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Table of Contents: Volume 10 Number 12 December 2016

ARTICLES

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Full Length Research Paper

Hydrogeochemical and isotopic characterization of the groundwater in the Dababa area (Chad)

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The Central-African country of Chad, located in the Sahel-Sahara zone, faces diverse shortages of portable water. The only reliable source of water available for drinking, domestic and agricultural use in the Dababa Division is groundwater. Conventional hydro-geochemical and isotopic methodology, coupled with piezometric data, allowed investigators to identify the numerous process affecting not only water quality, but also aided them to assess its suitability for different uses. The types of groundwater encountered indicated the presence of Ca-Mg-HCO_3, Na-HCO_3, Cl-SO_4 and Na-Ca-SO_4 in descending order of abundance. The data presented in this investigation shows three processes influenced the groundwater quality; these are the alteration of silicate minerals by dissolved CO_2, the cationic exchange and the evaporation phenomenon, in particular, in the piezometric depression. Additionally, to these findings, this article discussed the anthropogenic processes involved, whose effects are evident in many samples with nitrate concentrations above the WHO standards. Generally, the groundwater in the study area show signs of human contamination. Recent studies also indicate the development of cardiovascular diseases among the population of this area which are directly linked to the low total hardness (TH) values, or general softness, of the water. The groundwater in Dababa is, however, usable for agricultural and other domestic needs. Based on the calculation of Na‰ and the sodium adsorption ratio, the sampled waters are suitable for irrigation.

Key words: Groundwater, World Health Organization (WHO), hydrogeochemistry, isotope, Dababa, Chad.

INTRODUCTION

Access to clean water is one of the greatest concerns for all humanity. African governments, in general and Chad in particular are striving to provide their people with portable water. In the Dababa area, groundwater is the main source of drinking water and is very important in agro-pastoral activities, because of the scarcity of rainfall and hence surface water. Given that access to potable water for both human consumption and agriculture is

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essential to the development of a country, a better understanding of the origin and mechanisms for qualitative and quantitative water degradation will contribute to sustainable water management. Thus, an effective qualitative and quantitative management of groundwater resources is needed which requires a good understanding of how the reservoir functions. This knowledge includes the contribution of water found in arid areas where a decline of rainfall influences the ground-water recharge. In the Dababa region in Central Chad, the groundwater resource is located in the Quaternary (Lower Pleistocene) and Tertiary (Lower Pliocene). The Quaternary shallow water contributes >80% of drinking water and irrigation needs in the region (CBLT/BGR, 2012). This aquifer can be seen as exploitative and hazardous without any qualitative and quantitative monitoring. Abderamane (2012) and CBLT/BGR (2013) noted a considerable drop in groundwater levels and quality in the Chari-Baguirmi basin. However, the current level of understanding of the Dababa aquifer system-ESE of the Lake Chad basin is very limited. The water mineralization process of the whole area, as well as the flow direction of the water and its relationship with the surface water are unknown. The data herein is the result of the first hydrogeological investigation in the study area (8182.92 km²) home to 219,686 people, where agriculture and animal husbandry is the main economic activities (INSEED, 2012). The aim of this study is therefore to contribute to the knowledge of the functioning of aquifer system in relation to surface water in the investigated area, as well as, suggesting methods for the protection of groundwater resources.

With the aid instruments conventionally used in hydrochemistry, we firstly characterized the chemical faces of shallow groundwater to create an understanding of the water mineralization process. This helped us to establish not only water-rock interactions, but also determine areas of recharge and discharge. Secondly, using hydro-chemical experiments, we established the degree of portability of water to show the possible use in irrigation which aided us to assess the impact of human activities on the groundwater. Lastly, we applied geochemical and isotopic methods to investigate hydrogeological problems in semi-arid regions to get information on environmental issues and social development in the rural areas.

LOCATION AND CLIMATOLOGY OF STUDY AREA

The study area 8182,92 km^2 (Figure 1) is located between latitudes 11.70 and 12.60° North and longitudes 16.5 and 17.60° East. It is bounded to the south by the Chari River and to the west by the Lake Chad region.

The climate fluctuates between semi-arid and arid. The rainfall in this region is very irregular and influenced by the movement of the Inter-Tropical Convergence Zone (ITCZ), which is in turn controlled by two major wind systems, the NE Trade winds (or the Harmatan; hot and dry wind blowing from the high pressure zone in Saharan) and the SW Monsoons (cool and moist wind from the Atlantic Ocean). The annual rainfall of the area is also affected by the relief, while the southward shift of the isohyets in the Lake Chad basin is due to Adamawa Massif and Yadé that disrupt the advance of the monsoon towards Chad as a whole. Data from 30 years worth of observation in the Bokoro station (located in the centre of the study area) show an annual average rainfall of 542 mm with the peak of the data in August reaching 189 mm. Twenty years accumulation of records of temperatures show ranges between 15 and 41°C with an average of 28°C per year. December and January are the coolest months, while April and May are the hottest. The relative humidity of the air shows an annual change of 25 to 47% (1965 to 1995) with a mean of 36%. Olivry (1986) observed more than twice this value in Douala (Cameroon); which has an equatorial climate with a unimodal distribution pattern of monthly rainfall.

GEOLOGIC AND HYDRO-GEOLOGIC SETTINGS

Chad belongs to a large post-Palaeozoic sedimentary basin which is extended up to Niger, Nigeria and Cameroon. The sediments lie unconformably on the Palaeozoic or Achaean and Proterozoic sediments (Kusnir, 1995). The basement level of the study area includes the crystalline formations overlain by sedimentary formations. The base is flush with inselbergs such as Moyto, Kalkalé, Andreieb and Hadjer Terchap (Figure 1). It consists of late-tectonic alkaline granites, rhyolites, diorites and dolorites (Blanchot and Muller, 1973). Neogene hyperalkaline rhyolites, located on the same volcanic axis, are also contemporary to those encountered in Cameroon and Tibesti (Barbeau and Gese, 1957).

The thickness of the post-Paleozoic sedimentary fill varies from place to place; from several thousand meters in the grabens (Louis, 1970) formed during the Early Cretaceous period (Maurin and Guiraud, 1993) to less than 1000 m. Cretaceous sediments are mainly continental, except in places where the sea levels had risen during the Upper Cretaceous period following the transgressions in the Upper Cenomanian-Turonian and Maastrichtian Lower Paleocene-Terminals (Bellion, 1989).

The Cenozoic or Continental Terminal (CT) corresponds to fluvial and lacustrine sediments interbedded with sandy-clay to ferruginous horizons with intercalations of oolites and ferruginous armors (Moussa, 2010). These formations, which are the result of the weathering of crystalline rocks, attain a thickness of 200 m in the centre

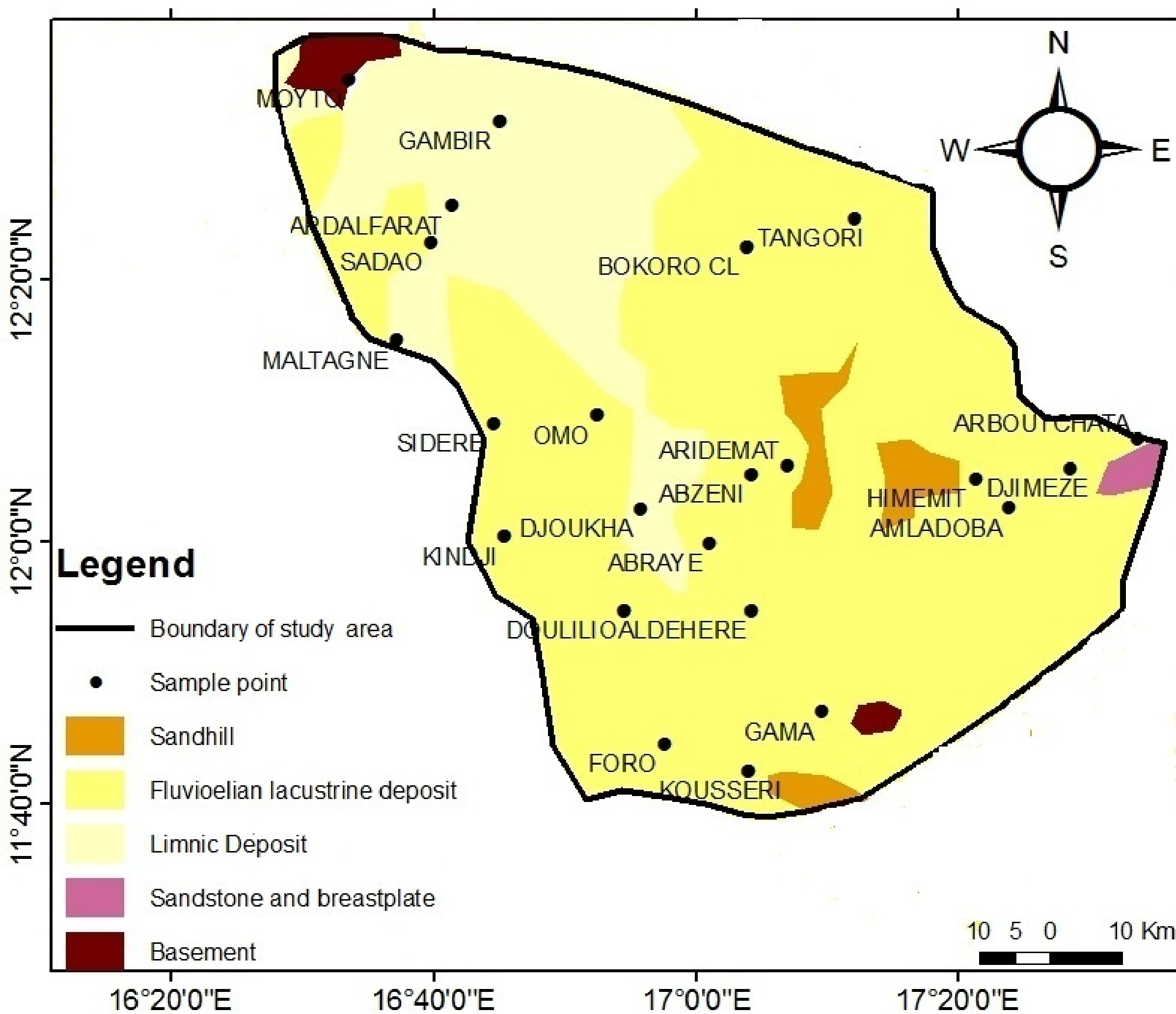

Figure 1. Location and geology of the Dababa area showing groundwater samples points.

of the basin.

At the upstream level of the Continental Cenozoic, lie unconformably the Pliocene and the Quaternary formations made up of discontinuous layers of varying thickness of lacustrine clays and altered limnic sands. The stratigraphic boundary between the Pliocene and Quaternary is not clear. Schneider (1989) proposed two types of limits: (i) the conventional limit corresponding to 1.8 Ma and (ii) the episodic palaeomagnetic Olduwai. The second is chosen because of its practicality and of its distinctive quality on the logs (Schneider and Wolf, 1992). However, Pliocene clay sedimentation (aquifer wall) marked the end of Quaternary and the beginning of the sedimentation of sand and clay deposits. The origin of these sediments, fluvial, lacustrine and deltaic, explains the rapid variation of the faces, laterally and vertically. These Pliocene and Quaternary sands still contain water. These multi-layered aquifers are captured in the Pliocene and locally communicate freely with the semi-Quaternary through leakages.

The shallow groundwater of the Dababa locality flows in the formations of the lower Pleistocene (UNDP/UN, 2002). At the eastern boundary of the zone, the water flows on the North Continental Terminal Formations. This aquifer extends northward to the Kanem region (which has wind sand) and southward into the Mayo Kebbi (Southern Continental Terminal). It is bordered to the southeast and east by the Pliocene formations. The depth of this aquifer varies from 35 to 75 m and furnishes all the wells drilled in this area (Leblanc, 2002). The shallow groundwater is recharged mainly by precipitation and to a lesser extent by the exfiltration of the deeper aquifers (Schneider, 2001). During the rainy season, rainfall and over-flooding rivers that build up in the

Table 1. Sedimentary formations and aquifers in Dababa.

Stratigraphics units		Aquifer sand non aquifers	Thickness
Quaternary	Holocene	Permeable roof	-
	Pleistocene	Shallow groundwater of sand	35 to 75 m
Neogene	Upper Pliocene	Sandy clays Sandy aquifer	80 to 145 m
	Middle Pliocene	Limnic clays with sandy intercalations	
	Lower Pliocene	Sandy aquifer	
Paleo-Neogene	Oligo-Miocene	Breast plate Aquifer of Continental Terminal (CT)	<10 m

backwaters and floodplains, give rise to temporary water courses that contribute to the groundwater recharge (Djoret, 2000). The lower Pliocene contains a confined aquifer beneath the Middle Pliocene clay sequences with a thickness that varies from 80 to 145 m with an average permeability (Schneider, 2001). The extreme depth and low productivity of this water reserve make it difficult to exploit. Together with the lower Pliocene and the Quaternary formations, an important multi-layered aquifer is established which has an estimated water reserve of 206 billion or 94.6 m^3 with a renewable volume of ~3600 million m^3 in Chari-Baguirmi (Abderamane, 2012). Schneider and Wolf (1992) also reported resources related to granitic massifs which are in the form of (i) fissured aquifers related to the direct infiltration of rainwater and runoff on mountains slopes and (ii) water contained in arenas from the breakdown of granite Massifs, with their substratum consisting of the bedrock, for example in the case of Moyto. Table 1 shows the stratigraphy and hydro-geological formations in the Dababa area.

SAMPLE COLLECTION AND ANALYSIS

In July 2015, which marks the beginning of the rainy season, twenty-three wells were sampled in the west-central part of the country. Water samples were collected in polyethylene bottles of 0.5 L with all necessary precautions. The samples were collected in a sedimentary (22 samples) and basement (01 sample) levels. Figure 1 shows all the sampled points. Their spatial distribution depended on the geographic location of the selected villages. The pH, electric conductivity (EC) and temperature of each sample was measured in the field using multi-WTW device parameters. Besides these measurements, the static levels were taken individually in each well by means of a potentiometric sensor. Latitude and longitude were also determined on the field using the GPS.

Major ions were analyzed in the "Laboratoire National d'Analyse des Eaux" in N'Djamena-Chad. Results show the major ions: Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, SO_4^{2-} and NO_3^-. The concentration of Na^+ and K^+ was determined by flame photometry, Ca^{2+} by titration and Mg^{2+} by subtraction between certain compounds. The contents of HCO_3^- and Cl^- were also measured by titration and those of NO_3^- and SO_4^{2-} using the DR2800 Spectro-photometer. Samples were filtered through 0.2 µm filters before the various analyses. The analytical precision of cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and anions (HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-) was checked through the ionic balance error (IBE) based on ions concentrations expressed in meq/L (Appelo and Postma, 1999). All the investigated points gave an IBE value of ±5%. The equipment and instruments were tested and calibrated using standard calibration methods as described in APHA et al. (1998). Total Dissolved Solids (TDS) were calculated by adding the main ionic species (Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, SO_4^{2-} and NO_3^-).

The isotopes 18O and 2H (Deuterium) were analyzed in Leibniz Institut for Applied Geophysics Laboratory (Hannover, Germany). Water samples were analyzed for δ2H using a fully automated chromium reduction system at 800°C (H/Device, Thermo Finnigan) directly coupled to the dual inlet system of Thermo Finnigan Delta XP isotope ratio mass spectrometer. Water samples were analyzed for δ18O using an automated equilibration unit (Gasbench 2, Thermo Finnigan) in continuous flow mode. All samples were measured at least in duplicates and the reported value is the mean value. All values are given in the standard delta notation in permill (‰) versus VSMOW according to $\delta[‰] = [R_{sample} / R_{reference} - 1] \times 1,000$.

RESULTS AND DISCUSSION

Summary statistics

Table 2 is a presentation of a summary statistic of physico-chemical and chemical parameters analyzed in

Table 2. Summary data of physico-chemical and chemical parameters of groundwater (n=23) in the Dababa area.

Parameter	Min.	Max.	Median	SD	Mean
pH	6.3	7.7	6.87	0.36	6.9
EC (µs/cm)	61	2900	181	647.59	474
Temp (°c)	27.4	33.5	30.95	1.64	30.69
TDS (mg/L)	54.95	2138.5	152.03	478.44	364.73
Ca^{2+} (meq/L)	0.12	7.75	0.7	1.4	1.7
Mg^{2+} (meq/L)	0.2	3.11	0.3	0.5	0.6
Na^{+} (meq/L)	0.17	20.26	0.6	2.8	2.3
K^{+} (meq/L)	0.06	1.02	0.2	0.2	0.3
Cl^{-} (meq/L)	0.02	7.46	0.2	0.8	0.6
NO_3^{-} (meq/L)	0.00	4.48	0.11	1.05	0.49
SO_4^{2-} (meq/L)	0.01	17.92	0.1	2	1.3
HCO_3^{-} (meq/L)	0.34	7.2	1.4	1.7	2.4
%Na	24.80	74	38.42	12.61	42.53
SAR	0.33	9.18	0.64	2.65	1.77

this study. The median distribution descriptor is much more robust than the average values, the findings will be used here as the main statistical descriptor. The pH values are between 6.3 and 7.7 with a median of 6.87, indicating that waters are generally weakly acidic to neutral; and that the dissolved carbonates are predominantly in the HCO_3form (Adams et al., 2001). The temperatures fall between 27.4 and 33.5°C with a mean of 30.95°C. The relatively high temperatures suggest a slow infiltration and shallow groundwater flow. The chemical composition of the Dababa groundwater shows a wide range of variation with a TDS of 54.95 to 2138.5 mg/L. However, the standard deviation values for each ion are low except for the nitrate ion. The low standard deviation values are explained by groundwater flow in a homogeneous geological environment, which is contributing to the chemistry of the water. The heterogeneity observed for NO_3 can be explained by the impact of the localized human pollution. The TDS values below 600 mg/L indicate that the groundwater is generally fresh. It also shows that it is weakly mineralized (Davis and De Wiest, 1966; Freeze and Cherry, 1979). The low values of TDS indeed correspond to groundwater silicate domain sand; this can be attributed to the slow dissolution rates of most silicate minerals (Appelo and Postma, 1999).

Calcium was found to be the dominant cation, which has an average concentration of 0.7 meq/L, followed by the Na+ with a mean concentration of 0.6 meq/L. Mg^{2+} and K^{+} respectively have a mean concentration of 0.3 and 0.2 meq/L. The HCO_3^{-} ion is the most dominant anion with a mean concentration of 1.4 meq/L, Cl^{-}(0.2 meq/L), NO_3^{-} (0.11 meq/L) and SO_4^{2-} (0.1 meq/L).

Dababa's groundwater seems to be affected by human activities as shown in the NO_3^{-} concentrations (Table 4) compared with WHO standards (10 mg/L). However, the water-rock interaction appears to be the major geochemical process responsible for the chemical quality of water.

Piezometry and spatial variation of the electrical conductivity

Depending on the availability and distribution of water points in the region, piezometric measurements were conducted in July 2015. The piezometric map (Figure 2) made using ArcGIS 10.2Software, enabled us to identify the following recharge areas: (i) two recharge areas to NW and (ii) three recharge areas in the S, SE and SW. The map also shows a current axis coinciding with the bed of the Batha de Lairi River. The hydraulic gradient of the southern and the north-western areas is quite high, indicating a high flow rate and low transmissivity of the aquifer. The electric conductivity ranges from 61 to 2900 µS/cm, in relation to the total dissolved solids contents (54.95 to 2138.5 mg/L). The spatial distribution map of the electrical conductivity of water from shallow groundwater of Dababa (Figure 2) shows that the highest conductivities are found in the discharge areas NW and NNE. Water mineralization generally increases from south to north. This geochemical evolution appears to be related to water-rock interaction. It may be the residence time of water in the aquifer which contribute to the mineralization and hence to the increased conductivity values. The well of Ardelfarat is characterized by a particular mineralization (EC = 2900 µS/cm). This can be explained by its location in the pastoral zone with a poor drainage system around the sample point, or it may be explained by the simple fact that it is in a piezometric

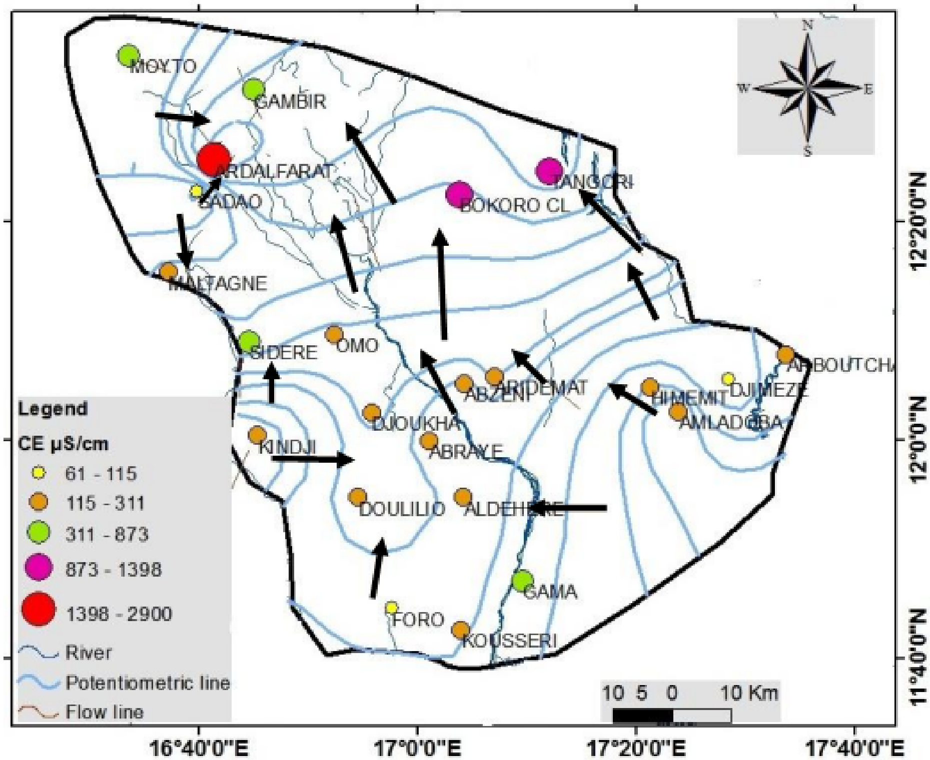

Figure 2. Piezometric map of Dababa associated with the spatial distribution of the electrical conductivity of shallow groundwater.

depression point of groundwater discharge. Lower values located in recharge areas can also be explained by dilution with infiltrated rainwater.

Major ion geochemistry

To classify groundwater of Dababa in west-central Chad and identify the geochemical processes, the piper diagram was used (Figure 3) (Piper, 1944). Diagrams software was used to represent the samples in the Piper and Riverside (Simler, 2007). This diagram shows that 66% of samples have Ca-Mg bicarbonate facies, 17% are of type Na-HCO_3, 13% are of type Cl-SO_4-Ca, and 4% have a $NaSO_4$ faces. $Ca(HCO_3)_2$ type characterized immature sedimentary waters of this aquifer. This type of water is found in almost all the waters of the area with a variable mineralization ranging from South to North of 61 to 457 µS/cm.

Sodium bicarbonate water types are found in the areas around the depressions and close to recharge area (Figure 4). The mineralization of these waters is very variable with values between 150 and 1324 µS/cm. The Piper diagram plot shows that the majority of calcium bicarbonate water types shift towards sodium bicarbonate water type end.

Na-SO_4 and Cl-SO_4-Ca types also noted by Abderamane (2012) in groundwater of Chari-Baguirmi, are mainly observed in the Ardalfarat (EC = 2900 µS/cm) depression, at the granitic intrusions and around the depression (172 µS/cm ≤ EC ≤ 1398 S/cm).

It is widely accepted today that each major ion dissolved in groundwater comes from three possible sources: (i) rain water, (ii) water-soil and water-rock interactions, and (iii) anthropogenic influences (Dafny et al., 2006).

In Figure 5, the relatively high concentration of chlorides zones correspond to high electrical conductivity. We distinguished (i) a southern sector with values ≤110 mg/L, which indicated an increase in southern content to the centre of the depression; (ii) the area of depression with values >110 mg/L. These high levels may have an explanation in the influence of evaporation phenomenon experienced by most hollow aquifers of Sahelian Africa (Coudrain-Ribstein et al., 1998).

The analysis of the map of sulphate contents (Figure 5) shows that it could be superimposed on a map of the electrical conductivities and the spatial distribution of the contents, which are not homogeneous in nature. As shown on the map, the lower levels are observed in the

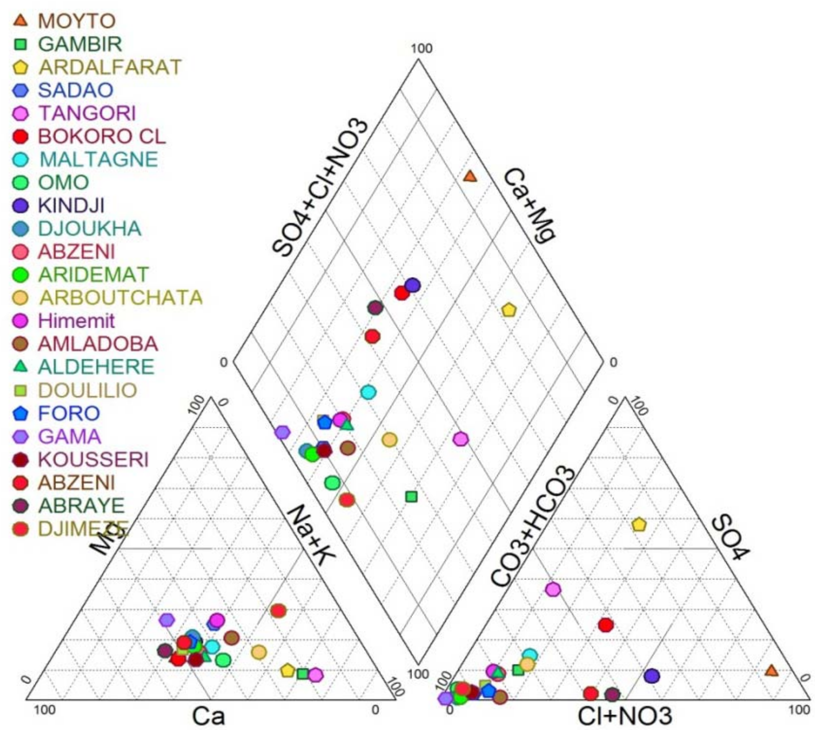

Figure 3. Chemical faces of groundwater in Dababa.

southern area of the depression in which they are less than 100 mg/L. There is also a gradual increase toward the centre of the depression. In addition, high concentrations in sulphates are also reported in Tangori, northwest of the study area, where besides the evaporation phenomenon which applies to the study area, an anthropogenic pollution is added. The highest value of bicarbonate is observed in north, and specifically in the north-eastern part, of the study region. The distributions of bicarbonate values do not seem to show any correlation with other elements. Calcium concentrations reach the maximum values of 150 and 155 mg/L in the wells of Bokoro and Ardalfarat, either at the centre or around the depression. These high levels suggest a Ca intake, either by evaporation phenomena, or by alteration of silicate minerals (e.g. feldspath).

Furthermore, the low concentrations can also be explained by a mineralization process such as cationic exchange (Figure 6). The spatial distribution of the K^+ is very heterogeneous. The highest concentration is at the base of outcrops and could have come from the alteration of rocks containing feldspath. The map of Na^+ contents (Figure 7) shows that the highest concentrations are observed in the region of the piezometric depression. These high values could have resulted from evaporation in the shallow groundwater. On the other hand, the lowest values are observed in the rest of the study area where groundwater is at the beginning of their migration towards the depression, that is, they have not yet undergone significant water rock interactions (Demlie et al., 2007). However, during the flow they might have gone through clay layers which are the basis of cation exchange. This phenomenon results from the fixing of Ca^{2+} after the release of two Na^+ or vice versa. The Mg contents could be explained by a similar process to that of Ca^{2+} ions described earlier. In short, Mg behaves in much the same manner as the calcium in the aquifer. The analysis of the map of nitrate levels (Figure 5) indicates that the spatial distribution of contents is not homogeneous. Examination of this map clearly shows highlighted areas polluted by nitrates (>50 mg/L) in the north of the study area. The presence of nitrates in these agro-pastoral areas owes its origin to an explanation related to redox reactions of organic materials associated with human activities or animal and vegetable production. Indeed, the long stay of livestock waste at the edges of water sources, the transport of these by droppings sump rope are the basic elements of the aquifer pollution. Additionally, a significant portion of the water flowing out of the trough around the wells, thus constituting quasi-permanent puddles that are enriched in nitrates from cattle dung left during watering (Abderamane, 2012).

The distribution of chemical parameters is in homogeneous in the aquifer as such correlations between

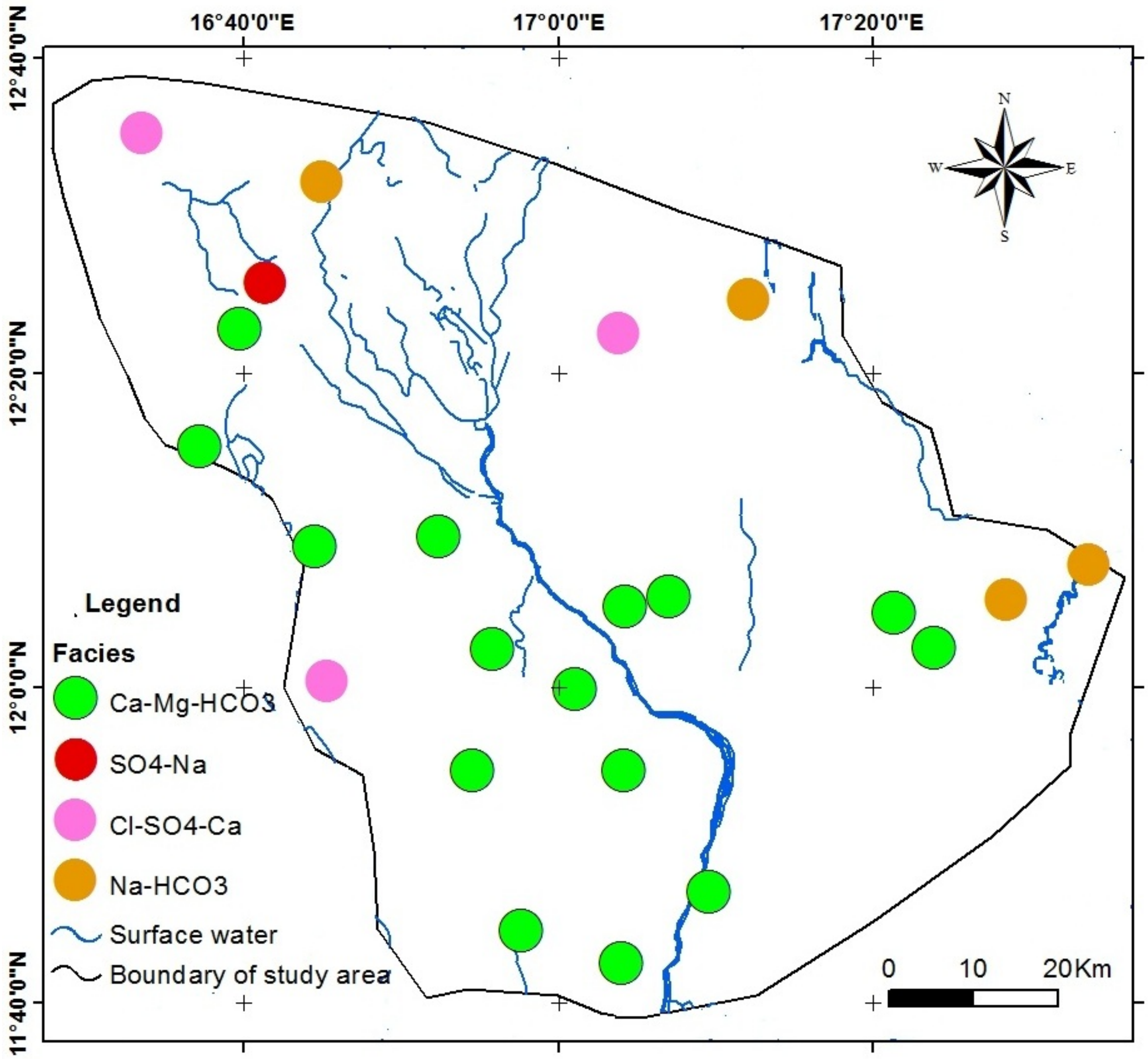

Figure 4. Spatial distribution of chemical water types in Dababa.

major ions which were determined using the Spearman correlation analysis (Table 3). A strong positive correlation (r = 0.94) was found between Na^+ and Cl^-. This high coefficient of correlation between Na^+ and Cl^- can be explained by a common origin of these ions in the groundwater. The source of bicarbonate ions in sandy aquifer derived to CO_2, engine silicate alteration reactions (Deutsch et al., 1982).The groundwater in Dababa has CO_2 partial pressure of $10^{-3.35}$ to 10^{42} higher than that of the atmosphere ($10^{-3.5}$). During the weathering of silicate minerals CO_2 is gradually converted into bicarbonate which shows positive correlation with Na^+ (r = 0.7), Mg^{2+} (r = 0.72) and Ca^{2+} (r = 0.67). There is also a positive relationship between Na+ and SO_4^{2-}, Ca^{2+} and SO_4^{2-} (Table 3). There is no correlation with the carbonate minerals in the study area. However, the combined increase of HCO_3^- and major cations could be due to the reaction between carbonic acid and silicate minerals within the sub-saturated and saturated zones of the aquifer (Stumm and Morgan, 1996). Reactions that are responsible for the release of Ca^{2+} and Na^+ which are always present in the sampled water. Carbonic acid comes from the dissolution of CO_2 by plants and micro-organisms that decompose organic matter in the soil.

The electrical conductivity is positively correlated with Ca^{2+} (r = 0.89), Na^+ (r = 0.96), Mg^{2+} (r = 0.96), HCO_3^- (r = 0.69), SO_4^{2-} (r = 0.96) and Cl^- (r = 0.96) suggesting that these elements are actively involved in the acquisition of

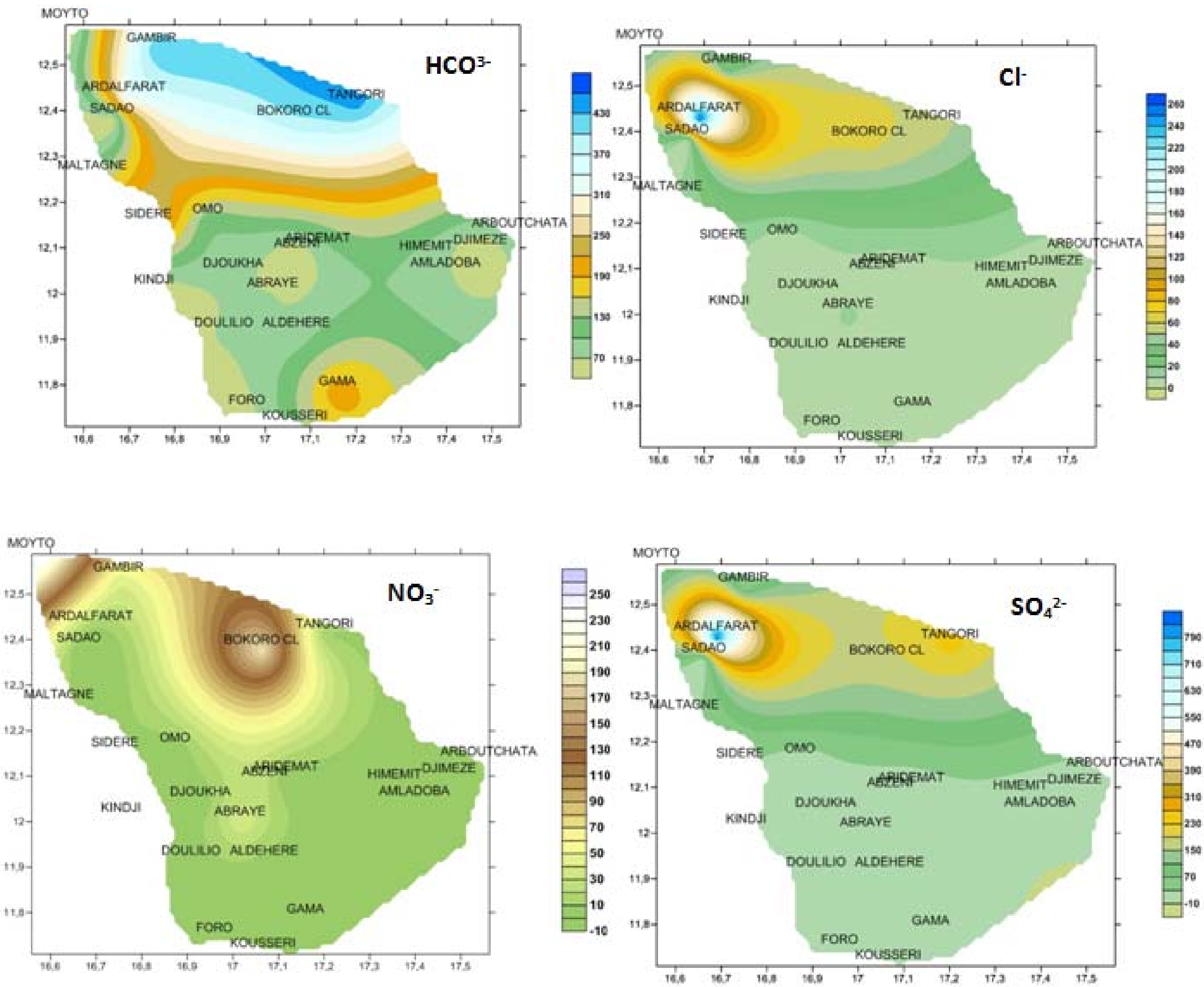

Figure 5. Spatial distribution of anions (Cl^-, SO_4^{2-}, HCO_3^- and NO_3^-) in mg/l in shallow aquifer of study area.

mineralization of the water (Abderamane, 2012). Cations and bicarbonates are from the weathering of silicate minerals in the aquifer. The porous nature of the sand causes a short residence time of water in the unsaturated zone and therefore, a minimal exchange with the bedrock explaining the observed low mineralization. Cl^- and SO_4^{2-} have not been derived from silicate weathering and generally they indicate mixtures of water from several sources.

Evaluation of groundwater quality in the Dababa area for drinking, domestic and irrigation uses; Suitability for drinking and general domestic use

In a country like Chad, where more than half of population lives in the rural areas (villages) with minimal infrastructure, with a general lack of adequate sanitation and hygiene, the concept of drinking (potable) water makes sense. The problem of drinking water is usually related to an exposure to inorganic toxic substances, heavy metals, high nitrate levels or other traces as well as bacteriological elements. However, the concentrations of chemical elements in groundwater can be natural or from pollution sources. The use of groundwater in the Dababa area for drinking and domestic use was evaluated based on the World Health Organization standards for drinking water (Table 4) (WHO, 2004). According to the work of Davis and De Wiest (1966) and Freeze and Cherry (1979) freshwater should have a TDS <600 mg/L, diluted enough to be drinkable. The EC represents the amount of total dissolved solids in the

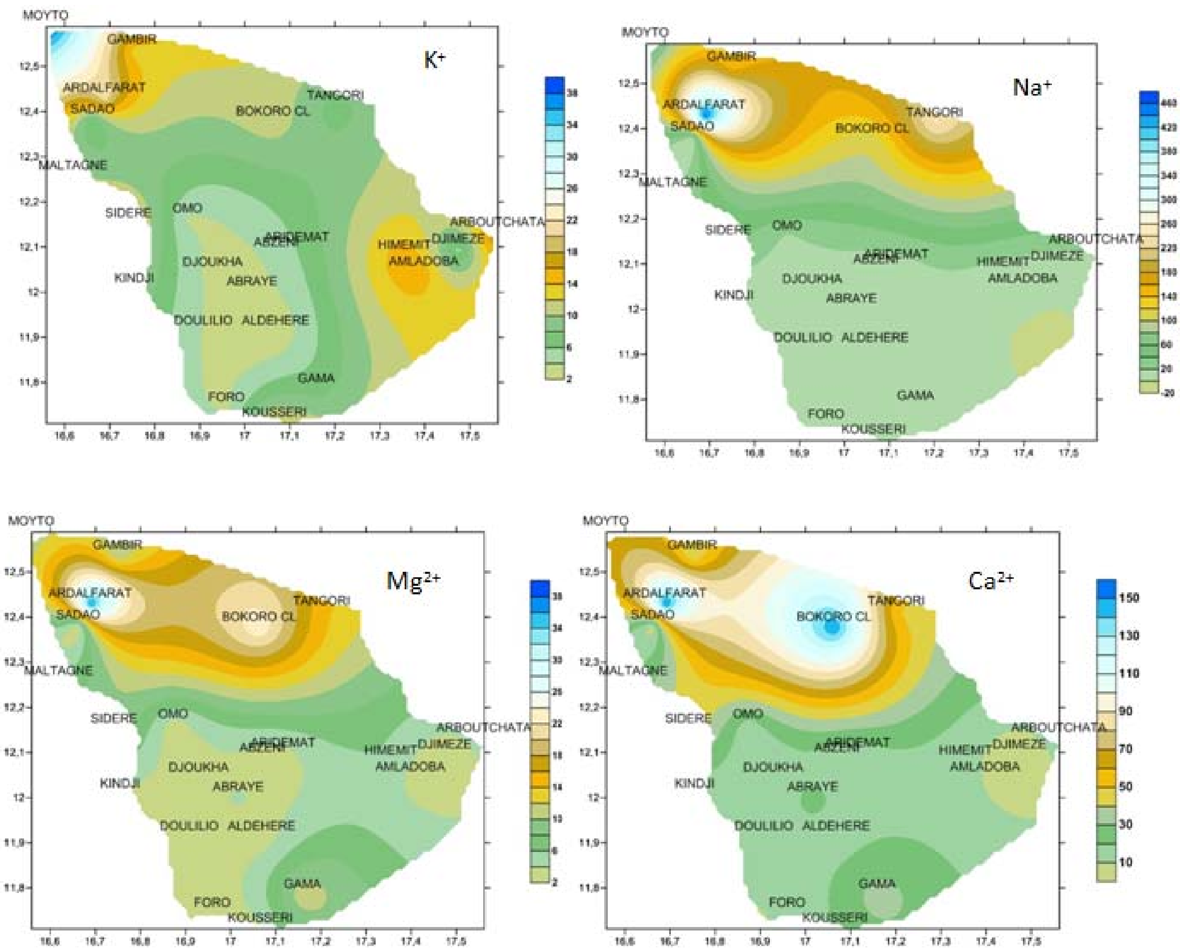

Figure 6. Spatial distribution of cations (Ca^{2+}, Na^{+}, Mg^{2+} and NO_3^{-}) in mg/l in shallow aquiferof study area.

water and also its inorganic filler. Only points Ardalfarat, Gambir, Tangori and Bokoro in the discharge zone near the depression, are not within the limits of 750 µS/cm. These wells are in excess of 500 mg/L TDS recommended by WHO for drinking water consumption and various domestic uses.

The pH meanwhile, has no effect on human health. It is strongly connected to the water chemical constituents. The groundwater in the study area has a pH (6.3 to 7.7) very close to the WHO range (6.5 to 8.5) for drinking water; with only 26% of the samples falling outside this limit. Hardness is an important criterion to evaluate the water for drinking, domestic and industrial uses (Karanth, 1987; Nagarajan et al., 2009). The hardness can be temporarily linked to bicarbonate and carbonate or permanently to sulphates and chlorides of Ca and Mg. Water hardness is usually expressed as the total water hardness (TH) and is expressed as follows:

$$TH = 2.5Ca^{2+} + 4.1Mg^{2+} \quad (1)$$

Where TH=total hardness in mg/L of $CaCO_3$, Ca = Ca^{2+} concentration in mg/L, Mg = Mg^{2+} concentration in mg/L (Todd, 1980). Table 5 is a presentation of the classification of groundwater in Dababa based on hardness (Durfor and Becker, 1964). About 40% of the sampled groundwater is considered hard compared to the WHO standard; while 60.87% of the groundwater in the study area can be considered soft, 17.39% moderately hard, 13.04% hard and 8.7% very hard. The problem of hard water is primarily because it does not have a good taste, it reduces the ability of soaps to foam and it causes precipitation (scaling) in pipes. The research of AkoAko et al. (2012) in the basaltic aquifers of Mount Cameroon found 44 out of 74 samples were soft and the 30 remaining moderately hard. Comparatively, waters in sedimentary terrain in Chad are less sweet. Though hardness is a parameter that depends on the geological environment and it should be noted that there is a link between water hardness and cardiovascular diseases. Dissanayake et al. (1992) found a negative

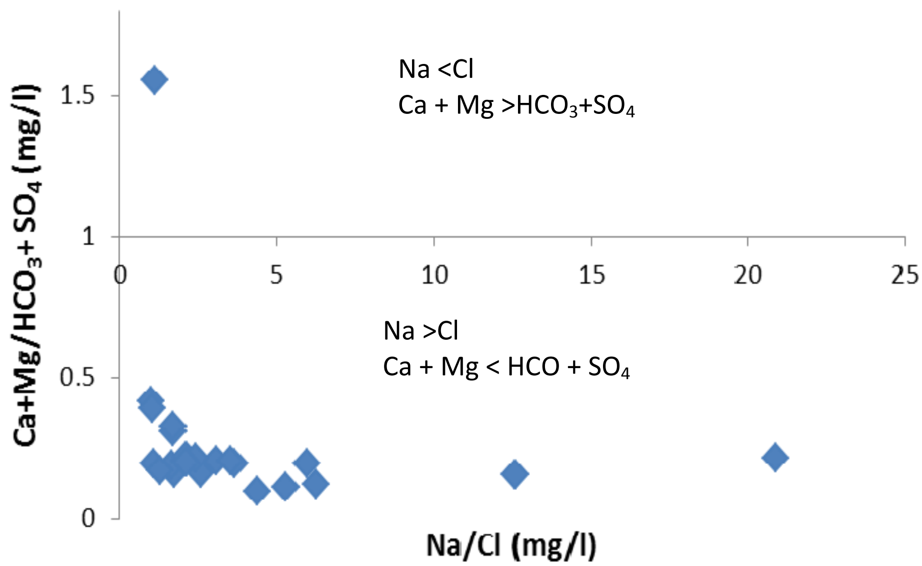

Figure 7. Relation between [(Ca + Mg) / (HCO_3 + SO_4)] and [Na/Cl], in the waters of quaternary Dababa.

Table 3. Spearman's correlation coefficients for physico-chemical and chemical parameters

Correlation	pH	EC	Ca	Mg	Na	K	HCO_3	Cl	SO_4	NO_3	pCO_2
pH	1										
EC	0.47	1									
Ca	0.41	**0.9**	1								
Mg	0.44	**0.97**	**0.95**	1							
Na	0.48	**0.96**	**0.76**	**0.89**	1						
K	-0.1	0.39	0.42	0.4	0.26	1					
HCO_3	0.51	**0.73**	0.67	**0.72**	**0.7**	0.09	1				
Cl	0.39	**0.95**	**0.81**	**0.91**	**0.94**	0.33	0.51	1			
SO_4	0.4	**0.94**	**0.79**	**0.9**	**0.96**	0.28	0.53	**0.99**	1		
NO_3	0.04	0.26	0.5	0.31	0.04	0.66	0.1	0.1	0.04	1	
pCO_2	-0.37	0.06	0.11	0.12	0.03	0.14	0.33	-0.02	-0.02	-0.11	1

correlation between the water hardness and the various forms of cardiovascular disease and leukemia in Sri Lanka. This implies that people consuming fresh water were more likely to suffer from cardiovascular disease than people who drink hard water. About 60% of the groundwater sampled was soft, indicating the people of this region who consume only this water have a high risk of suffering from cardiovascular problems. Magnesium was found to be one of the elements responsible for the hardness of water. On the other hand, high levels of Mg in water can make it diuretic and cathartic. Besides Ardalfarat sample, all the other points are below the permissible limit given by WHO, that is, 30 mg/L.

Sulphate ion (SO_4^{2-}) is one of the most toxic anions. The WHO (2004) recommends an upper limit of 250 mg/L. If water has a concentration of SO_4^{2-} higher than this standard, it can cause gastro-intestinal irritation resulting in a laxative effect (WHO, 1993). The sulphate values here are greater than 250 mg/L in the well of Ardalfarat. The remaining samples are below the allowable limit. After Ca, Na is the most represented cation in samples in the study area. The limit recommended by WHO for Na^+ concentrations in drinking water is 200 mg/L. High values of sodium can cause high blood pressure, heart problems, as well as kidney problems. Except in the points of Ardalfarat depression and Tangori in NE of the study area, the Na^+ and K^+ concentrations of the analyzed samples are within the

Table 4. Groundwater quality in the Dababa area and compliance to WHO (2004) drinking water standards.

Parameter	Range	Average	WHO (2004) limit	% of samples above or out of WHO guideline limit
pH	6.3-7.7	6.9	6.5-8.5	26.09
EC (µS/cm)	61-2900	474	750	17.39
Ca (mg/L)	2.31-155	33.34	75	8.7
Mg (mg/L)	2.41-37.3	7.65	30	4.35
Na (mg/L)	3.8-466	52.79	200	8.7
K (mg/L)	2.5-39.8	10.46	100	0
Cl (mg/L)	0.78-266	22.84	250	4.35
NO_3 (mg/L)	0.01-278	30.22	10	43.48
SO_4 (mg/L)	0.66-860	63.19	250	4.35
HCO_3 (mg/L)	20.8-439	144.25	200	26.09
TDS (mg/L)	54.95-2138.5	364.73	500	17.39
TH (mg/L $CaCO_3$)	15.66-540.3	114.72	100	30.43

Table 5. Hardness of spring waters in the Mount Cameroon area

Hardness (mg/L $CaCO_3$)	Water classification	Number of samples	%
0-75	Soft	14	60.87
75-150	Moderately hard	4	17.39
150-300	Hard	3	13.04
>300	Very Hard	2	8.7

Table 6. Major ion concentrations in quaternary groundwater wells. Na% indicates the suitability of water for irrigation.

Localization	K (meq/L)	Na (meq/L)	Mg (meq/L)	Ca (meq/L)	SO_4 (meq/L)	HCO_3 (meq/L)	Cl (meq/L)	Na%
MOYTO	1.02	1.03	0.85	3.21	0.56	0.34	0.59	33.54
GAMBIR	0.35	6.35	0.84	2.00	0.90	6.75	0.77	70.24
ARDALFARAT	0.54	20.26	3.11	7.75	17.92	5.30	7.46	65.71
SADAO	0.15	0.17	0.21	0.30	0.02	0.73	0.06	38.35
TANGORI	0.18	10.61	1.22	2.58	5.13	7.20	1.57	74.00
BOKORO CL	0.29	4.65	1.98	7.50	3.69	6.41	1.78	34.28
MALTAGNE	0.27	1.00	0.55	1.26	0.46	2.15	0.31	41.45
OMO	0.10	0.74	0.24	0.72	0.07	1.77	0.04	46.61
KINDJI	0.25	0.27	0.29	0.66	0.11	0.56	0.18	35.86
DJOUKHA	0.09	0.38	0.28	0.60	0.01	1.29	0.04	34.53
SIDERE	0.36	1.82	0.88	2.54	0.49	4.52	0.38	38.94
ARIDEMAT	0.16	0.40	0.27	0.69	0.02	1.42	0.07	36.51
ARBOUTCHATA	0.50	0.93	0.42	0.76	0.30	1.79	0.24	55.11
HIMEMIT	0.41	0.29	0.47	0.64	0.17	1.43	0.17	38.42
AMLADOBA	0.39	0.25	0.29	0.48	0.01	1.25	0.12	45.12
ALDEHERE	0.06	0.62	0.24	0.75	0.15	1.31	0.11	41.11
DOULILIO	0.10	0.40	0.25	0.74	0.07	1.26	0.12	33.86
FORO	0.09	0.30	0.22	0.53	0.04	0.98	0.08	34.72
GAMA	0.18	0.71	0.96	1.74	0.02	3.49	0.02	24.80
KOUSSERI	0.33	0.52	0.30	1.03	0.06	1.95	0.16	39.06
ABZENI	0.12	0.30	0.25	0.61	0.03	0.73	0.12	33.33
ABRAYE	0.09	0.56	0.36	1.20	0.04	1.16	0.35	29.39
DJIMEZE	0.13	0.23	0.20	0.12	0.03	0.61	0.02	53.31

Na% indicates the suitability of water for irrigation.

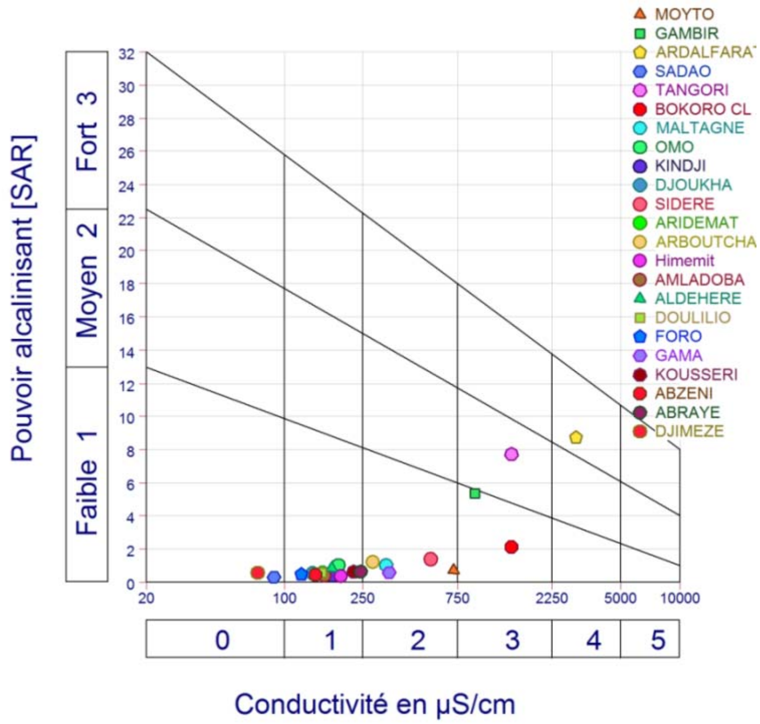

Figure 8. Diagram for classification of irrigation water according to the SAR.

limits prescribed by WHO. About 43% of samples had nitrate (NO_3^-) concentrations above the limit (10 mg/L) recommended by WHO. High nitrate contents constitute a potential danger when using the polluted resource as drinking water and consumption may generate the methomoglobine in children and cancerogenic diseases in adults (Ladouche et al., 2003).

Irrigational suitability

Water for the irrigation of plants in the study area is provided by pumping of the groundwater (wells and boreholes) and/or the use of flood waters of Batha de Lairi River. The quality of the water used for irrigation is evaluated using several methods. For the purpose of this study, we applied the classification of the United States Salinity Laboratory (1954), which is based on the sodium adsorption ratio (SAR) and electrical conductivity (EC). When sodium concentration is too high in irrigation waters, it tends to be absorbed by the clay particles in exchange for Mg and Ca ions. Sodium exchange process in the soil reduces the permeability and the result in less porous soils with low draining power. The sodium percentage of groundwater is calculated by using the following equation:

$$\% Na^+ = Na^+ + K^+/(Ca^{2+} + Mg^{2+} + K^+ + Na^+) \times 100 \quad (2)$$

Compared with the standard values, the maximum allowable concentration of Na^+ in groundwater for irrigation is 60%. The sodium percentage calculated for the shallow groundwater of Dababa varies between 24.80 and 74% (Table 2). Table 6 shows that sampled wells of Tangori, Gambir and Ardalfarat are above the norm. The proposed US Salinity Laboratory diagram, a plot of SAR values versus the EC values, is commonly used to assess the suitability of groundwater for irrigation purpose. The sodium adsorption ratio (SAR) is an important parameter for determining the suitability of groundwater for irrigation because it is a measure of risk of alkalinising cultures. It is derived from:

$$SAR = Na^+ + / [(Ca^{2+} + Mg^{2+})] \; 0.5 \; meq/L \quad (3)$$

The calculated value of the SAR in the study area ranges from 0.33 to 9.18 (Table 2). The electrical conductivity (EC) is also a good indicator of the risk of salinization. High EC will to reduce the osmotic activity or the ability of plants to absorb water and nutrients from the soil. Figure 8 shows a display of samples based on the degree of salinization. 86.95% of the groundwater has low salinity and therefore low alkalinity. 13.05% have a moderate to

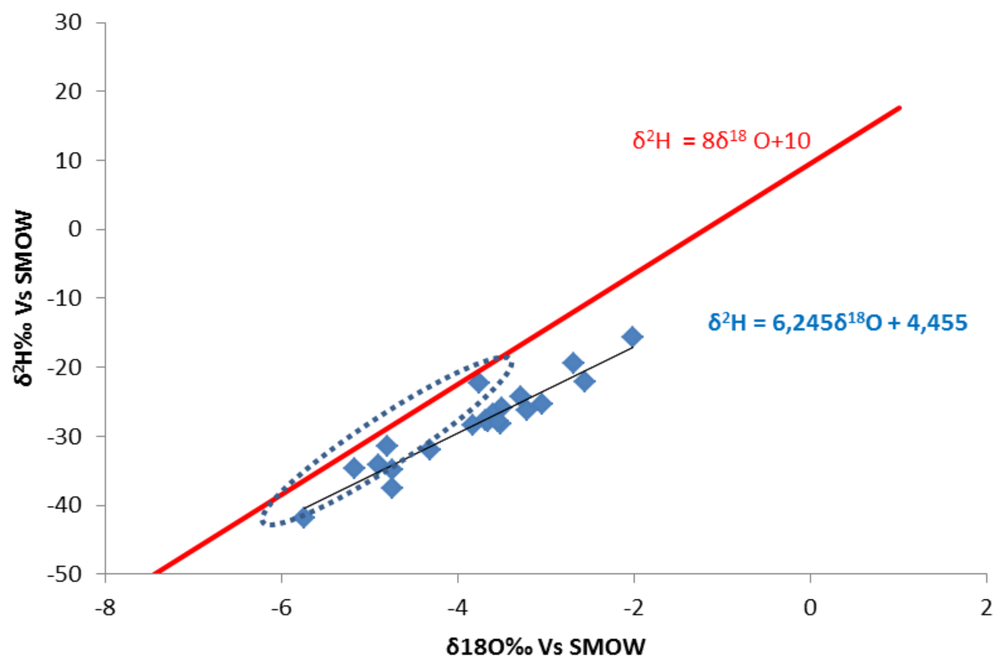

Figure 9. Relation between δ^{18}O vs. δ^{2}H in the waters of quaternary Dababa.

high salinity corresponding to Tangori and Ardalfarat' wells, while indicating wells that are unsuitable for irrigation.

Correlation between δ^2H and δ^{18}O

The waters of the Dababa aquifer system zone show very variable isotopic content in places where the water is enriched in heavy isotopes. Thus, the deuterium values obtained lie between -41.9 and 15.7‰ vs. SMOW with an average of -28.33‰ vs. SMOW. The contents of these waters oxygen-18 varies from -5.75 to 2.01‰ vs. SMOW with an average of -3.82‰ vs. SMOW.

The whole of the deuterium and oxygen-18 values obtained had been deferred in form of graphic δ^2H vs δ^{18}O (Figure 9). On the latter, it was also deferred to the world meteoric line (DDM) of equation $\delta^2H = 8 \times \delta^{18}O + 10$ (Craig, 1961). The water evaporation line present a slope of 6.25 [$\delta^2H = 6.25\ \delta^{18}O – 4.455$] and is registered under the world meteoric line. It is noted that all the waters show a deuterium depletion and are all carried in a weak slope line as compared to the world meteoric line. This oxygen 18 enrichment in the waters indicated that it is marked by evaporation before or during the infiltration.

Thus, two (2) type of groundwater can be distinguished:

(1) The first (I) type of waters appears to be recently recharged which is located near the DMM and therefore shows isotopic signatures similar to those of rainwater which contributed to aquifer recharge.

(2) The second (II) type includes groundwater that has undergone a very significant enrichment in ^{18}O as compared to previous samples. These waters represented by the samples collected around rivers (Lake Lairi Batha and the Bahr Errigueig), deviate significantly from the DMM.

The isotopic study starting from the relation ^{2}H versus ^{18}O showed that the initial isotopic composition had been modified partly by evaporation of rainwater in the course of infiltration. This led to a mixture of waters of different isotopic signatures.

Conclusion

This study is the first hydro-chemical investigation in the area of Dababa located in the east-southeast of the Lake Chad Basin. The data obtained allowed us to evaluate the quality and usability of the groundwater for people living in this part of Chad (Central Africa). The groundwater in the study area is predominantly Ca-Mg HCO_3 rich. There are also Na-HCO_3, Cl-$S0_4$-Ca and Na-SO_4 types. The hydro-geochemical data coupled with the piezometric data reveals that water chemistry is primarily controlled by water-rock interactions and to a lesser extent by the evaporation phenomenon which mostly affects wells in piezometric depressions. The cation exchange phenomenon has been demonstrated by the diagram (Ca +

Mg)/(+ HCO_3 SO_4) versus Na/Cl. This exchange, which is facilitated by the presence of clay minerals in the geological formation, is the cause of the large variation of the concentrations of cations (Ca^{2+}, Mg^{2+} and Na^+) in groundwater. The waters of the studied wells appear to have an average nitrates concentration of 43.48%, which is beyond the norms for drinking water according to the World Health Organization (WHO). These results confirm the impact of agriculture and domestic wastewater discharges on groundwater. Measure to protect the groundwater, the main source of drinking water for the people is imperative. Furthermore, TH values show that the majority of groundwater is linked with the development of cardiovascular diseases. However, the Dababa groundwater can be used for irrigation, except those of the Tangori, Gambir and Ardalfarat localities in the northern part of the study area which have values of Na% 74, 70.24 and 65.71, respectively (above the 60% standard prescribed by WHO).

The isotopic study highlights that rainfall show a significant depletion in heavy isotopes. The storm origin waters evaporation are enriched in oxygen-18 and deuterium. This phenomenon leads to a specific isotopic tracing which allows to distinguish between the two types of water. In particular, we can distinguish the isotopic composition of recent water ensuring groundwater recharge through infiltration and the ancient water of the aquifer.

Conflict of Interests

The author has not declared any conflict of interests.

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REFERENCES

Abderamane H (2012). Etude du fonctionnement hydrogéochimique du système aquifère du Chari Baguirmi. Thèse Université de Poitier, 324p.

Adams S, Titusa R, Pietersen K, Tredoux G, Harris C (2001).Hydrochemical characteristics of aquifers near Sutherland in the Western Karoo. South Afr. J. Hydrol. 241:91-103.

AkoAko A, Shimada J, Hosono T, Kagabu M, Akoachere RA, Elambo Nkeng G, EnekeTakem G (2012). Spring water quality and usability inthe Mount Cameroon area revealed by hydrogeochemistry. Environmental Geochemistry and Health. Official J. Soc. Environ. Geochem. Health 34(5):615-639.

APHA, AWWA, WEF (1998). Standard methods for the examination of water and wastewater. Washington, DC: American Public Health Association.

Appelo CAJ, Postma D (1999). Chemical analysis of groundwater, geochemistry, groundwater and pollution. Rotterdam: Balkema.

Barbeau J, Gèse (1957). Notice explicative sur la feuille de Fort Lamy. Carte géologique de reconnaissance à l'échelle de 1/1000000. DMG, AEF, Paris 35 p.

Bellion Y (1989). Histoire Géodynamique post-paléozoïque de l'Afrique de l'Ouest d'après l'étude de quelques bassins sédimentaires (Sénégal, Taoudéni, Illumeden, Tchad). Publication occasionnelle CIFEG 19, 332 p.

Blanchot A, Muller Y (1973). Prospection de recherche minière sur la base des études géologique et des recherches antérieurs. BRGM, Paris, 142 p.

CBLT/BGR (2012). Résultats de 441 analyses chimiques des eaux souterraines et de surface dans la partie Tchadienne du Bassin du Lac-Tchad. Rapport n°4, 20 p.

CBLT/BGR (2013). Études de la qualité des eaux souterraines dans la plaine d'inondation du Logone inférieur. pp. 12-49

Coudrain-Ribstein A, Pratx B, Talbi A, Jusserand C (1998). L'évaporation des nappes phréatiques sous climat aride est-elle indépendante de la nature du sol ? C.R. Acad. Sci. Paris Sci. Terre Planète 326:159-165.

Craig H (1961b). Standards for reporting concentration of deuterium and oxygen 18 in natural waters. Science 133:1833-1834.

Dafny E, Burg A, Gvirtzman H (2006). Deduction of groundwater flow regime in a basaltic aquifer using geochemical and isotopic data: The Golan Heights. Israel case study. J. Hydrol. 330(3):506-524.

Davis SN, De Wiest RJM (1966). Hydrogeology New York: Wiley. 463 p.

Demlie M, Wohnlich S, Wisotzky F, Gizaw B (2007).Groundwater recharge, flow and hydrogeochemical evolution in a complex volcanic aquifer system, central Ethiopia. J. Hydrogeol. 15:1169-1181.

Deutsch WA, Jenne EA, Krupka KM (1982). Solubility equilibria in basalt aquifers: The Columbian Plateau, eastern Washington, USA. Chem. Geol. 36:15–34.

Dissanayake CB, Senaratne A,Weerassoriya VR (1992). Geochemistry of well water and cardiovascular diseases in SiriLanka. Int. J. Environ. Stud. 19:195-203.

Djoret D (2000). Etude de la recharge de la nappe du Chari Baguirmi (Tchad) par les méthodes chimiques et isotopiques. Thèse. Univ. Avignon, 156 p.

Durfor CN, Becker E (1964).Public water supply of the 100 largest cities in the US (Paper 1812, 364). Washington, DC: US Geological Survey Water Supply.

Freeze RA, Cherry JA (1979). Groundwater (p. 604). Englewood Cliffs: Prentice Hall.

INSEED (2012). Deuxième Recensement Général de la Population et de l'Habitat (RGPH2, 2009). 45 p.

Karanth KR (1987). Groundwater assessment, development and management.New Delhi: Tata-McGraw-Hill.

Kusnir I (1995). Géologie, ressources minérales et ressources en eau du Tchad. Travaux et documents scientifiques du Tchad. Connaissance du Tchad I. 100 p.

Ladouche B, Duvail C, Marchal JP, Le Strat P, Chery L (2003). Détermination de l'origine des nitrates dans l'aquifère du Roussillon par le traçage isotopique des sources d'azote (Commune de Pia, Pyrénées Orientales). Rapport BRGM/RP-52745-FR, 54 p.

Leblanc M (2002).Gestion des ressources en eau des grands bassins semi-aride à l'aide de la télédétection et des SIG. Application à l'étude du bassin du Lac Tchad, Afrique, université de Poitier France, 115 p.

Louis P (1970). Contribution Géophysique à la connaissance du bassin u Lac Tchad. Mém. ORSTOM N°42, 311 p.

Maurin JC, Guiraud R (1993).Basement control in the development of the early Cretaceous west and central African rift system. Tectonophysics 228:81-95.

Moussa A (2010).Les séries sédimentaires fluviatiles, lacustres et éoliennes du bassin du Tchad depuis Miocène terminale. Thèse,

Université DE STRASBOURRG, 294p.
Nagarajan R, Rajmohan N, Mahendran U, Senthamilkumar S (2009). Evaluation of groundwater quality and its suitability for drinking and agricultural use in Thanjavur city, Tamil Nadu, India. Environ Monit. Assess. 171(1-4):289-308.
Olivry JC (1986). Fleuves et rivières du Cameroun. Paris: Collection "Monographies hydrologiques Cahiers ORSTOM" ; 781 p.
Piper AM (1944). A graphic procedure in geochemical interpretation of water analysis.Transactions-American Geophysical Union 25(6):914-928.
Schneider JL (1989). Géologie et hydrogéologie de la République du Tchad. Thèse Etat Univ. Avignon 1(2):818.
Schneider JL (2001). Carte de valorisation des eaux souterraines à 1/500000. Ministère de l'environnement et de l'eau. Vol. 2 A1: 1 500 000. Document DGDH, 706 p.
Schneider JL, Wolf JP (1992). Carte géologique et carte hydrogéologique au 1/1500000 de la république du Tchad. Edition BRGM, N° 209, vol.2 et 531p.
Simler R (2007). Diagrammes. Laboratoire d'Hydrogéologie d'Avignon. Université d'Avignon. Logiciel d'hydrochimie multi langage en distribution libre.
Stumm W, Morgan JJ (1996). Aquatic Chemistry, Chemical Equilibria and Rates in Natural Waters, 3rd ed. John Wiley & Sons, Inc., New York 1022 p.
Todd DK (1980). Groundwater hydrology. New York: Wiley.
UNDP/UN (2002).Bilan diagnostic des ressources en eau : schéma directeur de l'eau et de l'assainissement du Tchad. Parti 1 document, 120 p.
United States Salinity Laboratory (1954).Diagnosis and improvement of saline and alkaline soils. Washington: US Department of Agriculture.
WHO (1993). Guidelines for drinking water quality, recommendations (2nd ed.). Geneva: World Health Organization.
WHO (2004). Guidelines for drinking water quality. Geneva: World Health Organization.

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Role of indigenous knowledge systems in the conservation of the bio-physical environment among the Teso community in Busia County-Kenya

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The indigenous knowledge systems are a significant resource which would contribute to the increased efficiency, effectiveness and sustainability in environmental conservation among rural communities of developing countries in particular. They form the basis for community-level decision making in areas pertaining to food security, human and animal health, education and more important in natural resource management. However, despite their critical role in the conservation of the bio-physical environment, these practices and technologies are being marginalized or even forgotten among rural communities in different parts of the world. To ascertain the role played by these traditional practises on the bio-physical environment, this paper identified and established the Teso community indigenous environmental practices and assessed changes in these knowledge systems from the time of Kenya's pre-independence to the 2000s era. Data were collected using various social science methods such as the questionnaire and focused group discussions. The results showed that the use of totems, protection of sacred places, prohibitions and gender and age restraints declined by 41.3, 68, 41.8 and 38.2%, respectively. The evident decline in the use of the indigenous environmental knowledge systems has negatively impacted on the state of the bio-physical environment exemplified by the Chi-square Pearson (P) values of 0.00 between decline in the use of age and gender restraints and the deterioration in land fertility and only a few elders using the knowledge systems and reduction in the number of rivers, streams and wetlands as exemplified by the Chi-square Pearson (P) value of 0.02. In view of the above, it is recommended that rekindling, recording and preservation of indigenous environmental best practices among local communities such as the Teso for sustainable natural resources management be re-invigorated and integrated in conventional environmental management plans. This also calls for participatory decision-making between policy makers, implementers and actual resource users.

Key words: Indigenous knowledge systems, conservation, bio-physical environment.

INTRODUCTION

This study addresses the role of the indigenous knowledge systems in managing the bio-physical environment among local communities in developing countries using Teso community in Busia County in

Kenya as a case study area. It tracks the effects of changes in the use of different types indigenous knowledge systems used by the members of the Teso community on the bio-physical environment from pre-independent Kenya to the 2000s era. It argues that in spite of indigenous knowledge systems often being dismissed as unsystematic and consequently not being captured and stored in a systematic way with the implicit danger being its extinction, some aspects of indigenous knowledge and practices are still critical in the management of the bio-physical environment among local communities such as the Teso of Busia County.

Since time immemorial, various forms of indigenous knowledge systems (IKSs) have been used by societies in Africa and the rest of the World for many different purposes as determined by the needs of the society in question (Chikaire et al., 2012). The study reiterates that the above skills, knowledge and attitudes when harnessed and appropriately applied are capable of sustaining communities and can enhance development in areas such as natural resource management, education, healing and management of diseases, nutrition, wealth/income/business, entertainment, politics among others (Mutasa , 2015).

Current day literature uses different definitions of indigenous knowledge with the World Bank broadly defining it as "a complex set of knowledge and technologies existing and developed around specific conditions of populations and communities indigenous to a particular geographic locality" (Parrotta and Trosper, 2012). The http://www.sedac.cisen.columbia.edu web site defines indigenous knowledge as "a local knowledge that is unique to a given culture or society". It is further viewed as a body of knowledge, or bodies of knowledge of the indigenous/local people of a particular geographical area that have survived on for a very long time. These knowledge systems are developed through a process of acculturation and through kinship relationships that social groups form and are handed down to the posterity through oral tradition and cultural practices such as ritual and rites (Chikaire et al., 2012; Kala, 2012). Such forms of knowledge are also known by other names among them are: Indigenous ways of knowing, local/traditional/folk knowledge/ethno science and is thus a dynamic archive of the sum total of knowledge, skills and attitudes belonging to and practiced by a community over generations, and is expressed in the form of action, objects and sign language for sharing. This form of knowledge has continued to thrive in beliefs, medicine, disaster management, community development, art and craft, education, communication and entertainment, farming practices (soil conservation, intercropping, farm rotation, and food technology among other uses. (Wasongo et al., 2011; Hilhorst, 2015).

The UN Conference on Environment and Development in 1992 catalyzed the interest in the contribution of indigenous knowledge aimed at bettering the understanding of sustainable development. It highlighted the urgent need for developing mechanisms to protect the earth's biological diversity through local knowledge. The agenda 21 of the UNCED conference emphasized on the need for governments to work towards incorporating indigenous environmental management knowledge systems into contemporary socio-economic development programmes in order to attain sustainable development (Helvetas, 2011; Gaillard and Mercer, 2012))

Studies have shown that throughout the world and especially in the developing countries, indigenous/local people have formed "a science" by engaging in annual cycles of subsistence activities that have evolved into knowledge systems and technologies useful in maintaining and preserving the bio-physical environment within such a community. Thus, over the years, local communities have studied and known a great deal about the flora and fauna, and developed their own classification systems as well as versions of meteorology, astronomy, pharmacology, physics, biology, botany and the sacred commonly referred to as the inner world (IPCC, 2014).

Accordingly, thus, natural resource conservation has been in the traditions of local communities and has been expressed variously in the beliefs and practices used in their management and utilization. A study by Eneji (2012) indicate that the indigenous natural resource management practices evolved through the historical interaction of communities and their environment thereby giving rise to practices and cultural landscapes such as sacred forests and groves, sacred corridors and a variety of ethno forestry practices.

Thus, arising from the above were conservation practices that combined water, soil, flora and fauna. Indeed, these nature-society interactions lead to socio-cultural beliefs as institutional frameworks for managing the resultant practices that arose out of the application of the developed indigenous knowledge systems. Consequently, on the basis of the above the attitude of respect towards the earth as "mother" was widespread among indigenous communities worldwide and especially among people in the developing countries of Africa, Asia and Latin America.

Among these communities the ancient studies made

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Figure 1. Study area.

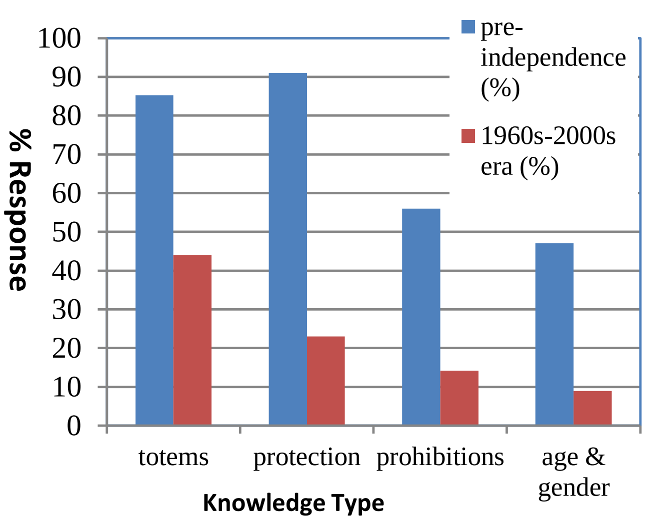

Figure 2. Trends in adherence to Teso Community indigenous environmental management systems.

explicit references to how forests and other natural resources were to be treated and utilized. Africa as a continent is richly endowed with highly diverse biological resources. This paper establishes the Teso community indigenous environmental knowledge systems and explores its contribution in the protection of the bio-physical environment for sustainable development. It tracks changes in the community's use and adherence to the indigenous environmental knowledge systems from the 1960s to the 2000s era and evaluates the effects of these changes on the quality of the bio-physical environment.

The study sought to establish the role played by the Teso community indigenous knowledge systems on environmental conservation and analyze effects of the changes/trend in the use of these knowledge systems on some selected elements of the bio-physical environment from Kenya's independence to the 2000s era.

The study focused on the geographic area covered by two administrative divisions, namely Ang'urai and Chakol Divisions of Teso District in Busia County. The District boarders Bungoma District to the North and East, Busia District to the south and the Republic of Uganda to the West. It lies between latitude 0°36'25.2"N, and longitude 34°16'33.6"E. Teso District is divided into four administrative divisions, namely Amagoro, Angurai, Chakol and Amukura, and covers a total land area of 558.5 km^2 (Figure 1).

The district's altitude ranges from 1,300 m above sea level in the south to an average of 1,500 m in the central and northern parts. Granite and other rocks are more pronounced in the landscape at Amukura and Chelelemuk areas. Some areas of the District are well watered by springs while others avail water through wells and boreholes. The District is also served by two main rivers –that is to say rivers Malakisi to extreme north and Malaba to the northen entry of the central region.

Teso District Location

Most parts of the District receive between 800 and 1,700 mm mean annual rainfall while other parts receive an evenly distributed rainfall of up to 2,000 mm. Temperatures for the whole District are fairly homogeneous with the mean maximum ranging between 26 and 30°C while the mean minimum range between 14 and 22°C. The land is fairly fertile with soils ranging from sandy soils in some areas such as Amagoro to the black-cotton clay soils that are more pronounced on the southern part of the District (Figure 2).

Teso is a rural District where subsistence agriculture is the dominant activity carried out by the majority of the inhabitants (Republic of Kenya, 2013-2017).

METHODOLOGY

A descriptive cross-sectional design was used in this study. Both quantitative and qualitative approaches of data collection and analysis were used. Quantitative approach was employed to quantify social phenomena by collecting, analyzing and interpreting numerical data focusing on links among a smaller number of attributes across many cases.

Qualitative approach, on the other hand, which is concerned with the phenomena relating to or involving quality or kind is usually conducted in natural settings. Qualitative approach was particularly useful in addressing issues on the Teso community indigenous environmental knowledge systems and the effects of changes in IEKS on the bio-physical environment from the time of Kenya's independence to 2000 s.

The target population for this study was drawn from selected members of the Teso community, top government representatives of different relevant departments in Teso District and top representatives of Non-Governmental and Private sector organizations whose operations have a bearing on environment and natural resource management in the District.

There was a special category of respondents consisting of the elderly (Sages) aged seventy (70) years and above who were purposely included in the study sample to help the researcher track the socio-economic and environmental trends in Teso District during the pre-independence and post-independence of Kenya. Both male and female respondents were included in the study sample. A total sample size of 384 respondents was selected based on Fischer's formula (Bryman (2012) and Bruce (2011).

Data collection

This research used several methods to collect data. These included the following tools; Research administered questionnaires were used to collect data from 249 household heads who were randomly selected in order to establish the Teso community indigenous knowledge systems and assess effects of the changes in indigenous knowledge systems on the bio-physical environment through time.

Questionnaires containing both closed and open-ended questions enabled the researcher gain useful and up to date information regarding the status trends in the use of the Teso community indigenous environmental knowledge systems from pre-independence to the 2000s era.

Key informant interviews

Changes in the Teso community indigenous environmental knowledge systems through time were investigated by use of in-depth interviews targeting 50 sages and follow-up discussions targeting 30 sages who were purposely selected from the two administrative Divisions of Teso District. Besides, interviews were also carried out with 15 heads of different government departments and representatives of related NGOs and private sector organizations to gain a deeper understanding of how indigenous knowledge systems are perceived and treated by different government representatives.

PRA and focus group discussions

Focus group discussions and follow-up discussions in a workshop based set-up were carried out with 40 household heads were used to cross-check the validity of the responses and brainstorm on emerging issues regarding trend in use of indigenous environmental knowledge systems and perceived effects on the state of the bio-physical environment.

Again, the transect walks in the two Divisions of data collection enabled the researcher obtain first-hand information on the state of the various elements of the bio-physical environment. Through structured observation, the researcher was able to witness the clearance of bushes and trees for charcoal burning purposes, silting in river banks, eroded riverbanks and hilly slopes, among other forms of environmental damage.

Secondary data

Extra data were obtained from secondary sources such as textbooks, newspapers, relevant journals and electronic sources such as the internet.

Data analysis methods

All questionnaire-based data were cleaned, coded and entered into SPSS for analysis. Analysis centred on cross-tabulation and correlation in order to ascertain the perceived relationship between the level of adherence to indigenous environmental knowledge systems and the status of some selected environmental descriptors.

Interview-based data were analysed qualitatively with narrative correlation being used in corroborating the results with questionnaire data in order to assess the relationship between changes in the use of indigenous knowledge systems and the status of certain selected elements of the bio-physical environment. PRA and FGD data were transcribed and typed into word with themes and sub-themes based on the study objectives created.

RESULTS AND DISCUSSION

Up to 98% of the respondents confirmed that there existed Teso community indigenous environmental knowledge systems. Totems, protection of sacred places, prohibitions as well as age and gender restraints were the most commonly applied norms in the conservation of the various elements of the bio-physical environment.

The study found out that the use of all the Teso community indigenous environmental knowledge systems had declined over time. The use of totems had declined by 73%, prohibition 86%, age and gender restraints 85% and protection of sacred places by 90%. This is presented in Figure 1.

Totems and the preservation of floral and faunal resources

The results from this study showed that during the years preceding Kenya's independence, different clans and sub-clans within Teso District highly upheld totemism. The Teso community members had a complexity of varied ideas and ways of behaviour based on the world view drawn from nature. The above in the views of Eneji et al., (2012) included ideological, emotional, reverent, and genealogical relationships of social groups or specific persons with animals or natural objects. Such animals and objects according to the Teso community members were viewed as companions, relative, protector, progenitor, or helper and were usually ascribed supernatural powers and abilities and were offered a combination of respect, veneration, awe and fear. Among the members of the Teso people of Busia County, (the African Mourning Dove, the Half-Collard Kingfisher, the Nubian Nightjar and the Barn Swallow) locally known as *Akabulutu, Amuruon, Asulwenyi* and *Emelete,* for instance were highly respected prior to Kenya's independence since such birds were treated as symbols for different clans and were also associated with good luck and wealth.

In gratitude, none of the people of the Iteso heritage whose ancestors treated the above as totems could kill, hurt or eat such birds. Furthermore, there were certain tree species that were never felled due to some beliefs that such were associated with water sources, having medicinal properties, associated with bad omen, ancestor or were associated with luck and wealth. The fig tree locally known as *Ebule* for instance was associated with spirituality and where traditionally community members used to worship under could never be tampered with.

Likewise, the Kigelia Africana tree locally known as *Edodoi* that was believed to be an effective cure for mumps where by the patient only needed to visit it very early in the morning (earlier than anybody else) and go rubbing the infected chicks around the plant several times was never carelessly felled.

The above is comparable to the findings by Adu-Gyamfi (2011), Eneji et al. (2012) and Awuah-Nyamekye (2014) who content that among most African indigenous communities, totemic objects and materials vary significantly over tribes and clans. They give examples of totem animals that include mere mammals (Leopards, Lions, Elephants, Monkeys, Buffalo), and birds such as the (Falcon, Raven, snake, parrot) among others. Similarly, turtles, crocodiles, snakes (python), scorpions, crabs and fishes. They note that all the communities surveyed had a belief that there existed a relationship between the totem object or material and the tribe or clan. In this regard members of a particular tribe or clan did not eat, kill or trap these animals and birds thus naturally enhancing their population.

Protection of sacred places, floral, faunal and water resources conservation

The study found out that prior to Kenya's independence the practice of ensuring that certain culturally defined and designated spots and territories was highly upheld by the Teso Community members. These included burial sites, places for ceremonies such as oathing, appeasing of evil spirits, cleansing of members infected by diseases considered contagious or members believed to have committed serious crimes such as murder and adultery, places inhabited by clan gods or spirits of once respected clan elders and medicine men which were protected by respective clans. Among the Teso community members activities such as farming, grazing of animals or even settlements were prohibited from such protected areas.

The Teso community members had various beliefs and practices related to both the dead and the living that had some links to the conservation of the environment. For instance, since time immemorial, members have had a belief that the dead and long buried relatives had their spirits continuously haunting the living family members to free them from the graves. Thus, to appease these departed relatives, there was a common practice of exhuming the remains of the same from the graves that were at least ten years old for preservation. This ceremony that is locally known as *Ekutet /Epunyas* was carried out by a special group of elderly men and women from the community and was done in the absence of children and foreigners.

Accordingly, once all the remains had been recovered from the grave, special baskets were used to transfer the same to some special central site where such remains were stored in places that were strictly being protected and only occasionally visited by the elderly who carried an assortment of traditional foods and drinks for appeasing the evil spirits. Accordingly, no human activity of any kind is carried out in such an area as it was believed that the spirits would not take it kind with anybody disturbing the peace of the dead or the spirits themselves. The area thus remained a very thick forest habiting a number of species or different organisms.

Such sites and places were considered sacred and were thus protected from any internal or external interference thereby encouraging natural growth of the vegetation that later turned out to be dense forests that formed important habitats for a variety of flora and fauna.

Besides, the Teso community members greatly recognized the importance of rivers, marshes and swamps as important dwellings places for ancestors and "God's creatures" (biodiversity) since various species of plants and animals thrived in them.

Thus, the conservation of water courses, streams, water pans and wells as well as the associated vegetation was protected through rules that ensured their sustainability. More important were the shrines, caves and the forests covering the springs which were never interfered with because of the belief that ancestors or evil spirits dwelt in such places. Again, reptiles such as snakes, frogs and toads that inhabited ponds, rivers and wells were protected from any harm due to the belief that they helped maintain / sustain the lives of these important water points. Also, the community members highly recognized and appreciated the importance of wells and rivers as crucial sources of water for livestock and human beings as well as a source of fish.

Therefore, in order to conserve these resources, there were strong rules and beliefs that protected such elements of the bio-physical environment. For instance, some forests were protected by taboos that forbade people from entering them and some trees were declared sacred and thus felling them constituted a breach of taboo with violators being fined some quantity of food or live animals as determined and directed by the village authority. In some instances, folklore and stories such as those claiming that witches were patronizing some forests, rivers, caves, shrines and wells at certain times or seasons to practice their trade and store their tools of trade helped instil fear of violating the rules.

Accordingly, therefore the effectiveness of the traditional Teso community sanctions prior to Kenya's independence was shown by the fact that forest reserves existed for generations and were important havens for biodiversity as they provided a sanctuary for plants, animals, birds until recently when such were cleared to pave way for modern agricultural activities.

This observation is consistent with that report by Ogbuagu (2011) who notes that sacred sites among different indigenous and local communities are highly protected places since they are considered to be of special significance to and play a vital role in the overall well-being of the of Indigenous and local communities. Such sites according to Bhagwat et al. (2011) and Rutte (2011) are viewed as naturally constructed places where cosmic energies are at confluence to enable communication with ancestors, special places for learning and practicing spirituality, philosophy and science; technologies and arts of the indigenous people. Many such sites are thus an expression of World views in which nature is animated; human values are attributed to nature and its elements. Such sites are internationally defined as "areas of land or water having special spiritual significance to peoples and communities" and are recognized as the oldest conserved areas in the World.

Further, UNESCO (2011) says that among other indigenous communities such places were considered sites of fascination, attraction, connectedness, danger, ordeal, healing, ritual, meaning, identity, revelation, and/or transformation. Accordingly, some of these sites were found in dense forests, thick vegetation, in water logged places, swamps and marshes, caves, hills, rocks, particular mountains, soils, water falls, ponds, among other spots.

The above concurs with the findings by Byers et al. (2001) who observed that among the Shona of Zambezi valley there exists a wide range of objects, sites which different community members consider as sacred and they include; trees, rivers, pools and mountain ranges as sacred. Accordingly their concept of sacred (*inoera*) connotes something that is life sustaining and linked to rain and land fertility. They view a sacred place (*nzvimboinoera*) as where spirits dwell and associated with it are rules of access as well as behaviours that are not allowed (taboos).

The above confirms the findings by Risiro et al. (2013) and Matsika (2012) who observed that among communities studied, deforestation was less than 50% in sacred forests than in their secular counterparts. They further observed that close to 133 species of native plants occurred in the sacred forests whereas they were variously, threatened endangered, extirpated elsewhere in Zimbabwe. The above studies thus concluded that strategies for biodiversity conservation that link culture and nature are more effective than those imposed from the top by government or /and agencies and that ignore the traditional beliefs, values, institutions, and practices of local societies.

Prohibitions and the conservation of floral resources

Members of the Teso community practised prohibitions which entailed restricting its members from acting of behaving in some certain unacceptable manner that contributed to the conservation of the various elements of the bio-physical environment. The study found out that among the Iteso people, members mandated to harvest medicinal plants for instance were encouraged to administer some treatment on the harvested part through practices such as the application of cow dung so as to accelerate the callus formation as well as the re-growth of the cambium layer of the affected tree. There were norms that prohibited young children as well as women (especially menstruating women) from harvesting medicinal plants because of the belief that such medicine would lose its medicinal value or healing power.

Likewise, the harvesting of young plants for medicinal use was prohibited and thus there were strict rules that only allowed the harvesting of mature plants for medicinal purposes.

Similarly, the digging of only secondary roots rather than the main (tap) root of the medicinal plants was also allowed so as to protect these plants from any form of damage. Besides, community members were encouraged to plant medicinal plants near homesteads especially as strips between or separating different land parcels for ease of access as well as for protection from outsiders.

It was common to find that felling or uprooting of the above was restricted to only those portion/ parts and quantities needed such as branches, leaves or roots being harvested. In particular, root tuber crops such as cassava and sweet potatoes were protected by harvesting only large roots or tubers through a process known as "milking,"-that is to say, only harvesting large and harvestable roots and tubers which assured the survival of the crop thereby enabling the conservation of these plants. Again, there were traditional claims which stated that some medicinal plants could only be harvested or reached after wearing special clothes, leaving special treated coins under the plant at night before harvesting or making a special prayer before collecting the roots, bark or leaves of certain tree species that helped the conservation of medicinal plants.

Likewise, taboos and restrictions on gathering of medicinal plants and the nature of tools used for harvesting by Teso community members which in most cases consisted of blunt knives helped to limit the volume of tree products harvested. Again, the Teso culture never permitted women to engage in any kind of construction activities and thus acts of clearing land or vegetation for whatever reason was a male activity. Also, the fetching of firewood entailed cutting or picking dead wood or only those tree branches that could be reached from the ground or cutting shrubs and not young trees.

Similarly, the cactus and euphorbia trees were seen as medicinal and were thus prohibited from being cut down carelessly. Also, the Meru Oak locally known as (*Eyolokome)* whose leaves were believed to be an effective mosquito repellent was equally prohibited from being felled. Indigenous trees such as *Melia Volkensii* locally known as (*Elirat)* and *Markhamia lutea* (*Eswaat*) besides being medicinal in nature were also associated with good luck and wealth and thus were found planted in nearly all homesteads and were never easily interfered with unless for building purpose.

There were also tree species that were never interfered with because of the Folklore and stories that if the fuel wood from such a tree was used for cooking the resultant smoke would lead to blindness and deafness. Similarly, a house constructed using such trees would be inhabited with evil spirits thereby bringing curses to the occupants. These prohibitions which were closely adhered to enabled the population of such trees to increase which in turn encouraged other associated vegetation to grow. The increase of the population of such trees also encouraged the presence of a wide range of birds and wild animal thereby helping in environmental conservation and ensuring a steady supply of traditional medicine and thus lower levels of morbidity and mortality among members.

The above findings correspond with the observation by Agyarko (2013) and Danquah (2014) who indicate that among the Ashanti of South-Western Ghana for instance, trees which were regarded as housing spirits were not be felled without performing rituals. In this regard, such a custom had a protective effect on trees such as odum (*Chlorophora excelsa*), African mahogany (*Khaya ivorensis*) and tall palm trees as betene (*Elaeis Guineensis*) and shea butter (*Butyrospermum parkii*) and the Dawadawa (*Parkia clappertoniana*) osese (*Funtumia sp.*) species.

Again, animals found in a particular habitat were regarded as sacred and thus were protected from hunting. The above particularly applied to the Black and White colobus (*Colobus polykomos*) and the mona monkey (*Cercopithecus mona*) in the Boabeng- Fiema wildlife sanctuary of Central Ghana. A similar situation was reported for the bats of Wli in the South Eastern part of the country whereby the overhanging rocks of the mountains that form the border with Togo is known to house an impressive colony of large bats, which are said to be conserved by the local community. In this regard, the Black and White colobus (*Colobus polykomos*) and the mona monkey (*Cercopithecus mona*) found in the Boabeng- Fiema wildlife sanctuary of Central Ghana are in particular protected by prohibitions (Elorm-Donkor, 2012).

Age and gender restraints and land resource conservation

Within the Teso community, different age groups and genders closely respected and upheld rules and guidelines that forbade them acting contrary to what was expected of them by culture. The traditional Teso culture for instance restrained women from climbing a tree for reasons particularly related to women's nature of dressing. Likewise, women and young unmarried boys were restrained from owning land and the accompanying land based resources such as water points and trees by being denied the authority to utilize such resources unless permitted by an elder or the household head. As a result of the said restraints, land-based resources were used sustainably leading to the conservation of the various elements of the bio-physical environment.

Besides, women and children were restrained from certain activities including felling certain types of trees. In particular, women were restrained from felling trees that were viewed as having medicinal properties; fetch firewood from condemned tree varieties such as those perceived as prone to lightening, those whose smoke was perceived as capable of causing blindness or deafness or those believed to attract evil spirits, among others.

Likewise decisions on the location of the home/ settlement were a preserve of the clan heads but not any member of the community. This enabled community members to settle in communal villages which led to the formation of homesteads rather than scattered houses thereby reducing pressure on land based resources. The study further, found out that community members were guided by clan elders on the suitable spots for activities such as settlement, farming, grazing, among others, thereby prohibiting them from venturing into areas perceived to be fragile, susceptible to diseases and lightening, among other dangers.

This ensured minimal or no disturbance to certain components of the bio-physical environment. In this regard, Awuah-Nyameke (2014) notes that among African communities institutionalized prohibitions such as taboos were thus designed to develop positive societal attitudes towards the environment.

Cross-tabulation and correlation analysis results

Prior to Kenya's independence when the Teso community socio-cultural structures were strong with most members adhering to them, there was some statistical significant relationship between observance of indigenous environmental knowledge systems and the quality of certain elements of the bio-physical environment. This is exemplified by the Pearson Chi-square (P) value of 0.00 at 95% between protection of sacred places and land fertility. Similarly, the results showed a statistically significant relationship between high level observance of protection of sacred places and variety of bird and wildlife as indicated by the Pearson Chi-square (p) value of 0.003 at 95% level of confidence.

Again, cross-tabulation analysis between high level observance of prohibitions as a knowledge system and land fertility as exemplified revealed statically a significant relationship as shown by the Chi-square (p) value of 0.01 at 95% level of confidence. Also, the results revealed a statistically significant relationship between prohibition and land fertility as indicated by the Pearson Chi-square (p) value of 0.01 at 95% level of confidence. From the 1960's to the 2000s era, the study revealed a statistically significant relationship between a decline in the observance of age and gender restraints and deterioration in land fertility as exemplified by the Pearson Chi-square (p) value of 0.000 at 99% level of confidence.

The correlation analysis results showed that prior to Kenya's independence there existed a positive though weak relationship between high level use of prohibitions and age and gender restraints with the vegetation cover which was dense and well distributed as indicated by the Pearson correlation coefficient (R^2) values of 0.032 and 0.037 respectively. Between 1960s to 2000s era however, a decline in the use of totems, protection of sacred places and age and gender restraints adversely affected land fertility, vegetation cover as well as the number and nature of natural springs, rivers and streams as indicated by the Pearson correlation coefficient(R^2) values of 0.219, 0.736, 0.186,0.125 and0.463 respectively.

Conclusion

The Teso community members have used various indigenous environmental norms such as prohibitions, protection of sacred places, totems and age and gender restraints in managing different elements of the bio-physical environment with varying successes. This is particularly with regards to protection of sacred places and enhancement of the vegetation cover prior to Kenya's independence as indicated by the Pearson correlation coefficient (R^2) values of 0.032 and 0.037 respectively.

From the 1960s to the 2000s the level of use of the previously dominant indigenous knowledge systems has declined with only a few elderly people still adhering to these knowledge systems. The drastic decline in the use of the indigenous knowledge systems (Totems 44%, prohibitions 14.2%, restraints 8.9% and protection of sacred places 23%) has negatively impacted on the state of the bio-physical environment including land fertility, the population of birds and wildlife, size of area covered by seasonal swamps as well as shrub-land as evident from the Land use/Land cover analysis as well as the cross tabulation results.

RECOMMENDATIONS

Based on these conclusions, this study makes the following recommendations.

i) The government through ministries of mineral and natural resources, NEMA, agriculture, forests, relevant NGOs, donor community and private sector should take adequate steps to focus on mainstreaming traditional (indigenous) best practices with proven value/utility into contemporary environmental management systems and enhance the capacity of the community members for its adoption and application in conserving the various elements of the bio-physical environment. Such practices should be identified, classified and documented in a way that they can easily be accessed by community members.

ii) In view of the above, there is need for collaboration between the above stakeholders and the community sages/ elders to facilitate the acquisition of indigenous best environmental practices held by the latter so as to enable documentation of the same for purposes of the future generations as well as for the current community members' application in the conservation purposes. In this regard, a fund should be set aside to serve as a token of appreciation to encourage and motivate the smooth acquisition of this knowledge from the sages in all the counties in the Country.

iii) At the individual level, the government with the assistance of NGOs and private sector organizations should sponsor environmental campaigns through electronic media such as video and films shows using local language so as to reach the illiterate community members. Relevant audio and visual educational materials should be developed possibly in the form of village bulletins, sponsored drama and local video shows in the local language so as to create awareness in the community.

Areas for further research

i) There is need for study on the process of designing a

framework that can integrate indigenous environmental best practices with scientific conservation approaches among rural communities.
ii) A study should be carried out to ascertain the most appropriate and cost-effective method for capturing, documenting and storing indigenous environmental management best practices currently under threat of being forgotten among rural communities.

Conflict of Interests

The authors have not declared any conflict of interests.

REFERENCES

Adu-Gyamfi Y (2011). Indigenous Beliefs and Practices in Ecosystem Conservation: Response of the Church. Scriptura 107:145-155.

Awuah-Nyamekye S (2014). Managing the Environmental Crisis in Ghana: The role of African Traditional Religion and Culture with Special Reference to Berekum Traditional Area. United Kingdom: Cambridge Scholars Publishing.

Agyarko OR (2013). God of Life: Rethinking the Akan Christian Concept of God in the Light of the Ecological Crisis" The Ecumenical Review. Available at: http://onlinelibrary.wiley.com/doi/10.1111/erev.12026/abstract

Bryman A (2012). Social Research Methods. New York: Oxford University Press.

Bruce L (2011). Qualitative Research Methods for Social Sciences. London: Pearson Education Limited.

Bhagwat S, Ormsby AA, Rutte C (2011). The role of Religion in Linking Conservation and Development: Challenges and Opportunities. J. Study Religion Nat. Cult. 5(1):39-60.

Chikaire J, Osuagwu CO, Ihenacho RA, Oguegbuchulam MN, Ejiogu-Okereke N, Obi KU (2012). Indigenous knowledge system: The need for reform and the way forward. Glob. Adv. Res. J. Agric. Sci. 1(8):201-209.

Danquah JB (2014). Akan Doctrine of God (194 Cb: A Fragment of Gold Coast Ethnics and Religion) UK: Routledge.

Eneji CV, Ntamu GU, Ajor JO, Ben CB, Bassey JE, Williams JJ (2012). Ethical Basis of African Traditional Religion and Socio cultural Practices in Natural Resources Conservation and Management in Cross River State, Nigeria. 2(2):034-043.

Elorm-Donkor L (2012). African Worldview and Christian Pneumatology: Divergences and Convergence Didache: Faithful Teaching 12:1.

Gaillard JC, Mercer J (2012). From knowledge to action: Bridging gaps in disaster risk reduction, Progr. Hum. Geogr. 37(1):93-114.

Helvetas N (2011). Nepal's Climate Change Policies and Plans: Local Communities' Perspective Environment and climate series 2011/1; Authors: Shiva Prasad Aryal and Bharat Pokharel; HELVETAS Swiss Inter-cooperation, Nepal.

Hilhorst D, Baart J, van der Haar G, Leeftink, FM (2015). Is disaster normal for indigenous people? Indigenous knowledge and coping practices. Disaster Prev. Manag. 24(4):506-522.

IPCC (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Kala CP (2012). Traditional ecological knowledge and conservation of ethno- botanical species in the buffer zone of Pachmarhi Biosphere Reserve, Madhya Pradesh. Indian Institute of Forest Management, Bhopal, Madhya Pradesh. 194 p.

Risiro J, Tshuma TD, Basikiti A (2013). Indigenous Knowledge Systems and Environment Management. A Case Study of Zaka District, Mansvingo Province, Zimbabwe. Int. J. Acad. Res. Prog. Educ. Dev. Vlm 2:1.

Matsika C (2012). Traditional African Education: Its Significance to Current Education Practices with Special Reference to Zimbabwe, Mambo Press, Gweru

Mutasa M (2015). Knowledge apartheid in disaster management discourse: Is marrying indigenous and scientific knowledge the missing link? Jamba: Journal of Disaster Risk Studies 7(1).

Ogbuagu BC (2011). We Who Are Strangers: Insights into How Diasporic Nigerians Experience Bereavement. Loss. J. Afr. Am. Stud. 16(2):300-320.

Parrotta, JA, Trosper RL (2012). Traditional Forest-related Knowledge: Sustaining Communities, Ecosystems and Biocultural Diversity. London: Springer.

Republic of Kenya (2013-2017). Busia County Integrated Development Plan. Nairobi: Government Printer.

Rutte C (2011). The Sacred Commons: Conflicts and Solutions of Resource Management in Sacred Natural Sites. Biol. Conserv. 144(10):2387-2394.

United Nations Educational, Scientific and Cultural Organization (UNESCO) (2011). Osun Osgbo Sacred Grove, 13.09.2011, Available from http://whc.unesco.org/en/list/1118

Wasongo VO, Kambewa D, Bekalo I (2011). Community-Based Natural Resource Management (p. 194). In: W.O. Ochola, P.C. Sanginga, I. Bekalo (Eds.), Managing Natural Resources for Development in Africa. A Resource Book. Nairobi, Kenya: Univ. of Nairobi Press. 4:165-210.

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Full Length Research Paper

The potential impacts of climate change on hydropower: An assessment of Lujeri micro hydropower scheme, Malawi

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Climate change has the potential to affect hydropower generation by either increasing or reducing flows (discharge) and the head. This paper assessed the impacts of climate change on hydropower generation with a focus on Lujeri micro-hydropower scheme in Mulanje district, Malawi. The study analyzed trends in weather time series (air temperature and rainfall) data from 1980 to 2011 in connection to changes in river discharge and their associated impacts on hydropower generation profile. The Mann-Kendall (MK) test was used to detect trends in air temperature, precipitation and discharge. Correlation analysis was also used to uncover the relationship between discharge and precipitation as well as between discharge and temperature. The MK results highlighted significant rising rates of air temperature, precipitation and discharge in some months and decreasing trend in some other months, suggesting significant changes have occurred in the area. The relationship between precipitation and discharge was not significant (p = 0.552), while that between temperature and discharge was significant (p = 0.0001). Therefore, as temperature showed significant increasing trend, it will be associated with decrease in discharge, consequently a decrease in hydropower generation (power is directly proportion to discharge). Hence, proper adaptation measures such as standby alternative sources of energy and storage mechanisms devices should be exploited to ensure electric power is available throughout the year, especially in the hot and dry season when the discharge is usually very low.

Key words: Climate change, discharge rate, hydropower, Malawi, precipitation, temperature.

INTRODUCTION

Environmental change, manifested by climate change and variability, is no longer a mythical discourse; the scientific consensus is not only that, human activities have contributed to it significantly, but the change is far more

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rapid and dangerous than thought earlier (IPCC, 2007a). Climate change and variability are now becoming one of the significant development challenges due to shift in the average patterns of weather. While climate change results from activities all over the globe, with rather unevenly spread contributions to it, it may lead to very different impacts in different countries, depending on local, regional environmental conditions and differences in vulnerability to climate change (UNEP, 2002). The Millennium Ecosystem Assessment (2005) shows that, in all ecosystems of the world, the climate changes impacts are rapidly increasing, such as, on water resources, environmental services and other livelihoods capital assets for sustainable human development. Thus, as also attested by Dhakal (2011) that the energy sector is one of the major users of water resources, climate change will particularly affect the temperature, precipitation and flow regime and consequently, hydropower generation.

Hydropower is power derived from the force or energy of moving water which is harnessed for useful purposes. Prior to the widespread availability of commercial electric power, hydropower was used for irrigation and operation of various machines, such as watermills, textile machines, sawmills, dock cranes and domestic lifts (Kreis and Steven, 2001). With the invention of electric generators, hydropower was a natural source of power for such generators in generating electricity according to the following power equation:

$$P\ (W) = \rho g \eta Q H \qquad (1)$$

Where P is power output (W), ρ is the density of water (kg/m^3), g is the gravity (m/s^2), η is turbine efficiency (%), Q is the discharge rate (m^3/s) and H is the head (m). In addition to the fact that hydroelectricity emits near-zero emissions, Jain (2011) highlighted that hydropower is a proven, mature, efficient and cost competitive renewable energy source. Hydropower requires relatively high initial investment but has low operation costs and it offers a hedge against volatile energy prices. Harrison *et al*. (1998) argued that exploitation of hydropower potential is considered by many governments and international bodies to be a key feature in economic development, especially in less developed countries.

The amount of electricity to be produced by a hydropower facility will mainly depend on the volume of water passing through the turbine in a given amount of time, the water head and the efficiency of the turbine. While many of the variables on the power equation will usually be fixed for a particular hydropower facility, the fluctuations in the quantity and timing of river discharge rate affects much the production of hydroelectric power. The discharge rate is in turn affected by seasonal and quantitative changes in precipitation and evapo-transpiration (Koch et al., 2011).

Hydropower is clearly among the most vulnerable areas to global warming because water resources are closely linked to climate changes (Pathak, 2010). Since climate change will certainly increase global air temperature, considerable regional impacts on the availability of water resources will occur concerning quantity and seasonality (IPCC, 2007b). At first glance, increased global precipitation would appear to suggest more water available for hydroelectric power production. However, higher temperatures will lead to increased evapotranspiration levels thus reducing the runoff (Harrison et al., 1998). Therefore, hydropower vulnerability to climatic conditions has a profound effect on its generation. Consequently, this is more critical to energy security for a country such as Malawi which sorely depends on hydropower for its electricity production.

Nearly all of Malawi's electricity is provided by hydropower from a cascaded group of interconnected hydroelectric power plants located on the Shire River and a mini-hydro on the Wovwe River, which constitute the interconnected system. Total installed capacity of these hydropower plants is 351 MW. However, changes in power demand scenarios within the past years, coupled with tremendous environmental degradation in Malawi has drastically negatively affected the operation and the efficiency of the existing power generation plants. This has forced the government to re-examine its power development options in the short and medium term. As one of its key strategy, the government plans to construct more hydropower stations along the major rivers of the country.

Nevertheless, hydropower will be impacted by climate change in a varying degree depending on the region and hydropower type; thereby run-of-river power plants as well as reservoir hydropower plants will be affected (Koch et al., 2011). Africa at large and southern Africa in particular, will be the most affected part of the world due to lack of adaptation and mitigating measures (IPCC, 2001). Similarly, according to Hamududu and Killingtveit (2006), the East and Southern African countries have a climate that is highly variable, unreliable and unpredictable. These impacts will directly affect hydroelectric production and have the potential to make hydropower either more or less vulnerable because it may lead to timing mismatch between energy generation and demand. As hydropower is the major source of electricity in Malawi, impacts on hydropower production would lead to serious disruptions in the energy infrastructure.

Study area (Lujeri micro hydropower scheme)

Lujeri Tea Estates grows and processes high quality tea on its estates under the imposing Mount Mulanje, the highest point in Malawi. Its tropical location and superior cultivar plant varieties produce excellent quality teas that

Figure 1. Map of Southern Malawi showing the study location.

are unusually high in health promoting anti-oxidants. Tea was first planted on the estate in the late 19th Century.

Electricity is required to run the machines in the factories as well as the estate's irrigation pumps and Lujeri is able to provide approximately 30% of its electricity requirements from the two micro hydroelectric power plants it owns and operates on the estate. These power plants are constructed on two rivers, Ruo and Lujeri River that run through the estate and this study was done on a plant constructed on Ruo River (which houses three turbines referred to as Ruo 1, 2 and 3). Both plants were commissioned in the 1930's. The closed circuit system of water reticulation returns all the water to the river from the two power stations. This makes the system eco-friendly as well.

The Ruo River (with a catchment area of about 4900 km^2) rises on the slopes of mount Mulanje (the southern portion of the eastern Shire Highlands) and is the largest tributary of Shire River. It flows through Mulanje district and also forms part of the Malawi-Mozambique border before joining with the Shire River. The power plant is located at the base of the Mulanje Mountain as shown in Figure 1.

Mulanje District is located approximately 65 km east of Blantyre district and is named after the highest Mountain in the South-Central Africa. The district local weather conditions are greatly influenced by the Mulanje Mountain and the climate is also partly affected by Chiperoni winds causing high rainfall on the windward (South East side of the Mulanje Mountain) while limiting it on the leeward side (Taulo et al., 2008). The average annual rainfall is 1600 mm and the average minimum annual temperatures ranges from 21 to 23°C and the maximum temperatures of about 32 to 35°C (Haarstad et al., 2009). Taulo et al. (2008) also noted that one most distinctive feature of Mulanje climate is the variation of rainfall over short distances, a characteristic attributed to the influence of Mulanje Mountain.

MATERIALS AND METHODS

The impact of climate change can be visualized in terms of changes in temperature, shift in weather pattern, rainfall distribution which have impact on the intensity of discharge and water accumulation in reservoir as well as the activities and natural phenomenon taking place in its catchment area (Dhakal, 2011). Generally, the study analyzed changes in recent weather time series (monthly and seasonal air temperature and rainfall) data from 1980 to 2011 in connection to changes in river discharge and their associated impacts on hydropower generation profile. The precipitation and temperature data used in this study was kindly provided by the Department of Climate Change and Meteorological Services and the discharge data by Water Department in the Ministry of Agriculture, Irrigation and Water Development. The discharge data used was from 1959 to 1990 because of unavailability of recent data. Pre-quality analyses of the data were done by the departments.

The recent trend of climate changes taking place in Mulanje

The precipitation and temperature data was used to analyze the changes in climate in Mulanje district over the years. The Mann-Kendall (MK) test was used to detect if any statistically significant trends exist in the data. This test, MK, is a powerful non-parametric method tool for analyzing long time series data such as precipitation, temperature and discharge. Under the null hypothesis (H_0), the assumption is that there is no trend in the data and the alternative hypothesis (H_1) carries the assumption that there is an increasing or decreasing trend over time. The mathematical computational for the MK test statistics S, Var (S) and the standard test statistic Z_S were calculated as follows:

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sign(\mathrm{Tj} - \mathrm{Ti}) \quad (2)$$

$$sign(\mathrm{Tj} - \mathrm{Ti}) = \begin{cases} 1 & if \ \ \mathrm{Tj} - \mathrm{Ti} > 0 \\ 0 & if \ \ \mathrm{Tj} - \mathrm{Ti} = 0 \\ -1 & if \ \ \mathrm{Tj} - \mathrm{Ti} < 0 \end{cases} \quad (3)$$

$$\sigma^2 = \frac{n(n-1)(2n+5) - \sum t_i(i)(i-1)(2i+5)}{18} \quad (4)$$

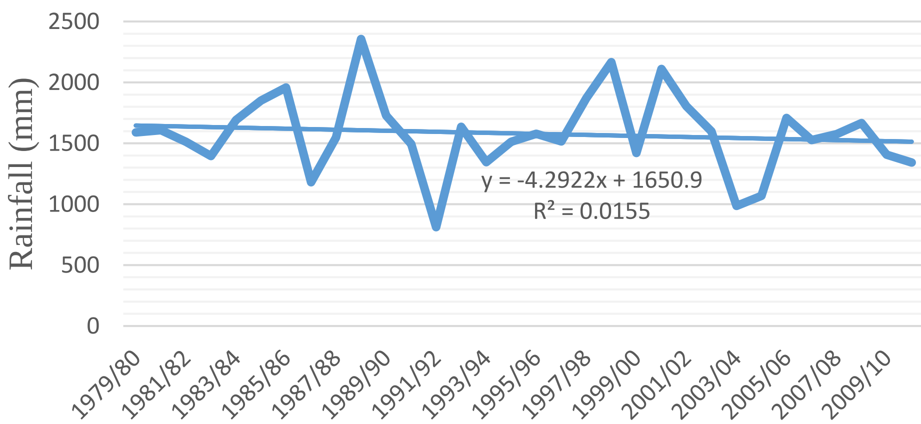

Figure 2. Total annual rainfall variation in Mulanje.

$$Z_s = \begin{cases} \frac{s-1}{\sigma} & for \quad S > 0 \\ 0 & for \quad S = 0 \\ \frac{s+1}{\sigma} & for \quad S < 0 \end{cases} \tag{5}$$

where T_j and T_i are the actual time series observation data, n is the period of the time series data, t_i denotes the number of ties up to sample i. The test statistic Z_S follows normal distribution and was used as a measure of significance of trend. Positive and negative values of Z_S signify an increase and decreasing trend, respectively. A significance level α is used to test if the null hypothesis (increase or decreasing) trend exist. If Z_S is greater than $Z_{\alpha/2}$, the null hypothesis is rejected implying that the trend is statistically significant. The chosen significance level for this study was 1.96 for p-value of 0.05. However, before running a MK trend test, autocorrelation was considered to remove the serial dependence of the time series data that would cause problems in testing of data and interpretation of results, according to the method proposed by Yue and Wang (2004).

The factors influencing discharge rates of Ruo River

The discharge rates are determined by factors such as climate, vegetation, soil type, drainage basin relief and the activities around the river basin such as farming. However, the study focused mainly on precipitation and temperature as the principle driver contributing to changes in discharge because of the limited availability of data to investigate the other variables. To accomplish this objective, the Pearson product moment correlation was used to uncover the relationship between discharge and precipitation as well between temperature and discharge. The correlation analysis used the formula presented in Equation 6:

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n(\sum x^2) - (\sum x)^2]\,[n(\sum y^2) - (\sum y)^2]}} \tag{6}$$

Where: x is the independent variable (precipitation/temperature), y is the depended variable (discharge) and n is the number of data pairs.

Power analysis

The study used estimated potential power because the owners of the plant do not regularly keep records of monthly average data on the amount of power generated from the plant. The study therefore adopted Equation 1 to estimate the potential power generated from the plant using observed monthly average discharge data. The machines at the plant are all Pelton turbines which have a world reputation of reaching efficiencies of about 90%. Nonetheless, old installation of the machines and inadequate in maintenance of hydropower station could drastically affect the efficiencies of these turbines. Similarly, several losses are also encountered during the conversion of potential and kinetic energy of water to electricity but typically hydropower turbines efficiencies range between 60 and 90% (Meijer et al., 2012). Hence, an average efficiency of 70% was assumed in this study to show a more realistic first impression of potential hydropower. Finally, the hydropower plant rated net head (for Ruo 1 and 2 is 365 m while for Ruo 3 is 355 m) was used in the calculations. The estimated potential generated power was analyzed using simple graphs in order to evaluate the changes in the annual average generated power and to depict the maximum average generated power in each month of the year.

RESULTS AND DISCUSSION

Recent climate trends

Recent climate trends were analysed by looking at changes in annual rainfall distribution and temperature overtime.

Annual rainfall variation

Projected precipitation over Malawi shows inconsistence among different Global Circulation Models (GCMs), with some models projecting increase and others projecting decrease in rainfall. Whereas, the 31 years of average annual rainfall data (1980 to 2011) in this study showed that the average annual rainfall of Mulanje is decreasing at the rate of about 4.29 mm per year (Figure 2). This is in agreement with the observation by MoNRE (2011) that the general trend is that the mean monthly rainfall will

Table 1. MK tests results for precipitation in monthly time series.

Variable	Kendalls tau	S	Var (S)	P-value (two-tailed)	Alpha	Interpretation	Trend
JUL	0.06	31	792.5	0.287	0.05	Accept	NST
AUG	-0.03	-13	646.9	0.637	0.05	Accept	NST
SEP	-0.22	-104	428.5	< 0.0001	0.05	Reject	Decreasing
OCT	-0.29	-145	634.4	< 0.0001	0.05	Reject	Decreasing
NOV	-0.16	-78	720.9	0.004	0.05	Reject	Decreasing
DEC	0.15	73	681.6	0.006	0.05	Reject	Increasing
JAN	0.10	52	770.7	0.066	0.05	Accept	NST
FEB	-0.22	-108	692.6	< 0.0001	0.05	Accept	Decreasing
MAR	-0.03	-16	137.4	0.201	0.05	Accept	NST
APR	-0.10	-49	299.0	0.006	0.05	Reject	Decreasing
MAY	-0.21	-104	257.2	< 0.0001	0.05	Reject	Decreasing
JUN	-0.15	-75	678.6	0.005	0.05	Reject	Decreasing

NST = No significant trend.

decrease with time. From this analysis, the maximum occurrence of rainfall occurred in 1988/89 season and the minimum rainfall occurred in 1991/92 season with total precipitation of 2356.5 and 811.2 mm, respectively. It was these years, 1991/92, when Malawi experienced severe drought across all regions of the country. It can also be observed from the results that the average rainfall is 1631.1 mm for the 31 year period, representing an average of about 135.9 mm of precipitation per month. However, Vincent et al. (2014) reported that the amount of rainfall in southern Malawi is between 150 and 300 mm per month and hence that for Mulanje is below this range. Bulckens (2013) also attested that rainfall in Mulanje district has decreased from an average of 2000 mm in 1960 to about 1500 mm in 2012. This clearly shows that there is a decline in annual rainfall distribution for period 1980 to 2011 and more analysis needs to be done to see whether this trend will continue.

In order to detect if the trends in the precipitation were significant, the Mann-Kendall (MK) test was applied on a monthly scale for the entire 31 years period. The summary results of non-parametric MK test for trend analysis of data are presented in Table 1. The results for monthly trend tests showed a mix of positive and negative trends with January, July and December depicting a positive trend and the rest of the months of the year showing negative trend. The increasing trend in precipitation for December was statistically significant ($p = 0.006$). Significant negative trend were detected in the months of February, April, May, June September, October and November; no significant trends were found for the other months. The significant decrease of precipitation in October and November confirms the observation by many studies that the rains are shifting towards December (Action Aid, 2006; Magrath and Sukali, 2009; USAID, 2013).

Temperature

The temperature data from 1980 to 2010 was also analyzed. Figure 3 shows that both mean monthly minimum temperature and mean monthly maximum temperature for Mulanje is increasing by about 0.04°C every year. Phiri et al. (2004) also observed (as cited in ActionAid, 2006: 5) that mean temperatures in the lower Shire had increased by 2.3% while mean maximum temperatures increased by 2% between 1970 and 2002. Meanwhile, the period 1960 to 2006, McSweeney et al. (2011) observed that mean annual temperature has increased by 0.9°C,an average rate of 0.21°C per decade.

Therefore, temperature projections for Malawi are mainly consistent, with all GCMs results predicting significant increase in temperature. The observation from the temperature analysis done here also shows consistency with the GCMs. This increase in temperature has also been perceived by villagers in a Participatory Rural Assessment (PRA) study (Magrath and Sukali, 2009; USAID, 2013) and the results highlighted warming temperatures as one of the most visible impacts of climate change in Malawi.

On running the MK test on mean monthly and mean maximum temperature data to detect if there is a trend in the 30 years period, the following results in Table 2 were obtained. The results indicate that there is significant increasing trend for both mean monthly and mean maximum temperature. Therefore, further impacts associated with the increasing temperature in Mulanje district should be considered.

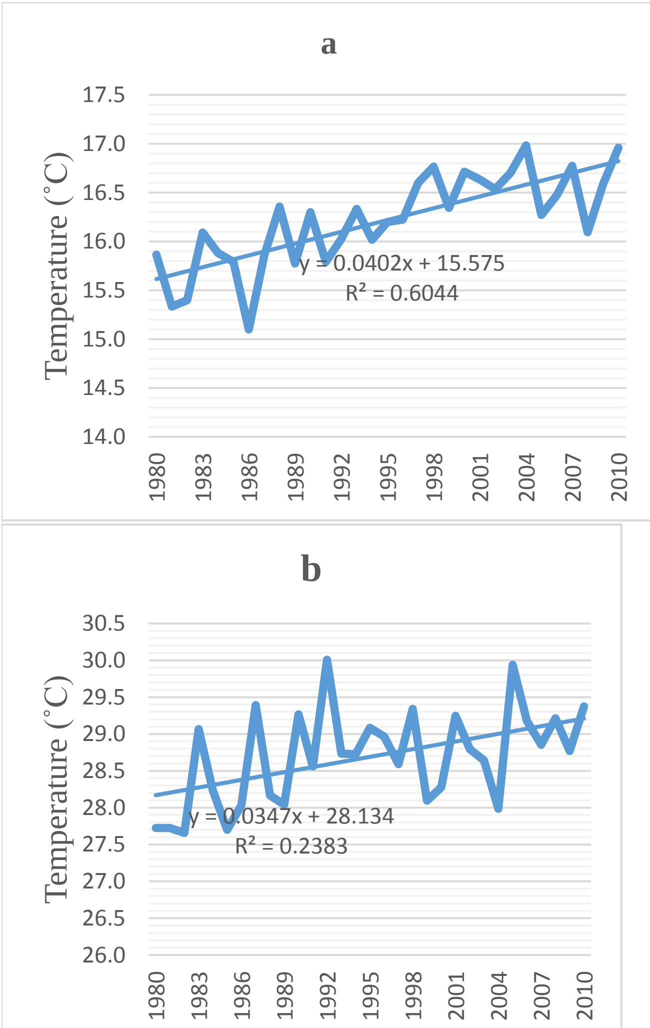

Figure 3. Annual Mean Minimum and Maximum Temperature.

Discharge analysis

Monthly discharge and annual discharge

The Ruo River hydrological data from 1959 to 1990 (station 14C2) was collected and analysed. On plotting a linear trend line for the 31 years data, the annual mean discharge indicates that the Ruo discharge is decreasing at a rate of 0.09 m^3/s every year as shown in Figure 4. This result is in alignment with the annual rainfall distribution which has also indicated a decreasing trend over the years. It was also observed that the minimum mean discharge was 8.17 m^3/s and occurred in 1982/83 rainy season. The year 1982/83 rainy season precedes the drought that occurred in 1981/82 season which had affected many areas in Malawi (MoNRE, 2011). It has been noted that the quantity of surface water resources in Malawi's river systems is highly dependent on runoff from rainfall and thus water resources are usually more abundant during the rainy season than the dry season (MoNRE, 2002). However, while attributing that data collection on the rivers flowing from the Mulanje Mountain is inadequate, Nangoma (2008) observed the rivers runoffs are no longer reliably and depict flow irregularity. If the decreasing trend of Ruo discharge is to go on it will have a negative impact on life activities that depends on and thus the trend needs to be researched further.

On the other hand, a mix of decrease and increase trend were obtained when the MK test was run to detect trend in monthly discharge. The results indicated that there was a positive trend in discharge in the months of January, February, March, April and December and all these months correspond to the rainy season. The increase in trend was significant for February, March and April. The results also indicated a statistically significant negative trend in discharge for the rest of the months of the year apart from May. The MK tests results for discharge in monthly time series are shown in Table 3. Therefore, it is of immense importance based on these results to look further on the impacts such as ecological, economical as well as social that would result if the decreasing discharge trends are to continue in future.

Rainfall and discharge relationship

One factor that affects discharge is the amount of rainfall. The relationship between the mean annual rainfall and mean annual discharge was investigated using Pearson product-moment correlation coefficient. It was assumed that the sample is of normality, linearity and homoscedasticity. Therefore, preliminary analyses were performed to ensure no violation of the assumption of normality, linearity and homoscedasticity. The results indicated a small, positive correlation between the rainfall and discharge, with $r = 0.111$, $n = 31$, $p = 0.552$. These results therefore show that as the amount of rainfall will be increasing, it will be associated with increase in the amount of river discharge and vice versa. However, the increase is not statistically significant as *P*-value is greater than 0.05. Hence, the results strongly suggest that other variables other than rainfall have major influence on discharge.

Temperature and discharge relationship

Similarly, temperature is another factor that may affect discharge. To understand the relationship between temperature and discharge, the mean annual maximum temperature and mean annual discharge was investigated using Pearson product-moment correlation coefficient. It was also assumed that the sample is of normality, linearity

Table 2. MK tests results for temperature in annual time series.

Variable	Kendall's tau	S	Var (S)	p-value (Two-tailed)	alpha	Interpretation	Trend
Mean monthly minimum temperature	0.58	268	651.9	< 0.0001	0.05	Reject	Increasing
Mean monthly maximum temperature	0.34	158	912.3	< 0.0001	0.05	Reject	Increasing

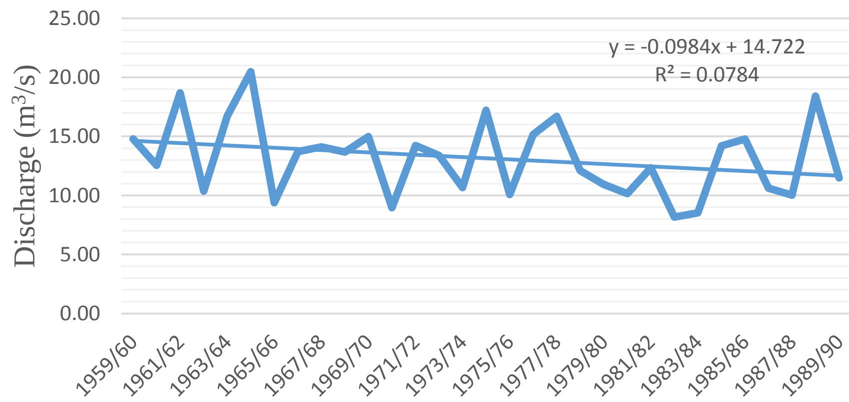

Figure 4. Annual mean discharge of Ruo River.

Table 3. MK tests results for discharge in monthly time series.

Variable	Kendall's tau	S	Var(S)	p-value (Two-tailed)	alpha	Interpretation	Trend
NOV	-0.26	-119	748.1	< 0.0001	0.05	Reject	Decreasing
DEC	0.10	45	3525.2	0.459	0.05	Accept	NST
JAN	0.18	85	4459.8	0.208	0.05	Accept	NST
FEB	0.35	165	3623.8	0.006	0.05	Reject	Increasing
MAR	0.37	173	1690.7	< 0.0001	0.05	Reject	Increasing
APR	0.28	129	446.3	< 0.0001	0.05	Reject	Increasing
MAY	-0.03	-13	2067.7	0.792	0.05	Accept	NST
JUN	-0.20	-93	1767.9	0.029	0.05	Reject	Decreasing
JUL	-0.31	-143	2468.8	0.004	0.05	Reject	Decreasing
AUG	-0.35	-161	1600.5	< 0.0001	0.05	Reject	Decreasing
SEP	-0.54	-253	2771.9	< 0.0001	0.05	Reject	Decreasing
OCT	-0.43	-201	1421.5	< 0.0001	0.05	Reject	Decreasing

NST = No significant trend.

and homoscedasticity. Therefore, preliminary analyses were performed to ensure no violation of the assumption of normality, linearity and homoscedasticity. It was observed from the results that there is a large, negative correlation between the temperature and discharge, with r = - 0.604, n = 31, p = 0.0001. The relationship between these two variables is statistically significant. This means that with any increase in temperature, it will be associated with decrease in the amount of river discharge. As it has been observed that temperature is increasing in the area (Figure 3), this will lead to further reduction in discharge.

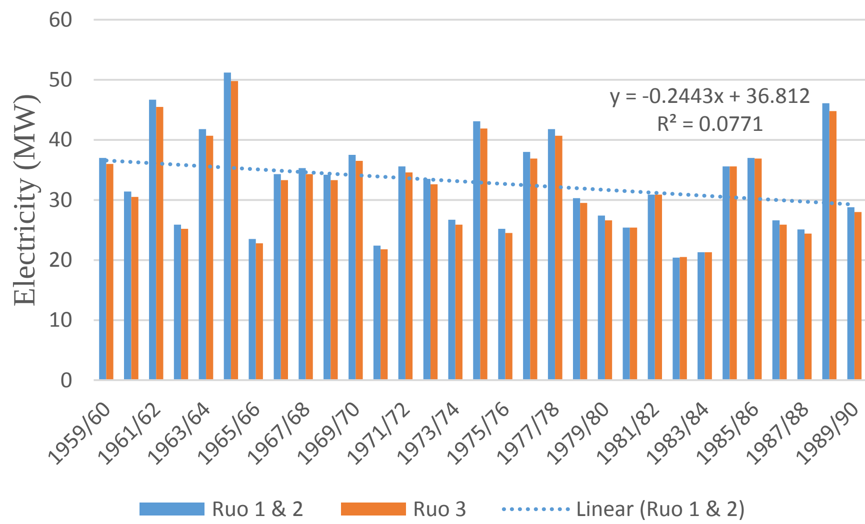

Figure 5. Estimated potential generated power from Ruo 1, 2 and 3.

Power generated

The potential monthly distribution of power generated from the plant was estimated by using Equation 2 and the results are shown in Figure 5. The trend for the annual distribution of potential generated power was also established. The results indicate that annually, the power generated will be decreasing by around 0.24 MW every year and this will have a negative impact on the operations of Lujeri Tea Estate. However, the actual power generated may likely be lower than the estimated results found in this analysis due to inadequate maintenances of the machines and that they were installed in early 1930's. It can also be observed that the pattern for this estimated potential power is analogous to Figure 5 since the annual mean discharge were used in the calculations. Therefore, the MK tests results for monthly discharge will play a greater role in the power that will be generated in future.

Conclusion

Climate change has the potential to affect hydropower generation by either increasing or reducing flows (discharge) and the head. This paper assessed the impacts of climate change on hydropower generation with a focus on Lujeri micro-hydropower scheme in Mulanje district, Malawi. The study analyzed trends in weather time series (air temperature and rainfall) data from 1980 to 2011 in connection with changes in river discharge and their associated impacts on hydropower generation profile. The Mann-Kendall (MK) test was used to detect trends in air temperature, precipitation and discharge. Correlation analysis was also used to uncover the relationship between discharge and precipitation as well as between discharge and temperature.

The MK results for monthly precipitation trend tests showed a mix of positive and negative trends with January, July and December depicting a positive trend and the rest of the months of the year showing negative trend. The increasing trend in precipitation for December was statistically significant ($p = 0.006$). Significant negative trend were detected in the months of February, April, May, June September, October and November; no significant trends were found for the other months; while the MK results on temperarture indicate that there is significant increasing trend for both mean monthly and mean maximum temperature. On the other hand, a mix of decrease and increase trend was obtained when the MK test was run to detect trend in monthly discharge. The results indicated that there was a positive trend in discharge in the months of January, February, March, April and December and all these months correspond to the rainy season. The increase in trend was significant for February, March and April. The results also indicated a statistically significant negative trend in discharge for the rest of the months of the year apart from May.

The annual rainfall distribution analysis showed a general decreasing trend with time. However, this annual rainfall change is not significant on the annual discharge. Hence, this could mean that there is no significant change in the annual hydroelectricity generated. Nevertheless, the analysis on the potential generated power revealed that there is a significant decrease in power annually. This is mainly attributed to the change in temperature. The relationship between the two variables (temperature and discharge) is significantly negatively correlated thus as temperature increases it will be associated with decrease in discharge. The analysis of temperature showed an increasing trend. Thus, the warmer temperatures will lead to increased evapo-transpiration in the rivers and in turn reduce discharge. As discharge is directly proportion to power generated, hence changes in climate will have a direct impact on hydropower thereby affecting hydropower generation. Therefore, proper adaptation measures such as standby alternative sources of energy, storage mechanisms devices and storage hydropower schemes should be exploited to ensure electric power is available throughout the year, especially in the hot and dry season when the discharge is usually very low.

Conflict of Interests

The author has not declared any conflict of interests.

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REFERENCES

ActionAid (2006). Climate change and smallholder farmers in Malawi: Understanding poor people's experiences in climate change adaptation. Retrieved from: https://www.actionaid.org.uk/sites/default/files/doc_lib/malawi_climate_change_report.pdf

Dhakal M (2011). Climate Change Impacts on Reservoir based Hydropower Generation in Nepal: A case study of Kulekhani Hydropower Plant (Master thesis, Pokhara University, Nepal). Retrieved from http://manjeet.com.np/wp-content/uploads/2012/03/CC-Impact-Reservoir-based-Hydropower-Generation-in-Nepal_Manjeet-Dhakal-2011.pdf

Harrison GP, Whittington HW, Gundry SW (1998). Climate Change Impacts On Hydroelectric Power. InPROC UNIV POWER ENG CONF. 1998 Sep 1:391-394.

Haarstad J, Jumbe CBL, Chinangwa S, Mponela P, Dalfelt A, Disch A (2009). Environmental and Socio-Economic Baseline Study – Malawi. Norwegian Agency for Development Cooperation. Retrieved from: https://www.norad.no/globalassets/import-2162015-80434-am/www.norad.no-ny/filarkiv/vedlegg-til-publikasjoner/environmental-and-socio-economic-baseline-study--malawi.pdf

Hamududu B, Killingtveit A (2006). Climate change impacts on Regional Runoff & Hydropower; the Case for East and Southern Africa. Retrieved from http://www.waternetonline.ihe.nl/symposium/10/full%20papers/Water%20and%20Environment/Hamududu%20B.docx

IPCC (2001). Climate Change 2001: Impacts, adaptation and vulnerability. Contribution of Working Group II to JJ McCarthy, OF Canziania, NA Leary, DJ Dokken and KS White. Cambridge, Cambridge University Press for Intergovernmental Panel on Climate Change.

IPCC (2007a). Climate Change: The Physical Science Basis: Summary for Policy Makers, Paris: IPCC, WMO, 2007.

IPCC (2007b). Climate Change: The Physical Science Basis; Contribution of Working Group I to the Forth Assessment Report of the Intergovernmental Panel on Climate Change; IPCC: Cambridge, UK.

Jain SK (2011). Climate Change and Hydropower Generation. Paper presented at IITD-CSE Conference, New Delhi. Retrieved from http://www.cseindia.org/userfiles/SharadJain.pdf

Koch F, Prasch M, Bach H, Mauser W, Appel F, Weber M (2011). How Will Hydroelectric Power Generation Develop under Climate Change Scenarios? A Case Study in the Upper Danube Basin. Energies 4:1508-1541.

Kreis and Steven (2001). The Origins of the Industrial Revolution in England, The history guide. http://www.historyguide.org/intellect/lecture17a.html

Magrath J, Sukali E (2009). The winds of change: Climate change, poverty and the environment in Malawi. Oxfam International.

McSweeney C, New M, Lizcano G (2011). UNDP Climate Change Country Profiles: Malawi. Retrieved from http://www.geog.ox.ac.uk/research/climate/projects/undp-cp/UNDP_reports/Malawi/Malawi.hires.report.pdf

Meijer LJJ, van der Ent RJ, Hoes OAC, Mondeel H, Pramana KER, van de Giesen NC (2012). World Hydropower Capacity Evaluation. Retrieved from: http://repository.tudelft.nl/assets/uuid:49d8d013-9a48-4222-85a1-0ebb53f83dc8/paper_hydropower_Lourens_Meijer_.pdf

Millennium Ecosystem Assessment (MA) (2005). International scientific assessment: ecosystem changes and human well-being. Retrieved from www.millenniumassessment.org

Ministry of Natural Resources and Environmental Affairs (MoNRE) (2002). Initial National Communication to the Conferences of Parties of the United Nation Framework Convention on Climate Change. Retrieved from http://unfccc.int/resource/docs/natc/mwinc1.pdf

Ministry of Natural Resources and Environmental Affairs (MoNRE) (2011). Second National Communication to the Conferences of Parties of the United Nation Framework Convention on Climate Change.

Nangoma D, Nangoma E (2008). Climate change and adaptation strategies: a case study of the Mulanje Mountain Forest Reserve and its surroundings. Retrieved from: http://pubs.iied.org/pdfs/G02311.pdf

Pathak M (2010). Climate Change: Uncertainty for Hydropower Development in Nepal. Retrieved from: http://www.nepjol.info/index.php/HN/article/download/4190/3564

Taulo JL, Mkandawire RW, Gondwe KJ (2008). Energy policy research baseline for Mulanje and Phalombe districts. Retrieved from: http://www.hedon.info/docs/E-MINDSET-EnergyBaselineReportForMulanje.pdf

United Nations Environmental Program/ Earths can (UNEP/Earthscan) (2002). Global Environmental Outlook 3. London: Earthscan.

USAID (2013). Malawi Climate Change Vulnerability Assessment. https://www.climatelinks.org/resources/malawi-climate-change-vulnerability-assessment-report-annexes

Vincent K., Dougill AJ, Mkwambisi DD, Cull T, Stringer LC, Chanika D (2014). Analysis of Existing Weather and Climate Information for Malawi. https://www.gov.uk/dfid-research-outputs/analysis-of-existing-weather-and-climate-information-for-malawi.

Yue S, Wang C (2004). The Mann-Kendall test modified by effective sample size to detect trend in serially correlated hydrological series. Water Resour. Manag. 18(3):201-218.

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