-}NO_3$ (r =

0.998, $p < 0.05$), phosphorus ($r = 1.000$, $p < 0.01$) and sodium ($r = 1.000$, $p < 0.01$) content of the water samples. N-NO_3 significantly and positively correlated with the phosphorus ($r = 0.998$, $p < 0.05$), chromium ($r = 0.998$, $p < 0.05$) and sodium ($r = 1.000$, $p < 0.01$). Also, N-NH_4 significantly correlated with the sulphate ($r = 1.000$, $p < 0.05$), iron ($r = -0.998$, $p < 0.05$) and calcium ($r = 1.000$, $p < 0.05$). Interestingly, the sulphate content of the water samples were highly significantly and negatively correlated ($r = -1.000$, $p < 0.01$) with the bacteria (enterobacteria*, E. coli* and *Streptococcus)* content of the samples, whereas magnesium content was found to be significantly and positively correlated ($r = 1.000$, $p < 0.05$) with the bacteria content of the samples. Looking at the sulphate levels of all samples (ranging from 0.043 to 0.17 mg/L) comparable to the WHO and EPA value of 250 mg/L, it means the water is prone to bacterial contamination. Thus from the correlation results, the bacteria content of the water can be reduced greatly by increasing its sulphate content and decreasing its magnesium content. These results conform to those of Wyszkowska and Wyszkowski (2002) who showed that magnesium content was found to be significantly and positively correlated with the bacteria content of water.

Conclusion

The health implication of polluted water to a community requires serious attention since people use untreated water for a wide range of domestic activities and most importantly for drinking. The results from this study indicated that the samples all had different species of bacteria, that is, enterobacteria*, E. coli*, *Streptococcus, salmonella* and *proteus*. This is indicative of faecal pollution which results in water borne diseases, typhoid fever being a typical example. The WHO studies advise that there should be no bacteria per 100 ml of water sample. Therefore, all the water samples were contaminated by bacteria, ammonium nitrogen and heavy metals with sample C being the most contaminated in most cases and sample A being the least. The highest level of contamination recorded for sample C (Tubah) could be due to its high population density and consequently, a lot of anthropogenic influences. In addition, the levels of chlorine in all the water samples were non detectable. This implies that the water sources were hardly disinfected and this was consistent with the presence of bacteria in all the samples. Considering the fact that the samples were collected from Bambui with no industrial activity surrounding it, it is clear that animal and anthropogenic activities as well as pipe leakages and plumbing activities are responsible for the contaminations recorded. It would be advisable for the water authorities to swing into immediate action with regards to treating the water, cleaning and protecting all storage facilities and maintaining the leakages. Furthermore, public health authorities should make the public aware of the potential danger of the public water supply, and encourage in-house treatment of the water before consumption (Djuikom et al., 2011). Specifically, the public should be informed that although the water is odourless and appears clean, it might contain infectious bacteria like *Vibrio cholerae* O1 and O139 that can cause cholera or other diarrhoea (Sirajul et al., 2007).

Conflict of Interests

The author has not declared any conflict of interests.

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