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Public health challenges as a result of contaminated water sources in Kumba, Cameroon

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Introduction

In the early twenty first (21st) century, unclean water was the world's second largest killer of children, especially under the age of five (WHO/UNICEF 2004). About 2.6 billion people lack access to adequate sanitation and acute diarrhea continues to exact a high toll on children in developing countries (WHO/UNICEF 2010). The provision of safe drinking water as well as water of acceptable quality in most part of Africa for human consumption remains a major challenge and threat to public health. Water is vital for sustainability of life and exposure to contaminated drinking water can be the source of large scale outbreaks of disease such as cholera, dysentery and cryptosporidiosis (Luffman, and Tran (2014). On a global scale, contamination of drinking water by pathogen poses the most significant health risk to humans and there have been several diseases outbreaks in the past resulting from the exposure to poorly treated drinking water (Ritter et al. 2002).

In Cameroon, water supply can only meet the needs of only 35% of city dwellers (Fouepe et al. 2011) such as Kumba, Douala, Yaounde, and Buea. Cases of water-borne diseases such as typhoid, cholera and amoebic dysentery are recurrent in most localities in Cameroon (Kuitcha et al. 2010) and these have been traced to the use of water from shallow, unprotected hand-dug wells. Between 2004 and 2006 on the average about 530 cases of cholera epidemics were reported in Banana plain of Mungo Division in Cameroon (GTZ 2008). Fonteh (2003) reported that in Cameroon, water-related diseases account for about two-third of all recorded diseases and is responsible for about 50% of reported cases of death. Studies from various parts of Cameroon, showed that many water sources used for drinking and domestic needs have alarming levels of microbiological contaminants (Ketchemen-Tandia et al. 2017; Magha et al.2015; Engstrom et al. 2015; Sorlini 2013; Takem et al. 2010;). Most available literature on element contamination of water in Cameroon (Ako et al. 2011; Kuitcha et al. 2008; Ndjama et al. 2008; Mafany et al. 2006; Fezu et al. 2006), focused on water quality assessment and distribution of fluoride in groundwater and incidence of fluorosis and optimal consumption dose (Fantong et al. 2010; 2013). However, there is scarcity of data on association of adverse effects on exposures to toxic trace elements in drinking water to human health. The few reported cases were on occurrence of As in drinking water in Ekondo Titi in southwest region (Lawrence et al. 1986; Mbotake 2006).

Water contaminated with toxic elements have negative effects on human health when they accumulate to levels that may exceed the acceptable limit for drinking and domestic uses (Radfard et al. 2018; Adamu et.al. 2015; Nganje et al. 2015; Mohammad et al. 2011; Edmund and Smedley.1996). Some trace elements (Cu, Cr, Mo, Ni, Se) are essential to humans at minimal level, while at higher levels, they are toxic. The long-term use of drinking water containing high levels of these contaminants may cause health problems. For example, exposure of contaminants such as As, Cd and Pb contamination is related to various diseases such as cancer related to non-cancer related. Exposure to low levels of these contaminants through time may pose serious health risk to humans (Radfarda et al. 2018). The toxicity and effects of these contaminants (pathogens and non-pathogens) and their exposure through ingestion of water in some parts of the world have been well documented (Ajibade et al. 2018; Radfard et al. 2018; Adamu et al. 2015; Nganje, et al.2015; O'Doyer et al.2014; Mohammad et al. 2013; Mohammad et al. 2011; Lugoli et al. 2011; Pitkanen et al. 2011; Ryan et al. 2010; Okonko et al.2008; Tamasi and Cini. (2004); Howard et al. 2003; Jordao et al. 2002; Hu 2002).

Kumba is the largest city in Southwest Region of Cameroon and due to rapid urbanization, was divided into three districts in 2010 viz: Kumba I, Kumba II and Kumba III. However, the area is characterized by high prevalence of water borne diseases due to the ingestion of poor quality water. This makes the supply and consumption of good quality water indispensable for preventing diseases and improving quality of life. Table 1 contains some incidences of various water-related disease from parts of the area of study. In 2012, there was scarcity of potable water in Kumba, due to objectionable taste and colour of pipe-borne water and this left the inhabitants in a desperate situation. The water crisis made the inhabitants to turn to natural springs, hand dug wells, bottled, sachet water and pipe borne water from surrounding localities with little or no knowledge on the quality of the water. Besides, less than 40% of the population have accessed to national potable water and adequate sanitation and hygiene due to the siting of pit latrines and discharging of waste near available water sources. These pit latrines are bound to discharge contaminants to water sources especially groundwater (Graham and Polizzotto 2013). Data on trace elements in Kumba has been documented by Ngole-Jeme et al. (2015). The study emphasized on the health risk of trace elements from unpaved road.

The objectives of the present study were to: (i) determine level of physicochemical and microbiological parameters of some potable sources in the Kumba area (ii) assess the quality of water and appraise the degree of contamination using some indices and (iii) assess the human health risk of drinking water from these sources. The present study, attempts to develop a baseline data base for future monitoring, while it is also expected that results of this study will be used by council planners for planning and utilization of water resources in the area, to improve on the quality of life and protect public health.

Materials and methods

Description of study area

Kumba and its environs are located in the South West region of Cameroon along the Cameroon volcanic line (CVL) between latitudes 3° and 4° North and longitudes 9° and 10° E (Fig 1). It has an estimated population of about 450,000 inhabitants from 2006 census. Kumba is a local road junction leading into neighbouring Nigeria, making it one of the main commercial towns in Cameroon. The area is located in the equatorial climatic region characterized by a dry and wet season. The dry season lasts from November to March, while the wet season lasts from April to September. It is drained by dendritic network of Meme River and its tributaries. Geologically the area is made up of Pan-African granite-gneissic which is overlain by Cretaceous-Cenozoic sandstone associated with basaltic lava flow and pyroclastic materials (Fig 1). Hydrogeologically, in adjacent areas, groundwater is found in pores, pyroclastic deposits, fissures and fractures (Nono and Lukong 2008). The most productive aquifers with yield in the range of 12 to 18 m³/h are around the Mount Cameroon region and are located in pyroclastic deposits (volcanic tuffs and scoria (Ako et al. 2011).

Sample collection and analysis

Sixty-four (64) water samples (Fig 1) were randomly collected between 2013 and 2014 following standard procedures (APHA) from four major water sources. The water sources include stream catchment/municipal reservoir (CW), pipe borne (PW), stream/spring (SW) and hand dug wells (HDW). Physical parameters including temperature, electrical conductivity (EC), pH and dissolved oxygen (DO) were determined in the field using portable field equipment. The samples were collected in polyethylene bottles, which were soaked in 10% HNO₃ for 24 hrs and rinsed several times with deionized water prior to use. At the sampling sites, the bottles were rinsed with the water samples prior to filling the bottles with the samples. Two sets of water samples were collected at each site. The samples were filtered through 0.45 µm membrane filters into sterilized polyethylene bottles. Samples collected for major and trace metal analysis were preserved by acidifying with a few drops of HNO₃ to achieve a pH of ≤ 2. The level of concentration of trace elements were determined using ICP-MS Elan 6000 and THERMO X-Series-200 at the Acme commercial laboratories, Canada and University of the West of Scotland in UK. **For trace elements analysis, high purity water was used for preparation of all solutions. The analytical precision was maintained by running known standards, blanks and duplicates after every ten (10) samples. Three replicates were run for each sample and the overall precision expressed as percent relative standard deviations (%RSD) and the overall data reproducibility was found within 5 %.**

For microbiological parameter, the water was collected in sterilized glass bottles and transported in ice chest to the laboratory for analyses. The water samples were kept at 4 °C in laboratory prior to analyses to avoid microbial activity. Bacteriological analyses were done in accordance with WHO standards (APHA 1998). The Multiple Tube/Most Probable Number was used to investigate the presence of coliform bacteria and the water samples graded as acceptable (low risk), unacceptable (high risk) or grossly polluted. The Standard Plate Count Method was used to estimate the quantity/ types of fecal coliforms present in the water samples and the results expressed as number of coliform forming units per milliliter (CFU/ml) of sample. The microbiology analyses were undertaken at the Department of Animal production, University of Dschang in Cameroon. **Triplicate determination of the samples were carried out and the data was presented as mean. For validation of the analytical procedure, repeated analysis of the samples against in house reference materials were used. The precision was also calculated as a percentage relative standard deviation (%RSD) of replicate analysis of the prepared standard, and was found to be less than 8%.**

Data Analyses and assessment method

Statistical analyses

Descriptive statistics were performed by means of the statistical package, STAISTICA (Pliz 1993) and excel spreadsheet. Correlation analyses showing the relation, association between the investigated elements for interpretation (Edet 2019). In addition, Principal Component Analysis (PCA) was applied to refine qualitative information on the most meaningful parameter which describe the whole data set interpretation, data reduction and summarize the statistical correlation with minimal loss of original information. The PCA describes the variations in a set of correlated variables with decreasing order of importance.

Species and saturation index

Mineral species and phases of As, Cd and Pb considered the most toxic and rank among the first ten on the toxicological profile for list of Toxic Substances Disease and Registry (ASTDR, 2015) were computed using the computer programme PHREEQC. This was to evaluate the contribution of mineral dissolution to highlight potential mineral controls on water chemistry by calculating the distribution of aqueous species and mineral saturation indices (Edet and Offiong 2002; Ako et al.2011). The Saturation Index (SI) indicates whether a particular water sample was either saturated or not with respect to a particular mineral.

$$Si = \log_{10} (IAP/KSP) \quad 1$$

Where Ksp = solubility product of at a given temperature and IAP = Ionic Activity Product.

Water quality and Contamination indices

Evaluation of water quality of the various water sources was carried out based on water quality index (WQI) as described by Asare-Domkor et al. (2018) and Edet and Offiong (2002). Each parameter was assigned a specific weight (w) based on their relative significance on water quality and relative weight (w_i) was evaluated as described below:

$$w_i = w / \sum_{i=1}^n W_i \quad 2$$

w = assigned weight of each parameter

W_i = sum of assigned weights of all the parameters and the number of parameters.

A maximum weight of 5 was assigned to total coliform (TC), pH, As, Pb, 4 for Cd and 3 for Al, Fe and Zn (Table 2). TC, As, Cd and Pb are of health significance (WHO 2008). Fe and Al are of aesthetic quality and Zn is an essential element with 3mg/l as maximum permissible limit and above these limits, they are toxic. The water quality calculations depend on the overall water quality using physical, chemical and biological parameters (Pius et al. 2012; Edet and Offiong 2002). The weightage scale was considered as the inverse of maximum concentration. World Health Organisation (2008) upper permissible limit for each parameter (Table 2) was used. The quality rating scale (q_i) for each of the water parameter was evaluated as:

$$Q_i = C_i / S_i * 100 \quad 3$$

Where C_i = concentration of each parameter, S_i = concentration of each parameter based on WHO (2008) and q_i = quality rating

$$S_i = W_i * q_i \quad 4$$

Where S_i = represent the sub index of the ith parameter

$$WQI = \sum S_i \quad 5$$

W_i = sum of assigned weight for all parameter

For overall water quality, WQI is classified as < 50.0 (Excellent); 50.1-100.0 (Good); 100.1-200.0 (Poor); 200.1-300.0 (Very poor) and > 300 (Unfit/unsafe).

The contamination index (C_d) relates the quality of water to human health risk and was calculated as (Edet and Offiong 2002):

$$C_d = \sum_{i=1} C_{fi} \quad 6$$

$$\text{where } C_{fi} = \frac{C_{Ai}}{C_{Ni}}$$

C_{fi} is contamination factor, C_{Ai} is the analytical value and C_{Ni} the upper permissible concentration of the ith component.

Only elements with analytical value above the maximum permissible concentration values were considered since concentrations of trace elements below this limit does not pose any hazardous problem to the quality of water. The calculated values are grouped into low ($C_d < 1$), medium ($C_d = 1-3$) and high ($C_d > 3$) contamination

The Trace Element Toxicity Index (TETI) was calculated as (Ali et al. 2017):

$$TETI = C_s * T_{si} \quad 7$$

Where C_s = concentration of the individual trace element and T_{si} = Total Score for each trace element obtained from the list of Hazardous Substances and Disease Registry (ASTDR, 2015). The calculated TETI proposed classification is as follows: very minimal ($TETI < 500$), low ($TETI = 500 - 1000$), moderate ($TETI = 1000 - 1500$), high ($TETI = 1500 - 2000$) and very high ($TETI > 2000$).

Human Health Risk Assessment

Risk of toxic trace elements in human health **was** assessed using average daily dose of the toxic trace element and this was used to estimate the health risk index to an exposed population. In this study, As, Cd and Pb which are considered toxic to human health through drinking of water was considered. The average daily dose (ADD) of the contaminant in the contaminated water will be calculated as presented below and as contained in Ngnaje et al (.2015). According to Paustenbach (2002), the average daily dose depicts the quantity of chemical substance ingested per kilogram of body weight per day and is given as:

$$ADD = C \times IR \times ED \times EF / BW \times AT \times 365 \quad 8$$

Where C is the concentration of the contaminant in drinking water (mg/l), IR is the ingestion rate per unit time (L/day), 2L; ED is the exposure duration (years), 30years; EF is the exposure frequency (days/year), 350; BW is body weight (kg), 60kg; AT is the average time (years) and 365 is the conversion factor from year to days.

Exposure assessment identifies the pathways by which humans are potentially exposed to toxicants and estimates the magnitude, frequency and duration of these actual and /or potential exposures. Contaminants such as As, Cd and Pb are considered as trace elements which are hazardous to human health. The health risk from consumption of contaminated water by the people of Kumba from hand dug wells, pipe-borne and stream water was assessed in relation to its non-carcinogenic as well as carcinogenic effects based on the calculation of ADD estimates and defined toxicity for each toxic trace element according to the following relationships;

Non-cancer risk was evaluated as shown below:

$$HQ = ADD / RfD \quad 9$$

Toxic risks refer to the non-carcinogenic harms incurred due to exposures. The extent of the harm is indicated in terms of hazard quotient (HQ), RfD is the reference dose. The reference dose is the daily dosage that enables the exposed individual to sustain this level of exposure over a prolonged time period without experiencing any harmful effect. The US EPA IRIS (Integrated Risk Information System) is the most frequently used RfD data. When more than one potential toxicant is present, the interaction is considered. The toxic risk due to potentially hazardous substances present in the same media are assumed to be additive.

The HQs are then summed to arrive at the overall toxic risk, the hazard risk index (HRI)

$$HRI = \sum HQ_i \quad i = 1 \dots n \quad 10$$

HRI is the hazard index for overall toxic risk. If the calculated HI is less than 1.0, the non-carcinogenic adverse effect due to drinking water is assumed to be negligible.

Results and discussion

Physicochemical parameters and trace elements

Statistical summary of physicochemical parameters and trace elements are presented in Table 3, while detailed results are presented in Appendix 1. Generally, the temperature, electrical conductivity (EC), total dissolved solids (TDS), Turbidity and total hardness (TH) for the different water sources are within WHO recommended guidelines for drinking water quality. The mean value for DO for all the water sources were below the WHO (2008) recommended limit of 5mg/l. The TDS (17.78-67.00 mg/l) showed that the water is not saline. The pH is slightly below the recommended limit of 6.5 – 8.5 depicting the water is mildly to slightly acidic with mean pH in the range of 4.3 – 6.6. The lowest and highest pH values were obtained from surface water (SW) and reservoir/catchment (CW). The acidic nature or low pH of the water may be associated with decayed vegetation, breakdown of the rocks especially granite, sandstone and ash (Fig. 1) releasing H_4SiO_4 in the water. In addition, sandstone is the major aquiferous unit in the area. Acidic nature of the pipeborne water (PW) may be due to the acidic nature of the source water. The corrosiveness (Boughton and McCoy 2006) of water to pipes and plumbing increases as the pH decreases. Pathogen survivals and metal solubility can be affected by pH changes in sensitive people (Khan et al.2013; Mohammad et al. 2011).

The average values of Al, Fe and Pb for all the water samples were respectively above the maximum acceptable limits (MAL) of 200µg/l, 300µg/l and 10µg/l set by the World Health Organisation (WHO 2008). The concentrations of these elements which exceeded the permissible level could be toxic even though Al and Fe may be present in non-labile forms. The Al remained mobile within the groundwater probably as a result of microbial mediated organic complexing (Bowell et al. 1996). The role of microorganisms in the mobilization of Al in deeply weathered profiles of the African soils as well as Al leaching from kaolinite into ground waters in Tanzania by the action of indigenous population of microorganisms have been reported by Mcfarlane and Bowden (1992); Bowell et al. (1996).

The highest mean values of Al, As, Cd, Cr, Cu, Fe, Pb, Si, Sr, V and Zn were obtained from groundwater (HDW) with the maximum values from Location G 38, while the highest mean values of Co and Mn were obtained from SW and Mo from CW respectively. Location 38 is in direct contact with the weathered bedrock. The highest mean and maximum values of these parameters obtained from HDW (groundwater) may be attributed to the long residence time in the water with the aquifer materials and the acidic nature of the water which keeps the elements in solution. The mobility of element and release rate is dependent on changes in the pH and redox conditions from natural processes like microbial activity or anthropogenic activities (Smedley and Kinniburgh 2002). The high concentration of these elements may be geogenic associated with the dissolution of the bedrock. Locations G 27, G 28, G 29, G 30 and G 31 had values of Ni above the recommended level of 20 µg/l, since these locations are not associated by any mining operations, the major source of the Ni could be natural from the underlying basaltic lava flow (Fig 1). Ni has been considered by WHO (2008) to be of health significance and the International Agency for Research on Cancer (IARC 1987) has determined that some nickel compounds are carcinogenic to humans and that metallic nickel may possibly be carcinogenic to humans. The people in this region are mostly low income earners that could not afford the cost of pipe borne water. They depend on these sources of water for domestic purposes such as bathing so they may probably suffer from skin rash due to exposure to nickel. Skin contact with metallic or soluble nickel compounds can produce allergic dermatitis (Duda-Chodak and Blaszczyk 2008). Only locations G 40 and G 45 had values for Mn of 550 and 330µg/l respectively above the recommended limit. The possible source of the Mn may be anthropogenic probably from waste dump sites. High Al and Fe levels are of significance to water quality as they have impact on the aesthetic quality in terms of taste and colour, while As, Cd, Mn, Ni, Mo and Pb are of health significance as recommended by WHO (2008). Pipe borne water (PW) recorded the lowest mean values of As (2.14 µg/l), Cd (1.03 µg/l), Co (1.79 µg/l), Cu (149.69 µg/l) and Mn (93.86 µg/l). Catchment water (CW) recorded the lowest mean values of Al (410 µg/l) and Zn (115.54 µg/l), while SW recorded the lowest mean values of Al (540 µg/l), Mo (0.26 µg/l), Pb (23.93 µg/l), Si (4638 µg/l), Sr (50.16 µg/l) and V (1.47 µg/l).

About 50% of the minimum values of Al, As, Cd, Cr, Fe, Mn, Mo and V were from SW, follow with about 40% of Co, Ni, Si, and Zn from PW and 10% of Pb and Sr from CW. The low concentration obtained from SW may be due to the short residence time of the water with the bedrock. Maximum concentrations of Mn (5140 µg/l) and Ni (70. µg/l) in 8% of the water samples were higher than their various maximum acceptable values. The maximum concentrations were obtained from surface water (SW). Exposure of the local population of Kumba to low levels of As, Cd, and Pb over time may cause health problem. Parviainen et al. (2015) suggested that long-term use of drinking water containing high concentrations of As poses risks to human health. Mo, Ni, Si, Sr, and V are not commonly detected in water. Si, Sr and V are not listed by WHO (2008) guidance but their occurrences in all the water samples are of significant concern as they can impact on the water quality. V can induce genotoxicity and irritation of the respiratory tract (Costigan et al. 2001). Substantial amount of Si is registered in all the samples with G 38 having the highest concentration. The occurrences of Si may be attributed to the dissolution of silicate bearing bedrocks of the study area. The major species (Table 4) with more than 50% content include Cd^{2+} (99%), $\text{H}_2\text{AsO}_4^{2-}$ (71.15%) and Pb^{2+} (62.18%) indicating that the water conditions are such that the inhabitants of the study area are exposed to the toxic elements through a significant soluble component of these elements.

Microbiological parameters

The mean value for total coliform (TC) (Table 3, Appendix 2) is 133.25 ± 74.31 CFU/100ml (CW), 22.57 ± 8.36 CFU/100ml (PW), 75.60 ± 59.4 CFU/100ml (SW) and 8.40 ± 3.36 CFU/100ml (HDW). The mean TC from all the water sources except hand-dug wells were above the WHO recommended limits of 10 CFU/100ml.

Specific microbes isolated were Enterobacteria, *Escherichia coli* (E-coli), *Streptococcus* and *Salmonella/shigella* (Table 3) were high. The (WHO 2008) recommended keeping the number as low as possible. The presence of total coliform (TC) and identify microbes are indication of anthropogenic contamination mainly from feces. In addition, the presences of E-coli and other microorganisms in the various water sources indicates the presences of fecal contamination (Ajibade 2018; Boughton and McCoy 2006) and can cause health problems to humans depicting high risk of water contamination by fecal pathogens. These fecal coliforms are pathogens known to cause water borne diseases and are indications of anthropogenic contamination probably from unlined pit latrines, septic tanks, surface drains, animal waste and waste dumps sites, some of which are located less than 30m from the water sources in the study area. Siting of pit latrines and waste dump sites less than 30m from water sources is a common practice in the study area in particular and sub-urban communities in Cameroon in general (Tanawa et al. 2002; Takem et al. 2010).

The contamination of HDW by micro-organisms may be explained by the sandy and shallow nature of aquifer which are mostly less than 10m making the water susceptible to frequent contamination by microbiological organisms from nearby pit latrines and septic tanks. Most of the HDW are located without consideration to the groundwater flow direction and this is hazardous as they may be contaminated from the same source and aquifer. As reported by Takem et al. 2010 for informal settlements of Douala, Cameroon, the microbial load may come from many sources such as subsurface leaching from nearby pit latrines, direct washing of fecal material from waste dumps and feces disposed of reckless which are all mixed and wash directly into springs. Additional sources of microbial contamination in the area of study, may be due to direct runoff of fecal material from waste dump and disposal of feces which drains directly into the SW bodies. Shallow water aquifer is very sensitive to human activities due to shallow water level, dumping of wastes into open wells and contamination through surface run off into the wells (Edet 2019).

Correlation, principal component analyses and factor analyses

Correlation matrices of physicochemical parameters for the different water sources are presented as Table 5 with correlation coefficient (r) >0.50 , $P < 0.05$ are shown to be good correlation. The correlation showed both good and poor correlation among various parameters. The good correlation with physical parameters and trace elements such as Al, Cd, Co, Cr, Fe, Pb, with temp, EC with As, Co, Pb and pH with Cu, Mn, Mo, Pb and Zn depicts the contribution of the environmental factors on the composition of the water. Good correlation ($r > 0.5$, $p < 0.05$) reflect concentration effect, while good negative correlation ($r > -0.5$, $p < 0.05$) reflects dilution and effects of environmental parameters on these elements. The positive correlations among the trace elements for the various water sources (CW, PW, SW and HDW), implies their common sources and similar fluvio-geochemical behavior such as water rock interaction, silicates weathering, from the basement rocks, volcanic rocks and associated products. The negative correlations between the elements indicates antithetic relationships. The relative low r -values obtained for PW indicates anthropogenic influence.

Correlation analysis (Table 6) of total coliform (TC) and the microbes with DO show poor correlation. Enterobacteria E-coli, streptococcus and salmonella/shigella show weak correlation with TC with r value in the range of 0.34-0.49. E-coli streptococcus and salmonella show good correlation with Enterobacteria with r values of 0.87, 0.71 and 0.66 respectively. Streptococcus show a good correlation with E-coli and salmonella/shigella with r values of 0.56 and 0.51 respectively at $p < 0.05$. The good correlation between the microbes indicate their common sources. Streptococcus is a sign of recent fecal contamination (Ajibade 2018).

Principal component analysis (PCA) was performed for the various water sources grouped together using the physical, chemical and microbiological parameters. Principal Component Analysis of the analytical parameters with varimax rotation eigen values >1 are presented in Table 7. PCA 1 showed 32.5% of the total variance with high loadings for Al, As, Cd, Co, Cr, Cu, Fe, Mo, Ni and Pb reflects the main potentially toxic elements (PTE) signature indicative of bedrock geology. As, Cd, Co, Cr, Cu, Mo, Ni and Pb are chalcophilic in nature while, Al and Fe are lithophilic in character depicting their volcanic and crustal sources (Manson and Moore 1982). PCA 2 has 14.0% with high loading for Enterobacteria, E-Coli, Streptococcus and Salmonella/Shigella. The possible source of these parameters may be due to anthropogenic inputs possibly from unlined pit latrines, sewage and landfill drainage. PCA 3 has 10.0% with high negative loadings for EC, turbidity, TH and DO while PCA 4 has 7.4% of total variance with high negative loading for Si and Sr indicating their antithetic relationships. PCA 5 accounts for 6.9% of data variance with high loading for temperature, Al, V

and Zn suggesting the control of environmental factors on weathering and decomposition of rocks as a result of high temperature and rainfall.

Assessment of level of contamination

Water Quality Index (WQI) and Contamination Index (C_d)

Calculated WQ indices used for assessment of water quality is presented in Figure 2. The water quality index showed that about 75% of water samples from the CW areas with the highest value recorded in location C4 were unsafe for consumption, while that of C1 is of good quality water and this represent 25% of the water samples. 57.1% of the PW samples were in the class of good quality water which implies that it is good for consumption, while 42.8% are in the poor class with the highest value from P2. In the case of SW, 40% of the samples were in the class of good and very poor quality, while 20% are in poor class. For HDW, 2.1% are in the excellent class, 62.5% in good class, 14.5% in poor class, 6.3% in very poor class and 8.3% in unfit class. The highest value for WQI of 371.3% was obtained from location G27. Only location G14 is in the excellent class with value of 34.6% for HDW. These results suggest that the quality of HDW is better than that of CW, PW and SW. Generally, the water quality index showed more than 85% of the water samples are of poor quality. Oral ingestion of water classified as poor, very poor and unsafe water are likely due to the presence of coliforms and microorganisms and can adversely affect the health of humans in the area of study.

Contamination index (Figure 3) calculated for water samples from all the locations are in the high level class with the highest value of C_d of 946.6 from location G38. The exceptions include P3, P6, P7 and G14, which are classified as moderate. The high level of contamination may be due to high of concentration of Al, Fe, Mn, and Pb. Location G38 with the highest C_d value had the highest concentration of Al, Fe, Mn and Pb. Thus, the water is generally impacted with these elements as shown in Table 3 and Appendix 1. All the locations had the concentration of Al, Fe, and Mn above the maximum permissible level as recommended by WHO (2008).

Trace elements toxicological index (TETI) presented in Figure 4 depicted that Location G 38 had the highest TETI and is consider as the highest risk site with significant impact from Al, Pb, Fe and Mn. HDW recorded the highest TETI and the lowest value was obtained from PW. In terms of the water sources, the TETI is in the order HDW>SW>CW>PW. 1.2% of the water are in the class of very minimal toxicity, 45.1% in low toxicity, 16% in moderate toxicity, 6.3% in the class of high toxicity and 21.9% in the class of very high toxicity. Trace elements toxicological index in each location showed that Al, had the significant impact on the quality of water. Fe, Mn, and Pb show considerable impact with location 38 having the highest risk sites.

Microbiological characteristics and assessment

In terms of total coliform (TC), about 74 % of the contaminated water samples are in the class of high risk to grossly polluted (Appendix 2). The order of TC contamination is CW > PW > SW > HDW and for the identified pathogens is SW > CW > PW > HDW. All the water samples investigated revealed contamination mainly with bacteria like *E. coli*, *Shigella* spp., *Enterobacter* spp., *Streptococcus* spp., and *Salmonella* spp., which are potential pathogens. These pathogens alongside with *Vibrio cholerae*, *Yersinia enterocolitica*, *Campylobacter jejuni* and *Campylobacter coli* are considered as the bacteria that pose a serious disease risk whenever present in drinking water (WHO 2006). Also, the presence of *E. coli* in water is nearly always associated with recent fecal pollution, which may pose an immediate health risk to anyone consuming the water (Eaton et al., 2005; WHO, 2007). E-coli can also cause acute renal failure and hemolytic anemia and wells with high coliforms count were indicators of high organic loads and indices of pollution from leachates, seepages from waste dump sites within the vicinity of these water sources and infiltration into storage from run off. However, the bacterial loads were least in water samples graded as acceptable with low health risk and high for water samples classify as grossly polluted with high risk to human health. Failure to protect water sources, especially groundwater along with inadequate water treatment are the primary reasons for bacterial contamination of drinking water in the area of study. Increase in microbial activity may influence the mobility of certain elements in aquifer through variety of geochemical mechanism (Bowell et al.1996) and these have health implications when water is extracted for drinking. Mobilization of metals by microorganisms can be achieved through autotrophic and heterotrophic leaching, chelation by microbial metabolite siderophores and methylation which can result in volatilization (Gadd 2004). Such processes can lead to dissolution of insoluble metal compounds and minerals as well as desorption from exchangeable sites (clay minerals). Fe and Mn can be oxidized by certain heterotrophic bacteria as part of their normal physiological processes (Bowell et al, 1996).

Human risk assessment

In this study, ingestion of contaminants through drinking water is the major exposure pathways and is important in assessing risk to humans (Gupta and Sinha 2009) and the intake assessment depends on the concentration of the toxic elements in water that is consumed. In terms of toxic trace elements, Pb is the major contaminants that exceeded the acceptable quality of drinking water in all locations with few locations having As and Cd concentrations above the permissible level. The daily intake (ADD), Hazard quotient (HQ) and Hazard risk index (HRI) are presented in Tables 8. With the exceptions of locations GW 38 for HDW with HQ values of 184.41 (As), Cd (12.91) and Pb (38.53), the ADD and HQ values were <1 for the various water sources exposure pathways implying that generally, there is minimal non-cancer risk due to ingestion of the water from Kumba. The results of HRI (Table 8) showed that HDW offer more risk with locations G15, G21 and G38 having values of 1.16, 1.15 and 238.84 > 1 indicating that the residents of these areas may be exposed to non-cancer adverse effect due to cumulative effect through time from ingestion of the contaminated water. The implication for the highest concentrations of these toxic elements in HDW is that the inhabitants drinking water from this well may be exposed to serious health risk and therefore require monitoring. It was observed during sampling that, due to scarcity of potable water, people occasionally drink water from these well regardless of its poor quality. The risk based on HRI for the different water sources is in the order HDW $>$ PW $>$ CW $>$ SW. The As cancer risk through ingestion of water does not exceed the recommended level of 1 in 10000 (0.0001), computed as ADD/SF, for regulatory purposes (Table 8). Since the majority of the people in the study area are mostly farmers and low income earners, they should be guided about the consequences of ingestion of water loaded with elevated concentrations of elements due to high level of intake. For management purposes, water sources, especially those ingested by humans in Kumba should be regularly treated and properly managed so as to protect the health of humans and domestic animals

Conclusion

The water sources are contaminated with Al, Fe and Pb and are exposed to low levels of some potentially toxic elements (As, Cd, Cu, Mn) which are of significance to human health. As and Cd are non-essential trace elements and are not required by humans even at minimal concentrations. Chronic exposure to low levels of As may result to usual pattern of skin hyperpigmentation, cancer and damage to internal organs. Cu and Mn are essential trace elements to humans but above their maximum allowable limits they are toxic. Daily intake of Cu above the recommended level in drinking water can result to gastric irritation and Mn toxicity in humans can lead to neurological disorder and impaired memory. The main chemical species are predicted to be Cd^{2+} , $\text{H}_2\text{AsO}_4^{2-}$ and Pb^{2+} and they provide major risk factors for the water exposure pathways. Correlation and Principal Component Analysis indicated a common source for the contaminants and principal component analysis showed five factors that were related to geogenic and anthropogenic inputs.

Water quality, contamination and trace elements toxicological indices highlight that most of the water sources are polluted and are poor, unsafe and of high risk for drinking and domestic uses. The water quality index showed more than 85% of the water samples are of poor quality with about 75% of water samples from the CW areas unsafe for consumption. The local population of Kumba are significantly exposed to microbial contamination with about 74% of the water samples in the class of grossly polluted depicting high risk to human health. The order of TC contamination is CW $>$ SW $>$ PW $>$ HDW with CW being the source of contamination of PW.

Human health risk assessment showed that the ADD, HQ and HRI for As, Cd and Pb for exposed individuals in the Kumba area were less than 1 for most of water and greater than 1 for some locations, which constitute about 4.62% of all the locations. The risk based on TETI and HRI for the different water sources is in the order HDW $>$ PW $>$ CW $>$ SW. The local population of Kumba should be educated on the relevance of treating their water so as to prevent health hazards associated with water related diseases. Water sources for drinking should be regularly treated and properly managed so as to protect the health of humans and to reduce mortality rates from water related diseases. Hence the present study serves as a baseline data base for future monitoring and is expected to be used for management of water resources in the area, to improve and protect public health.

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References

Abbas, A., & Amir, H., Mahvi, F.A. (2018). Drinking water quality and arsenic health risk assessment in Sistannad Baluchestan, Southwestern Province, Iran. *Human and Ecological Risk Assessment*, 0(0), 1–18. <https://doi.org/10.1080/10807039.2018.1458210>

Adamu, C., Nganje, T. N., & Edet, A. (2015). Heavy metal contamination and health risk assessment associated with abandoned barite mines in Cross River State, southeastern Nigeria. *Environmental Nanotechnology Monitoring and Management*, 3, 10–21.

Agency for toxic substances & Disease Registry (ASTDR). (2018). Toxicological Profile for hazardous substances. US Department of Health and Human Service Atlanta, GA

Ajibade, O.S., Adewuyi, G. K., & Ogunjobi, G. .A .(2018). Microbiology Assessment of groundwater from Hand dug wells in Igbo-Ora, Ibarapa Central Local Government area, Oyo State, Southwestern Nigeria. *Science & Engineering Investigations*, 7(75), 78-84

APHA. (1998). Standard methods for the examination of water and wastewater. 20th Ed., Washington D.C: American Public Health Association.

Ako, A.A., Shimada, Y., Hosmo, T., Ichianagi, k., Nkeng, G.E., Fantong, W. Y., Takem, G.E.E & Roger N.N. (2011). Evaluation of groundwater quality and its suitability for drinking, cosmetic and agricultural uses in the Banana Plain (Mbanga, Njumbé, Penja) of the Cameroon Volcanic Line. *Environmental Geochemistry and Health*, 33, 559-259.

Ako, A.A., Nkeng, G.E., & Takem, G.E.E. (2008). Water quality and occurrence of water borne diseases in the Douala 4th district, Cameroon. *Water Science and Technology*. Ref.NO.WM 046.

Ali, A., Strezoy, V., Davies, P., & Write, I. (2017). Environmental Impact of coal mining and coal seam gas production in surface water quality in the Sydney basin, Australian. *Environmental Monitoring and Assessment*, 189 (408), 2-16.

Asare-Donkor, N.K, Ofosu, Y.O., & Adimado, A.A. (2018) Hydrochemical Characteristics of Surface water and ecological risk assessment of sediments from settlements within the Birm River basin in Ghana. *Environmental System Research*, 7(9), 1-17.

Boughton, C.J., & McCoy, K. J. (2006). Hydrogeology, aquifer geochemistry and groundwater quality in Morgan County, West Virginia. West Virginia Conservation Agency and the eastern Panhandle Conservation district, Scientific Investigations report 5198, 1-36.

Bowell, R.J., Mceldowney, S., Warren, A., Mathew, B., & Bwankuzo, M. (1996). Biogeochemical factors affecting groundwater quality in central Tanzania In Appleton, J.D., Fuge, R., McCall, G.J. (eds) *Environmental Geochemistry and Health with reference to developing countries*. Geological Society Special Publication. 113, 107 – 130.

Costigan, M., Cary, R., Dobson, S. (2001). Vanadium Pentoxide and other inorganic Vanadium compounds. *Consise International Chemical Assessment Document* 29, Wealth Organisation, pp 1-69

Duda-Chodak, A., & Blaszczyk, U. (2008). Review paper on the impact of nickel on human health. *Journal of Elementol.* 13(4), 685-696

Eaton, A.D., Clesceri, L.S., Rice E.W., Greenberg A.E., Franson, M.A.H. (2005). *Standard Methods for the Examination of Water and Wastewater*. 21st Edn, Washington D.C, American Public Health Association.

Edet, A.E, (2019). Seasonal and spatio-temporal patterns, evolution and quality of groundwater in cross River State, Nigeria: Implications for groundwater management, *Sustainable Water Resources Management*, 5, 667-686

- Edet A.E., & Offiong. O.E. (2002). Evaluation of water quality pollution indices for heavy metal contamination monitoring. A case study from Akpabuyo - Odukpani area. lower Cross River Basin, Southeastern Nigeria. *Geojournal*, 57, 295-304.
- Edmund., W.M., & Smedley,P.L. (1996). Groundwater geochemistry and health overview. In S.P, Appleton Fuge R and McCall,G.S.H (Eds), *Environmental Geochemistry and Health with reference to developing countries*. Geological Society special publication,113, (pp. 91 – 106).
- Engshrom, E., Balton, B., Morberg, U., Thunyik, R., Geuly, T., & Mangolde, M. (2015). Prevalence of microbiological contamination in groundwater sources & risk factor assessment in Juba South Sudan. *Science of the Total Environment*, 515-516, 181-187
- Fantong, W.Y., Satake,H., Ayonghe,S.N.,Suh,C.E.,Adelena, S.M.A.,Fantong,E.B.S., Banseka, K.A., Uehara, Y., Gwanfogbe, C.D., Woincham,, L.N., & Zhang, Y. (2010). Geochemical provenance and spatial distribution of fluoride in groundwater of Mayo Tsanaga River Basin, Far North region Cameroon: Implications for incidence of fluorosis and optimal consumption dose. *Environmental geochemistry & Health*, 32, 147-163
- Fantong, W.Y., Fouepe, A.T., Njomou, S.L.B., Banseka, H.S., Katsuro, A., Adelena, S.M.A., Mendjo, J.W., Aka, F.T., Ohba, T., Hell, J.V., & Nkeng, G.E. (2013). Temporal pollution by nitrate (NO₃), and discharge of springs in shallow crystalline aquifers: Case of Akok Ndoe catchment, Yaounde (Cameroon). *African Journal of Environmental Science and Technology*, 7(5), 175-191.
- Fezu, W.M.L., Ngassoum, M.B., & Mbofung, C.F.M. (2006). Physico Chemical properties of Spring/Mineral waters commonly used by grazing animals' cattle in Wakwa (Cameroon). *Journal of Animal & Veterinary Advances*, 5(9), 718 – 386
- Fowler, B.A., Chou, S.J., Jones, R.L., Sullivan, D.W., & Chen, C. J. (2015). Arsenic, In: In:G.F. Nordberg; B.A, Fowler; Nordberg, M (Eds), *Handbook on the toxicology of metals* (pp. 581-624). Elsevier
- Fonteh, M. F (2003). Water for all and the environment. The United Nations-Cameroon Water Development Report. United Nations Economics Commission for Africa. Addis Ababa, Ethiopia.
- Fouepe, T, A., Ndam, J.R., Riotte,J., Takem, G.E., Mafany, G.T., Marechal, J.C., & Ekodeck, G.E. (2011). Estimation of groundwater recharge of shallow aquifer on humid environment in Yaounde, Cameroon using hybrid water-fluctuation and hydrochemistry methods. *Environmental Earth Science*, DOI:10.1007/s12665-0-0822-4.
- Gadd, G.M. (2004). Microbial influence on metal mobility and application for bioremediation. *Geoderma*, 122, 109-119.
- Graham, J.P., & Polizzotto, M.L. (2013). Pit latrines and their impacts on groundwater quality: a systematic review. *Environmental Health and Perspectives*, 121(5), 521 – 530).
- German Technical Cooperation (GTZ 2008). Project pour l' ameliolation de l'accès a l'eau potable et de l'assainissement de base dans les trios communes rurales de Manjo, Loum et Penja/Njombe, Province de Littoral- Camerooun.Doula – Cameroon.
- International Agency for Research on Cancer (IARC 1987). Overall evaluations of carcinogenicity: an updating of IARC monographs, 1–42, Lyon, 226 (IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Suppl. 7).
- Jordao, C., Pereira, M., & Bellato, C. (2002). Assessment of water systems for contaminants from domestic and industrial sewages. *Environmental Monitoring and Assessment*, 79:75–100. doi:10.1023/A:1020085813555
- Khan, M.U., Malik, R.N., & Mohammed, S. (2013). Human health risk assessment from heavy metal via food crops consumption with wastewater irrigation practices in Pakistan. *Chemosphere*, 93,2230 - 2238
- Jordao, C., Pereira, M., & Bellato, C. (2002). Assessment of water systems for contaminants from domestic and industrial sewages. *Environmental Monitoring and Assessment*, 79:75–100. doi:10.1023/A:1020085813555

- Ketchemen - Tandia, B., Boum - Nkot, S.N., Ebondji, S.R., Nlend, B.Y., Emvoutou, H. & Nzegue, O. (2017). Factors Influencing the Shallow Groundwater Quality in Four Districts with Different Characteristics in Urban Area, Douala, Cameroon. *Journal of Geoscience and Environment Protection*, 5, 99-120.
- Kuitcha, D., Kamgong, K.B.V., Sigha, N.L., Lienou, G., & Ekodeck, G.E (2008). Water supply sanitation and health risks in Yaounde, Cameroon. *African Journal of Environmental Science & Technology*, 2(11), 379-386
- Howard, G., Pedley, S., Barret, M., Nalubega, M., & Jobal, K. (2003). Risk factors contributing to microbiological contamination of shallow groundwater in kampala, Uganda. *Water Resources*, 371, 3421-3429.
- Hu, H. (2002). Human health and heavy metals exposure In: M. McCally (Ed), *Life support: The environment and human health* (pp.1 – 10). New York: MIT press.
- Lawrence, A, R 1986, report on a visit to the Cameroun, 10-24 Sept 1986
- Lugoli, F., Leopizi, M.I., Bagordo, F., Grassi, T., Gurdo M., & De Donno, A. (2011). Widespread Microbiological groundwater contamination in the South-Eastern Salento, (Apulia – Italy). *Journal of Environmental Monitoring*, (13), 292. DoI 10-1039/COEM00193
- Luoma, S. (2015). Arsenic in bedrock, soil, and groundwater-The first arsenic guidelines for aggregate production established in Finland. *Earth Science Reviews*, 150, 709-723.
- Luffman, I., & Tran, L. (2014). Risk factor for E-coli 0157 and Cryptosporidiosis infection in individuals in the karst valleys of East Tennessee, USA, *Geosciences*, 4, 202-218
- Mafany, G.T., Fantong, W.T., & Nkeng, G.E. (2006). Quality of groundwater in Cameroon and its vulnerability to pollution, In: X. Yang & U. Brent (Eds), *Groundwater pollution in Africa*, (pp 47-55), Balkema, The Netherlands: Taylor and Francis
- Magha, A., Awah, T. M., Nono, K. D. G., Wotchoko, P., Tabot, A. M., & Kabeyene, K.V. (2015). Physico-Chemical and Bacteriological Characterization of spring and Well Water in Bamenda III (NW Region, Cameroon). *American Journal of Environmental Protection*, 4(3), 163-173.
- Mafarlane, M.J., & Bowden, D.J. (1996). Mobilisation of aluminium in the weathering of profiles of the African surface in Malawi. *Earth Surface Processes and Landforms*, 17, 789-205
- Mason, B., & Moore, C. (1982). *Principles of geochemistry*, New York: John Wiley and sons.
- Mbotake, T.I. (2006). A preliminary study of sources of arsenic contamination in South West Cameroon. *Journal of Environmental Hydrology*, 14, 1-11
- Mohammad, R., Mohebbi, A., Reza, S. B., Ahmad, M. A., Kooshari, A.V., Sharareh, L., Sogol, O., Mehrnoosh, A. C., & Azita, M. (2013) Assessment of water quality in groundwater resources of Iran using a modified drinking water quality index (DWQI). *Ecological Indicators* (30): 28 -34.
- Mohammad, S., Shah, M.T., & Khan, S. (2011). Health risk assessment of heavy metals and their source apportionment in drinking water of Kohistan region, Northern Pakistan. *Microchemistry Journal*, 98, 334-343
- Ndjama, Y., Kamgang, K.B.V., Sigha, N.L., Ekodeck, G.E., & Tita, M. A. (2008). Water supply, Sanitation, and health risk in Douala, Cameroon, *African Journal of Environmental Science & Technology*, 2(11) 432-429
- Nganje, T.N., Hursthouse, A.S., Edet, A., Stirling, D., & Adamu, C.I. (2015). Assessment of the health risk, aesthetic and agricultural quality of rain water, surface water and groundwater in shale bedrock areas of southeastern Nigeria. *Water Quality, Exposure and Health*. 7(2), 153–178.
- Njitchoua, R., Dever, L., Fontes, J.C.H., & Naah, E. (1997). Geochemistry, Origin and recharge Mechanism of groundwater from the Garoua Sandstone aquifer, Northern Cameroon. *Journal of hydrology*, 190:123-140
- Ngole-Jeme, V.M. (2016). Heavy metals in soils along unpaved roads in south west Cameroon. *Contamination levels & health risk. Ambio*, 45 (3), 374-386

- O'Dwyer J., Douling, A., & Adley C.C. (2014). Microbiological assessment of private groundwater derived potable water supplies in the mid-west region of Ireland. *Journal of Water & Health*, 2, 310-317
- Okonko, O., Adeyaye, O.D., Orunnusi, T.A., Fajobi, E.A & Shituh, O.B. (2008) Microbiological & physiochemical analysis of different water supplies used for domestic purposes in Abeokuta and Ojota, Lagos state Nigeria. *African journal of Biotechnology*, 7(5), 617-621
- Pathek, D.R., Hiratsuka, A., & Awata, I. (2009). Assessment of nitrate contamination in groundwater of shailw aquifer in Kathmandu, Nepal: In: Trends and sustainability of groundwater in highly stressed aquifers (Proc. Of Symposium JS.2 at the joint IAHS & IAH convection, Hyderabad, India, September 2009), IAHS publication, 329, pp.178-183.
- Parviainen, A, Loukola-Ruskeeniemi, K, Tarvainen, T., Hatakka, T., Harma, P., Backman, B., Ketola, T., Kuula, P., Lehtinen, H., Sorvari, J., Pyy, O., & Ruskeeniemi, k. (2012). Arsenic in bedrock, soil and groundwater – The first Arsenic guidelines for aggregate production established in Finland. *Earth Science Reviews*, 150, 709 – 723.
- Pitkanen, T., Miettinen, I.T., Lett, O. H., Heikkilä, A., Maunula, R., Aula, V., Kuronen, H., Vepsäläinen, A., & Nousiainen, L.L (2011). Microbial contamination of groundwater in a small community water supplies, Finland. *Ambio* (40), 371-390 doi
- Pius, A., Jerome, C., & Sharma, N. (2012). Evaluation of groundwater quality in and around Peeya industrial area of Bangalore, South India using GIS techniques. *Environmental Monitoring and Assessment*, 184, 4067 – 4077.
- Pliz, J. (1993). *Statistics for windows*. Statsoft Inc, Tulsa.
- Paustenbach, D.J. (2002). *Human and Ecological Risk Assessment: Theory and Practice*. New York: John Wiley and Sons.
- Radfard, M.M., Masud, Y.A., Ramin, N .N., Hamed, B., Shahrokh, N., Mahdi, H., Nader, Y. , Mahmood, Y.,
- Ritter, L, Solomon, K., Sibley, P., Hall, K., Keen, P., Mattu, G., & Linton, B. (2002). Sources, Pathway and relative risks of contaminants in the surface water and groundwater: a perspective prepared for the Walkerton Inquiry. *Journal of Toxicology and Environmental Health*, 65(1), 1-142
- Ryan, R.P., Hough, R.M., & Watkers, R.T (2010). Enrichment exposure assessment of As, Cr & Pb of the soils in the Vuelly of Stawell, Victoria, Australia. *Environmental Geochemistry and Health*, 32, 193:205
- Smedley, P., & Kinniburgh, D.G. . (2002). A review of the source, behavior and distribution of arsenic in natural waters and groundwater, eastern Wisconsin, USA. *Hydrology Journal* 8, 161-176.
- Sorlini, S, Palazzini, D., Sieliechi, M. J., & Ngassoum, B. M (2013). Assessment of Physical-Chemical and Drinking Water Quality in the Logone Valley (Chad - Cameroon). *Sustainability*, 5, 3060-3076.
- Steenland, K., & Boffetta, P. 2000. Lead and cancer in humans: where are we now? *Am J Ind Med* 38:295–9. doi:10.1002/1097-0274(200009)38:3<295: AID-AJIM8>3.0.CO;2-L
- Takem, G.E., Chadraeskhara, D., Ayonghe, S.N., Tambidural, P. (2010). Pollution characteristics of alluvial groundwater from springs and bore wells in semi – Urban informal settlement of Douala, West Africa. *Environmental Earth Sciences*, 61, 287-298.
- Tamasi, G., & Cini, R. (2004). Heavy metals in drinking waters from Mount Amiata (Tuscany, Italy). Possible risks from arsenic for public health in the Province of Siena. *Science of the Total Environment*, 327, 41–51.
- Tanawa, E., Djeuda Tchaponada, H.B., Ngnikum, E., Temigoua, E., & Siakeu B. (2002) Habitat and protection of water resources in suburban areas in African cities. *Build Environment*, 37, 269 – 275
- Tchamabe, B. C., Ohba, T., Kereszturi, G., Nemeth, K., Aka, F.T, Youmen, D., Miyabuchi, I., Yasuo, O.S., Tanyileke, G., & Hell, J.V. (2015). Towards the reconstruction of the shallow plumbing system of the Barombi

- 772 Mbo Maar (Cameroon) – Implications for diatreme growth processes of a polygenetic maar volcano, Journal of
 773 Volcanology and Geothermal Research (2015), doi: 10.1016/j.jvolgeores.2015.06.004
 774
- 775 World Health Organization (2008). Guidelines of drinking water quality. 3rd edn. Incorporating the first and
 776 second Addenda, vol.1 Recommendation, Geneva.
 777
- 778 World Health Organization (2007). Guidelines of drinking water quality. 3rd edn. Incorporating the first and
 779 second Addenda, vol.1 Recommendation, Geneva. World Health Organisation, 121 – 143.
 780
- 781 World Health Organization (2006). Guidelines of drinking water quality. World Health Organization, Geneva,
 782 Switzerland .
 783
- 784 World Health Organisation/United Nations Children Fund. (WHO/UNICEF 2010). Progress on drinking water
 785 and sanitation.
 786
- 787 World Health Organisation/United Nations Children Fund . (WHO/UNICEF 2004)Joint monitoring programme
 788 for water supply and sanitation, Meeting the Minimum Development Goal(MDG) drinking water and sanitation
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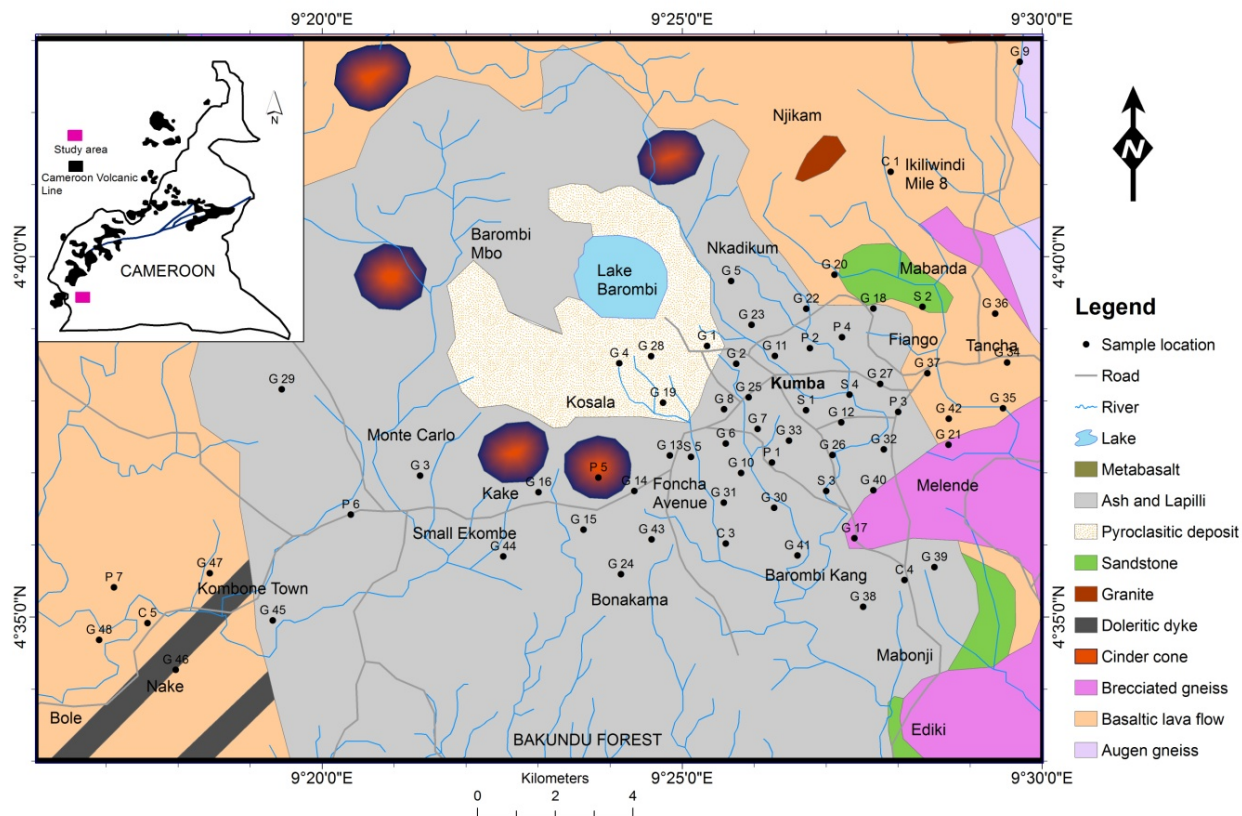


Fig.1 Map of the study area showing the sample locations and geology of the area of study (modified after Tchambe et al. 2015).

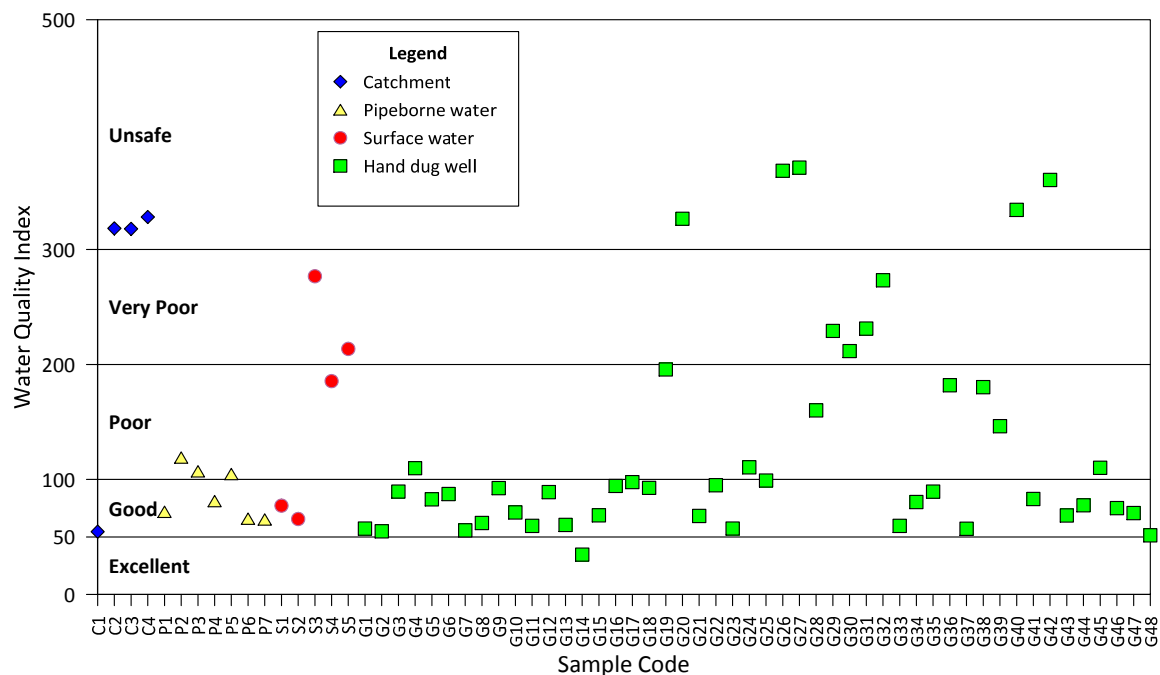


Fig 2 Plot of Calculated Water Quality Index (WQI) against sample location

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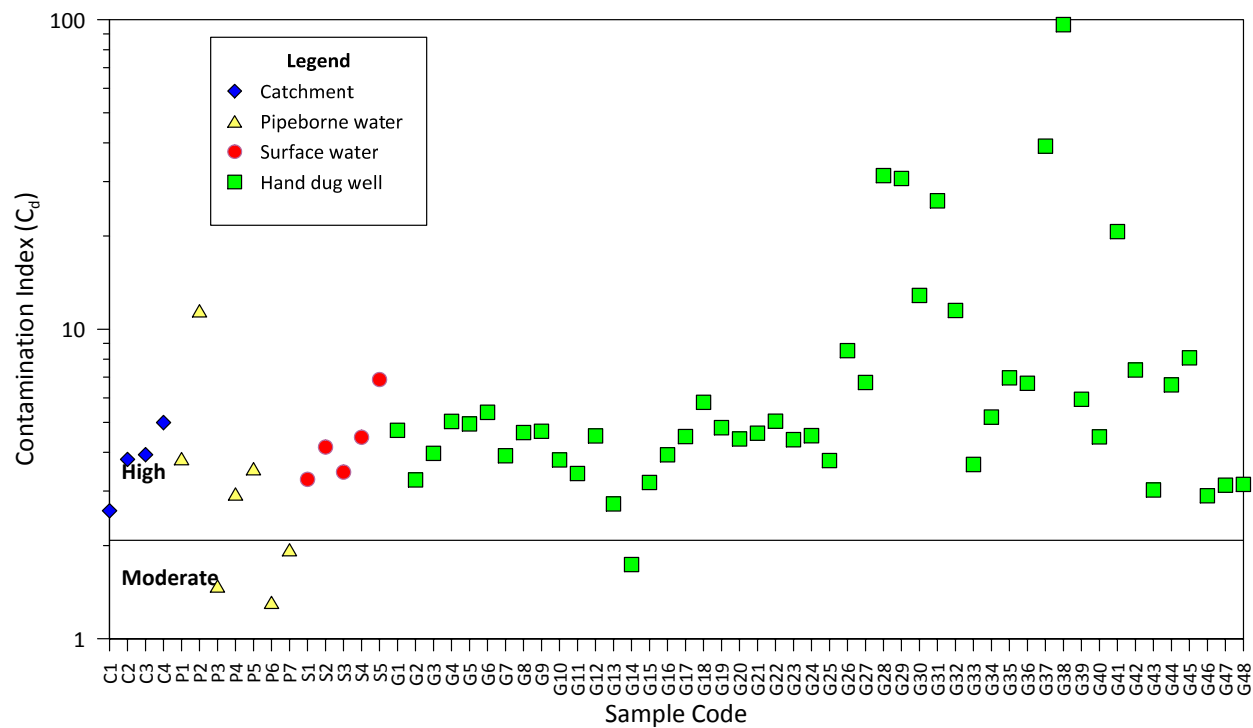


Fig 3 Plot of Contamination Index (C_d) against sample location

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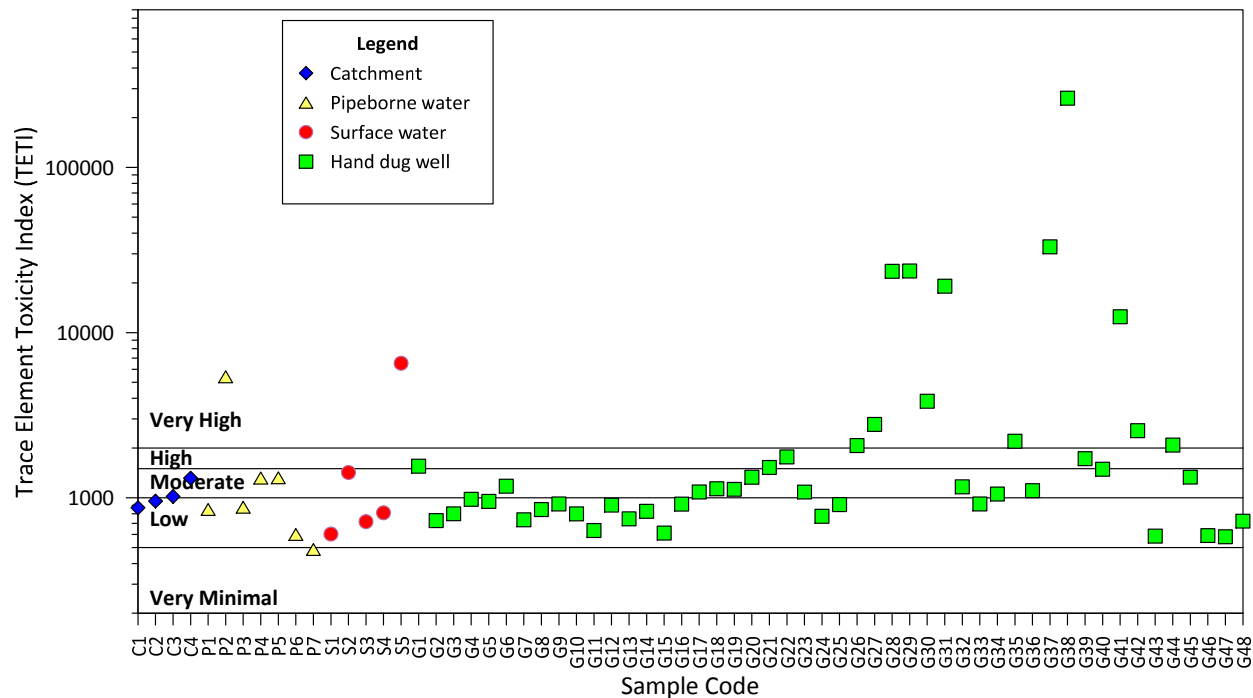


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Public health challenges as a result of contaminated water sources in Kumba, Cameroon.

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Table 1 Incidence of various water-related diseases recorded in parts of Kumba (2010 – 2014)

Year	Dysentery	Diarrhea	Giardiasis
2010	1562	2261	910
2011	1616	1968	871
2012	1518	1989	712
2013	1718	2003	691
2014	1881	2013	818

Source: Baptist health center, Kumba, Cameroon (2014)

Table 2 Weights and relative weights of parameters used for WQI computation

Parameter	Unit	WHO (2008)	Assigned weight(w)	Relative weight (w _i)
pH		6.5 - 8.5	5	0.14
DO	mg/l	5	3	0.09
TC	CFU/ml	10	5	0.14
As	µg/l	10	5	0.14
Cd	µg/l	2	4	0.11
Cu	µg/l	2000	2	0.06
Pb	µg/l	10	5	0.14
Ni	µg/l	300	3	0.09
Zn	µg/l	3000	3	0.09
			35	1.00

DO (Dissolved oxygen) and TC (Total coliform)

77 Table 3 Summary statistics of physicochemical parameters, trace elements and microbiological parameters of various water sources (Catchment water (CW),
78 Pipe borne water (PW), surface water (SW) and hand dug well (HDW) alongside **World Health Organization** (WHO 2008) guidelines
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Water type		CW				PW				SW				HDW				WHO (2008)
Parameter	Units	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	
Temp	°C	26.0	27.4	26.8	0.6	25.9	27.5	27.0	0.6	25.8	28.0	27.0	1.0	2.7	84.0	28.9	10.4	
EC	µS/cm	47.0	82.0	58.0	14.9	39.0	65.0	58.1	9.0	38.0	115.0	61.8	32.1	34.0	135.0	59.2	42.7	1400
pH		4.6	6.6	5.6	0.9	5.1	6.2	5.6	0.6	4.5	6.4	5.4	0.8	5.1	5.8	5.3	0.3	6.5-8.5
Turbidity	NTU	0.04	0.9	0.5	0.4	0.8	1.6	1.3	0.4	0.1	0.7	0.5	0.2	0.7	2.6	1.3	0.7	5
Total hardness	mg/l	20.0	52.0	38.0	13.6	16.0	60.0	40.0	16.4	14.0	42.0	26.0	11.4	16.0	38.0	30.0	8.6	500
Al	µg/l	410.0	1150.0	912.5	325.4	370.0	7300.0	1684.3	2503.6	540.0	1720.0	824.0	505.1	460.0	2690.0	1038.0	950.1	200
As	µg/l	1.0	4.0	2.7	1.3	0.9	4.6	2.1	1.2	0.8	2.8	1.5	0.8	2.5	3000.0	65.9	1.4	10
Cd	µg/l	0.5	3.8	2.2	1.4	0.3	3.6	1.0	1.2	0.2	1.2	0.6	0.4	0.4	700.0	15.8	0.3	3
Co	µg/l	0.5	8.4	6.0	3.5	0.2	4.9	1.8	1.9	0.5	46.8	11.4	19.8	1.3	300.1	10.4	2.2	
Cr	µg/l	3.5	8.4	6.6	2.1	2.8	5.9	4.5	1.2	0.9	7.7	3.3	2.7	4.2	382.1	14.5	2.4	50
Cu	µg/l	23.3	83.9	63.9	25.5	17.4	102.0	49.7	28.4	6.4	57.3	32.5	18.2	26.9	8420	223.3	20.0	2000
Fe	µg/l	990.0	2580.0	2035.0	695.3	750.0	2080.0	1312.9	472.6	430.0	2100.0	1362.0	625.3	890.0	4730.0	1832.0	1628.7	200
Mn	µg/l	110.0	290.0	200.0	76.9	19.0	250.0	93.9	94.9	60.0	5140.0	1306.0	2183.2	20.0	330.0	94.8	132.1	200
Mo	µg/l	0.2	0.9	0.6	0.3	0.1	1.2	0.4	0.4	0.1	0.6	0.3	0.2	0.1	0.4	0.2	0.1	70
Ni	µg/l	6.7	20.9	13.8	6.1	2.1	15.8	7.1	5.0	5.7	71.0	20.8	28.3	3.9	759	26.6	0.8	20
Pb	µg/l	17.4	43.0	36.0	11.2	21.3	36.8	29.3	6.4	17.2	28.6	23.9	6.0	27.3	7314	186.6	10.3	10
Si	µg/l	3820.0	19250.0	8792.5	6538.8	2950.0	28050.0	11915.7	11404.9	3460.0	6890.0	4638.0	1317.2	5910.0	21520.0	13534.0	5815.1	
Sr	µg/l	13.2	161.3	62.6	62.4	34.0	162.8	73.3	56.3	19.2	138.0	50.2	49.4	25.9	67.3	48.5	17.6	
V	µg/l	1.1	4.0	2.9	1.3	1.3	11.3	4.1	4.5	0.1	2.6	1.5	0.9	1.8	7.2	3.9	2.2	
Zn	µg/l	81.7	140.9	115.5	25.5	76.7	431.8	170.1	123.9	46.9	1063.0	287.8	434.9	80.2	175.9	110.8	40.5	3000
DO	mg/l	4.6	5.9	5.3	0.6	4.5	6.1	5.6	0.6	4.9	7.0	5.5	0.9	5.7	8.9	6.5	1.3	5
Total coliform	per 100	13.0	180.0	133.3	74.3	12.0	36.0	22.6	8.4	18.0	160.0	75.6	59.2	3.0	12.0	8.4	3.4	10
Enterobacteria		100.0	400.0	250.0	128.1	100.0	350.0	207.1	93.2	200.0	500.0	360.0	114.0	50.0	150.0	96.0	36.5	0
Esch-coli		75.0	250.0	162.5	74.7	21.0	200.0	117.3	56.5	50.0	300.0	190.0	96.2	30.0	75.0	48.0	16.8	0
Streptococcus		100.0	200.0	125.0	44.9	30.0	200.0	93.6	61.6	100.0	300.0	190.0	82.2	10.0	30.0	24.0	8.9	0
Salmonella/Shigella		25.0	200.0	112.5	74.7	0.0	100.0	35.3	34.1	100.0	300.0	150.0	86.6	5.0	20.0	13.0	5.7	0

Table 4 Distribution of major species of potentially toxic elements (PTE) in the water

PTE	Component	Total concentration (%)	Chemical Specie identified
As	AsO_4^{3-}	29.00	H_2AsO_4^-
		71.20	HAsO_4^{2-}
Cd	Cd^{2+}	100.00	Cd^{2+}
		0.20	CdOH^+
Pb	Pb^{2+}	62.20	Pb^{2+}
		37.50	PbOH^+
		0.30	$\text{Pb(OH)}_2 \text{ (aq)}$

Table 5 Significant positive and negative correlation between physicochemical parameters and trace elements

Parameters	CW		PW		SW		HDW	
	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative
Temp	pH, DO, Al, As, Cr, Fe, Pb, V, Zn		pH,		EC, pH, Al, Cd, Co, Sr		pH, Cd, Co, Sr	
EC	As,	Cd, Co, Cu, Mo, Ni,	pH, DO, Co, Pb	Si	DO,		DO	
pH	DO, Al, As, Cr, Fe, V, Zn	Cd, Ni	DO, Co, Cu, Fe, Mo, Pb		Al, Cd, Co, Mo, Si, Zn		Al, Cd, Co, Mo, Zn	
DO	Co, Mn	Cd, Mo, Ni	Co, Pb			Si		
Al	As, Cr, Cu, Mo, Pb, V, Zn	Mn	As, Cd, Ni		Cd, Co, Mn, Ni, Sr Cr, Cu, Fe, Mo, Pb, Si, V	Cu, Fe, Pb, V	Cd, Co, Mn, Ni, Sr, Zn	Cu, Fe, V Co, Mn, Ni, Sr, Zn
As	Cr, Pb, Si, V, Zn	Co, Mn	Cd, Cr, Ni			Co, Mn, Ni, Sr, Zn	Cr, Cu, Fe, Mo, Pb, Sr, V	
Cd	Cu, Mo, Ni	Mn	Ni	Co	Co, Mn, Ni, Sr, Zn	Cu, Fe, V	Co, Mn, Sr, Zn	Cu, Fe, V
Co		Si, Sr	Cu, Mn, Mo		Mn, Ni, Sr, Zn	Cu, Fe, Pb, V	Mn, Sr, Zn	Cu, Fe, V
Cr	Cu, Fe, Pb, V, Zn	Mn	Fe, Mn, Ni, Pb, Zn		Cu, Fe, Mo, Si, V	Mn, Ni, Sr	Cu, Fe, Mo, Si, V	Mn, Ni, Sr
Cu	Fe, Mo, Ni, Pb, V, Zn	Mn	Fe, Pb		Fe, Mo, Pb, Si, V	Mn, Ni, Sr, Zn	Pb, Si, V	Mn, Ni, Sr, Zn
Fe	Mo, V, Zn	Mn	Pb, Zn		Mo, Si, V	Mn, Ni, Sr, Zn	Mo, Si, V	Mn, Ni, Sr, Zn
Mn		Mo, Ni, Pb, V	Mo		Ni, Sr, Zn	Pb, V	Ni, Zn	Pb, V
Mo	Ni, Pb				Si, V		Si, V	
Ni		Si, Sr	Si		Sr, Zn	Pb, V	Sr, Zn	V
Pb	V, Zn		Zn		V	Sr, Zn	V	Sr, Zn
Si	Sr		Sr, V		V		Zn	V
Sr			Zn		Zn	V		Zn
V	Zn		Zn			Zn	Zn	

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Table 6 Pearson's Correlation matrices for microbiological parameters including DO

Parameters	DO	Total coliform	Enterobacteria	E-coli	Streptococcus	Salmonella/Shigella
DO	1.00					
Total coliform	-0.18	1.00				
Enterobacteria	-0.05	0.49	1.00			
E-coli	-0.13	0.42	0.87	1.00		
Streptococcus	0.01	0.34	0.71	0.56	1.00	
Salmonella/Shigella	-0.04	0.39	0.66	0.51	0.76	1.00

52 Table 7 Varimax principal component analysis (PCA) of all water sources grouped
53 together for physicochemical and microbiological parameters
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Parameter	Factor				
	1	2	3	4	5
pH	0.007	0.223	-0.235	-0.354	0.408
Temp	-0.017	0.057	0.119	0.081	0.803
Cond	-0.016	-0.041	-0.826	0.076	-0.155
Turb	-0.006	0.004	-0.573	0.062	0.069
TH	-0.002	-0.030	-0.791	-0.214	-0.006
Al	0.553	0.095	0.106	0.147	0.719
As	0.996	0.024	0.008	0.011	0.015
Cd	0.996	0.025	0.010	0.013	0.025
Co	0.987	0.055	0.007	-0.020	-0.004
Cr	0.971	-0.006	0.020	0.010	0.027
Cu	0.996	0.024	0.005	0.014	0.024
Fe	0.970	0.073	-0.001	0.031	0.139
Mn	0.188	0.297	-0.153	-0.186	-0.060
Mo	0.551	-0.102	-0.123	0.092	-0.146
Ni	0.993	0.054	0.012	0.011	0.060
Pb	0.996	0.025	0.012	0.012	0.015
Si	-0.048	-0.207	0.149	-0.829	-0.020
Sr	-0.038	0.081	-0.059	-0.907	-0.122
V	-0.032	0.053	-0.006	-0.026	0.581
Zn	-0.003	0.107	0.097	0.093	0.882
Total coliform	0.270	0.494	0.087	-0.116	0.462
DO	-0.064	-0.039	-0.317	0.284	-0.185
Enterobacteria	0.063	0.938	0.013	-0.103	0.097
E-coli	-0.080	0.857	-0.002	-0.107	0.122
Streptococcus	0.095	0.821	0.009	0.257	0.020
Salmonella/Shigella	0.121	0.798	0.153	0.178	-0.016
Eigenval	8.774	3.765	2.705	1.985	1.859
% total variance	32.495	13.945	10.020	7.352	6.885
Cumul. Eigenval	8.774	12.539	15.244	17.229	19.088
Cumul. %	32.495	46.440	56.460	63.812	70.697

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69 Table 8 Average daily dose (ADD), Hazard quotient (HQ), Hazard risk index (HRI) and cancer risk factor
70 (ADD/SF) for As
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7.1										Cancer risk factor
S/N	Code	Water type	ADD(mg/kg/day)			HQ			HRI	As
			As	Cd	Pb	As	Cd	Pb		ADD/SF
1	C1	Catchment (CW)	2.95E-05	5.717E-06	0.0003	0.0983	0.0057	0.0938	0.1978	1.96698E-05
2	C2		1.844E-05	9.036E-06	0.0003	0.0615	0.0090	0.0917	0.1622	1.22936E-05
3	C3		2.821E-05	5.901E-06	0.0004	0.0940	0.0059	0.1243	0.2243	1.88093E-05
4	C4		6.085E-05	7.561E-06	0.0008	0.2028	0.0076	0.2350	0.4454	4.0569E-05
5	P1	Pipeborne water (PW)	4.241E-05	9.958E-06	0.0011	0.1414	0.0100	0.3045	0.4559	2.82754E-05
6	P2		4.813E-05	7.007E-06	0.0008	0.1604	0.0070	0.2403	0.4077	3.20864E-05
7	P3		7.007E-05	1.641E-05	0.0007	0.2336	0.0164	0.2086	0.4586	4.67158E-05
8	P4		2.729E-05	1.236E-05	0.0005	0.0910	0.0124	0.1444	0.2477	1.81946E-05
9	P5	Surface water (SW)	3.965E-05	3.872E-06	0.0006	0.1322	0.0039	0.1644	0.3004	2.64313E-05
10	P6		2.877E-05	3.319E-06	0.0005	0.0959	0.0033	0.1570	0.2562	1.91781E-05
11	P7		3.651E-05	8.851E-06	0.0006	0.1217	0.0089	0.1681	0.2986	2.43414E-05
12	S1		3.909E-05	2.95E-06	0.0004	0.1303	0.0030	0.1254	0.2587	2.60625E-05
13	S2	Handug well (HDW)	3.541E-05	7.376E-06	0.0005	0.1180	0.0074	0.1312	0.2566	2.36038E-05
14	S3		4.02E-05	1.236E-05	0.0007	0.1340	0.0124	0.1976	0.3439	2.68001E-05
15	S4		2.766E-05	6.27E-06	0.0004	0.0922	0.0063	0.1006	0.1991	1.84405E-05
16	S5		3.246E-05	4.61E-06	0.0002	0.1082	0.0046	0.0606	0.1734	2.16368E-05
17	G1		6.583E-05	5.901E-06	0.0006	0.2194	0.0059	0.1818	0.4071	4.38883E-05
18	G2		3.504E-05	8.483E-06	0.0006	0.1168	0.0085	0.1660	0.2912	2.33579E-05
19	G3		4.334E-05	9.036E-06	0.0007	0.1445	0.0090	0.2060	0.3595	2.88901E-05
20	G4		3.319E-05	1.033E-05	0.0005	0.1106	0.0103	0.1491	0.2701	2.21286E-05
21	G5		6.454E-05	1.549E-05	0.0007	0.2151	0.0155	0.2139	0.4445	4.30277E-05
22	G6		3.707E-05	5.901E-06	0.0007	0.1236	0.0059	0.2039	0.3334	2.47102E-05
23	G7		5.68E-05	1.199E-05	0.0007	0.1893	0.0120	0.1939	0.3952	3.78644E-05
24	G8		7.192E-05	1.309E-05	0.0003	0.2397	0.0131	0.0796	0.3324	4.79452E-05
25	G9		5.163E-05	5.717E-06	0.0004	0.1721	0.0057	0.1006	0.2785	3.44222E-05
26	G10		1.992E-05	3.135E-06	0.0003	0.0664	0.0031	0.0922	0.1617	1.32771E-05
27	G11		4.739E-05	1.936E-05	0.0005	0.1580	0.0194	0.1423	0.3196	3.15947E-05
28	G12		0.0001033	8.667E-06	0.0010	0.3442	0.0087	0.2745	0.6274	6.88444E-05
29	G13		0.0001082	1.715E-05	0.0008	0.3608	0.0171	0.2271	0.6050	7.21637E-05
30	G14		0.000118	1.383E-05	0.0012	0.3934	0.0138	0.3456	0.7529	7.86793E-05
31	G15		0.0002502	0.0001031	0.0008	0.8341	0.1031	0.2182	1.1554	0.000166825

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S/N	Code	Water type								Cancer risk factor
			ADD			HQ			HRI	As
			As	Cd	Pb	As	Cd	Pb		ADD/SF
32	G16	Handug well (HDW)	9.054E-05	8.759E-05	0.0008	0.3018	0.0876	0.2218	0.6112	6.03618E-05
33	G17		8.483E-05	6.565E-05	0.0005	0.2828	0.0656	0.1359	0.4843	5.65508E-05
34	G18		0.0001082	0.0001387	0.0009	0.3608	0.1387	0.2514	0.7509	7.21637E-05
35	G19		5.256E-05	6.307E-05	0.0006	0.1752	0.0631	0.1685	0.4067	3.50369E-05
36	G20		0.000113	9.036E-05	0.0006	0.3768	0.0904	0.1600	0.6271	7.536E-05
37	G21		0.0002121	0.0001049	0.0012	0.7069	0.1049	0.3405	1.1523	0.000141377
38	G22		2.342E-05	7.929E-06	0.0005	0.0781	0.0079	0.1509	0.2369	1.56129E-05
39	G23		7.376E-05	8.851E-06	0.0006	0.2459	0.0089	0.1791	0.4339	4.91746E-05
40	G24		5.256E-05	9.958E-06	0.0003	0.1752	0.0100	0.0817	0.2668	3.50369E-05
41	G25		2.785E-05	4.979E-06	0.0003	0.0928	0.0050	0.0988	0.1966	1.85634E-05
42	G26		3.688E-05	2.287E-05	0.0006	0.1229	0.0229	0.1639	0.3097	2.45873E-05
43	G27		6.639E-05	1.033E-05	0.0005	0.2213	0.0103	0.1491	0.3807	4.42571E-05
44	G28		7.763E-05	2.139E-05	0.0005	0.2588	0.0214	0.1375	0.4177	5.17562E-05
45	G29		3.227E-05	6.454E-06	0.0006	0.1076	0.0065	0.1654	0.2795	2.15139E-05
46	G30		1.383E-05	2.25E-05	0.0003	0.0461	0.0225	0.0906	0.1592	9.22023E-06
47	G31		4.426E-05	7.026E-05	0.0008	0.1475	0.0703	0.2266	0.4443	2.95047E-05
48	G32		4.85E-05	6.823E-06	0.0010	0.1617	0.0068	0.2766	0.4451	3.23323E-05
49	G33		3.319E-05	1.586E-05	0.0008	0.1106	0.0159	0.2276	0.3541	2.21286E-05
50	G34		5.163E-05	1.199E-05	0.0005	0.1721	0.0120	0.1475	0.3316	3.44222E-05
51	G35		3.707E-05	5.717E-06	0.0007	0.1236	0.0057	0.1902	0.3195	2.47102E-05
52	G36		2.969E-05	3.872E-06	0.0005	0.0990	0.0039	0.1354	0.2382	1.97928E-05
53	G37		9.976E-05	6.934E-05	0.0009	0.3325	0.0693	0.2463	0.6481	6.65086E-05
54	G38		0.055324	0.0129083	0.1349	184.4046	12.9083	38.5353	235.8483	0.036880927
55	G39		4.426E-05	4.131E-05	0.0006	0.1475	0.0413	0.1660	0.3548	2.95047E-05
56	G40		5.163E-05	1.254E-05	0.0007	0.1721	0.0125	0.1897	0.3743	3.44222E-05
57	G41		4.426E-05	1.309E-05	0.0007	0.1475	0.0131	0.1939	0.3545	2.95047E-05
58	G42		0.0001088	2.25E-05	0.0010	0.3627	0.0225	0.2898	0.6749	7.25325E-05
59	G43		2.489E-05	8.298E-06	0.0004	0.0830	0.0083	0.1122	0.2035	1.65964E-05
60	G44		8.298E-05	1.678E-05	0.0007	0.2766	0.0168	0.1897	0.4831	5.53214E-05
61	G45		5.717E-05	1.033E-05	0.0006	0.1906	0.0103	0.1818	0.3826	3.81103E-05
62	G46		1.66E-05	2.508E-05	0.0004	0.0553	0.0251	0.1159	0.1963	1.10643E-05
63	G47		4.684E-05	6.454E-06	0.0005	0.1561	0.0065	0.1438	0.3064	3.12259E-05
64	G48		6.454E-05	1.549E-05	0.0007	0.2151	0.0155	0.2139	0.4445	4.30277E-05