Evaluation of Factors Influencing the Quality of Surface and Ground Sourced Sachet Water in Sokoto Metropolis using Principal Components Analysis (PCA)

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ABSTRACT

Sachet water has become popular in Nigeria where its monitoring and evaluation became part of Water Resource Management. This research assessed the chemical and microbial quality of sachet water produced from surface and underground sources in Sokoto metropolis. 114 water packaging enterprises were surveyed and 83 of them were selected for analysis using Yemen's formula. Chemical analyses were done using Atomic Absorption Spectrometer, while the Multiple tube technique was used for microbial analysis. The study found that 18.1% of the samples were not safe for consumption. It was also discovered that there was no significant differences between the qualities of the sachet water produced from surface and ground water sources (p = 0.060). P.C.A. conducted indicates that the quality of sachet water sampled is determined by: weathering, water treatment, corrosion of the plumbing system, sewage pollution, urban runoff, atmospheric deposition, mining and industrial activities. Finally seven remedial measures are recommended.

Key words: Groundwater, Sachet Water, Surface Water, Water quality, Water quality contaminants, Water quality Standards and Guidelines

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INTRODUCTION

Water is essential to sustain life, and a satisfactory supply must be available to all [51], [55]. In addition, water of good quality is a basic requirement for human physiology [40] and a precondition for ensuring high quality life, strong economy [32] and development of human rights. Therefore, water quality management has become an important component of water resource management in modern times [29]. The reliance upon a single source of piped water supply for consumption, sanitation, lawn, irrigation, firefighting and other domestic uses was started to be questioned [13]. To this end, [18] observes that pipe borne water in Nigeria is persistently inadequate in terms of quantity and quality. He further stressed that an alternative to the seeming inadequate water supply is found in packaged water commonly sold in sachets (popularly known as pure water). Thus monitoring and evaluation of sachet water enterprises has become part of Water Resource Management in Nigeria.

It is against this background therefore, that this research seeks to examine the factors that influences the quality of sachet water which are produced from surface and underground sources in Sokoto metropolis where the pure water syndrome is fast growing.

Previous researches tend to ignore the possibility of having deferential quality between the ground and surface sourced sachet water. To address this therefore, this research makes comparative analysis of the surface and ground sourced sachet water quality in the study area. This is based on the assumption that 'variability may exist between the quality of sachet water produced from borehole on one hand, and that produced from surface sources on the other hand'.

Only the water quality parameters recommended by the Standard Organisation of Nigeria (SON) (as provided in the Nigerian Industrial Standards (NIS)) were measured for this research (appendix 1), and the values obtained from the laboratory analysis were compared with the Nigerian Industrial Standard for Drinking Water [47]. The research covered chemical parameters such as Ca^{+2}, Cl^-, Cr^{6+}, Cu^{+2}, EC, $CaCO_3$, Fe^{+2}, Pb, Mg^{+2}, Mn^{+2}, Ni, pH, Na, SO_4^{2-}, TDS and Zn. With regards to microbial parameters, Most Probable Number (MPN) is determined.

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MATERIALS AND METHODS

The Study Area

Sokoto metropolis lies between latitudes 12° 55′ N and 13° 10′ N, and longitudes 5° 09′ E and 5° 17′ E (Sokoto Master Plan). It extends to a 16 km radius from Shehu Kangiwa square. As for the 2006 census, the metropolis had a population of 427,760 [36]. The main relief characteristic of Sokoto State is the popular Sokoto Plain, which is a uniform low land with an average height of 300m above mean sea level [31]. The state is underlain by a sequence of inter bedded semi consolidated gravels, sands, clays, and some limestone and ironstones of cretaceous to quaternary age, which are resting on Precambrian basement complex rocks [30] without any notable out – crop [31]. It is mainly drained by River Rima and its tributary, – the Sokoto River. Other tributaries include Bunsuru, Gangare, Zamfara, Gawon Gulbi, and Ka Rivers [30], [31]. The Climate is Tropical Continental controlled by Tropical Continental and Tropical Maritime Air Masses [31]. The vegetation of the area is Sudan savanna type which is affected by consistent challenge from desert-like conditions.
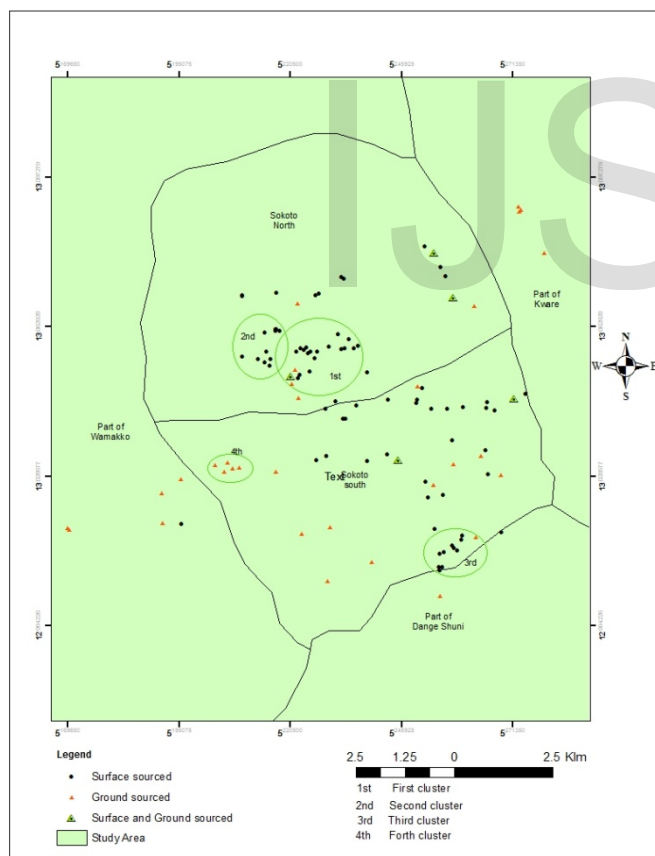

Figure 1 Spatial distribution of sachet water companies in the study area

Sampling procedures

According to NAFDAC source there were 147 sachet water brands in Sokoto State out of which 130 were located within Sokoto metropolis. A reconnaissance survey was conducted to all the sachet water companies, through which the list was updated to 114 brands (Figure 1). Consequently, the companies were divided into two categories: the first group comprises of sachet water companies that use surface water for their production, while the second group comprises of the sachet water companies that use groundwater for their production. The first group comprised of 78 brands while the second comprised of 31 brands; totaling 109. Moreover the other five companies obtain their raw water from both surface and under-ground sources; these were removed from the list, so that the aim of the research would not be defeated. Therefore, these 109 sachet water brands provided the sampling frame for this research.

Yemen's (1967) formula for sample size determination was used to select 86 brands out of the 109 Sachet water brands. Thus:

$$n = \frac{N}{1 + N\,(e)^2}$$

where N = Population size;   e = 0.05

Only 28% of the 109 companies obtain their water from borehole; the remaining 72% obtain water from surface source. Hence stratified sampling techniques were used to select 62 and 24 brands from the surface water and groundwater groups respectively [11]. However during the sample collection, two out of sixty two brands to be collected from the surface water group were closed for the day, while one insisted that he will not sell his water to the researcher. Therefore a total of 59 samples were collected from the surface group instead of the proposed 62.

Sachet water samples were purchased from producers [6], [22], [44] and transported to laboratory in insulated containers with ice packs within 8 - 24 hour [19], [39]. Meanwhile the samples were coded and lebeled for easy identification, thus: First digit represents raw water source (those produced from surface water are represented by '1' while those produced from groundwater are represented by '2'); the next two digits represent the serial number of the sample in its group; finally, the last two digits represent serial number of the sample in the entire samples.

Techniques of laboratory analysis

Atomic Absorption Spectrometer (AAS) was used to determine Ca^{+2}, Cr^{6+}, Cu^{+2}, Fe^{+2}, Mg^{+2}, Mn^{+2}, Na, Ni, Pb, and Zn [7], [10], [48], [56]. According to [10], for many metals difficult to be determined by other methods (such as Flame Emission), AAS technique exhibits superior sensitivity, with detection range of 0.01-1µg [56]. Sample preparations were based on the APHA [10]. Hardness (as $CaCO_3$) was determined using the formula: Hardness = $2.5(Ca^{2+})$ + $4.1(Mg^{2+})$ [10], [24]. Ovum was used to determine the TDS [24]; the pH and EC were determined using pH and EC meters respectively.

Multiple tube technique (otherwise known as Most Probable Technique) was used for microbial analysis [2], [28], [34], [40], [44], [45], [51], [54]. In this method, coliforms were detected in three stages, which include Presumptive test, Confirm test and Completed test [23]; and the number of coliforms is determined by a statistical estimation called Most-Probable-Number (MPN), which is expressed as MPN per 100 ml of water [26]. All the media used were weighed out and prepared according to the manufacture's specification.

Statistical analysis

Principal Component Analysis (PCA) was applied for the parameters that were obtained from the 83 Sachet water samples [48]. The PCA is based on Pearson's correlation matrix and the classification was based on the Gildford's rule of thumb for interpretation of product movement correlation (Table 1).

Table 1   Gildford's role of thumb for interpretation of product movement correlation

r-value	Interpretation
0.0 - 0.29	Negligible or little correlation
0.3 - 0.49	Low correlation
0.5 - 0.69	Moderate or marked correlation
0.7 - 0.89	High correlation
0.9 - 1.00	Very high correlation

Source: Sulaiman (2013)

According to Kaiser's criterion [48], one should only retain and interpret any component with eigenvalue greater than 1.00. This is because each of the observed variables contributes one unit of variance to the total variation in the data set. As such, any component that displays an eigenvalue greater than 1.00 is believed to be responsible for a greater amount of variation than is contributed by one variable. Thus a component with such a characteristic is responsible for a significant amount of variance and deserves to be retained, whereas a component with an eigenvalue less than 1.00 is responsible for less variation than is contributed by one variable. However, the main aim of PCA is to reduce redundancy in a given data set, which is achieved through decreasing the number of observed variables to a relatively small without jeopardizing the actual interpretation of the data in question; therefore retaining components that account for less variance than contributed by individual variables will defeat the aim of PCA. [48] used the PCA technique to explain the factors influencing water chemistry in Kapas Island, Malaysia. Student "t" test was used to statistically determine whether there is a significant difference between the qualities of surface and ground sourced sachet water in the study area.

RESULTS AND DISCUSSION

Chemical analysis

Only one sample (1.2%) has chromium level (0.0515 mg/L) above the maximum permissible limit (0.05 mg/L) Appendix A). However since toxic Cr IV is usually converted to non-toxic Cr III in water [53], the sample with Cr above the maximum permissible limit may not be of serious concern. Thus it is concluded that 100% sachet water produced in the study area are safe for consumption as far as Cr is concern. In a related development, only three samples (3.6%) (2.03 mg/L each) were above the maximum allowable limit for Nickel (0.02 mg/L) (Appendix B). Exposure to Ni was only proofed to be carcinogenic through inhalation [55], but remain a mere possibility through drinking water [47]. Therefore the three samples that showed Ni levels above the minimum permissible limit may not be of significan health concern.

On the other hand, the maximum detection for lead (Pb) in this study was 0.0128 mg/L (appendix B). Thus, Pb concentrations are not offensive in all the samples used for this study [47]. Similarly, all the sachet water samples used for this study showed that concentration of Cu was well below the maximum permissible limit (01mg/L) by the SON (Appendix A). Thus 100% of the sachet water in the study area are safe for drinking as far as Cu is concerned. In a related development, concentrations of Manganese in all the samples used for this study were not offensive (i.e. not > 0.2 mg/L). Concentration of iron is also below the maximum allowable limit (0.3 mg/L) for all the samples. Similarly, Zinc was detected in all the samples used for this research, at concentrations well below the maximum allowable limit by the SON (3 mg/L) Appendix A).

In a related development, Na^+ and SO_4^{2-} concentrations were well below the maximum limits of 200 mg/L and 100 mg/L respectively. [47], [53] and [55], relate no health hazard to Na and SO_4 in drinking water but maintained that elevated levels (>200 and >250 respectively) can give unpleasant taste depending on the associated counter ion. Thus all sachet water in the study area are platable as far as Na and SO_4 is concerned. Similarly, chloride detected from the samples was also well below the maximum allowable limit (250 mg/L). Mean while according to [55] "Chloride occurs in drinking water at a concentrations well below those at toxic level".

Hardness (as $CaCO_3$) was well below the maximum allowable (150 mg/L) limit for all but one samples used for this research. However 1.2% of the samples were hard-water, 4.8% were moderately hard, while the remaining 94% were soft [24]. The principal components of hardness in drinking water are Ca and Mg; thus it is usually express as $CaCO_3$ [27], [51], [53], [55]. Usually hardness is caused by dissolved calcium and to a lesser extent, magnesium. However all the samples had Mg levels greater than the permissible level (0.2 mg/L).

All the samples used for this study had TDS value below the maximum allowable limit (500 mg/L) Appendix A). TDS in drinking water is not of health concern, but it affects palatability at a level above 600 mg/L [53], [55]. Conductivity has been used as surrogate to TDS except that it is measured as micro-Siemens per centimeter (μS/cm) [53], and like conductivity, it is not known to exert any healt impact in drinking water [47]. However, all the samples used in this research showed conductivity concentrations well below the maximum allowable limit.

12.1% of the samples had pH value outside the permissible range (6.5 – 8.5). In general, 12.1% of the samples were neutral, 33.7% were basic, 54.2% were acidic. pH has no direct impact on the consumer health as consequence of exposure through drinking water, but it affects concentration of other metals (lead, copper etc.) and effectiveness of chemical coagulation and chlorination [55]. However, many chemical reactions and biological activities within the water body are controlled by pH [51]. Therefore 12.1% of the samples that are outside the permisible range may not affect the safety of the sachet water in the study area.
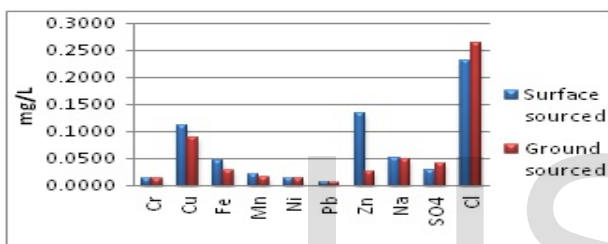

Figure 2 (a)   Mean concentration of chemical parameters of the surface and ground sourced sachet water in Sokoto metropolis
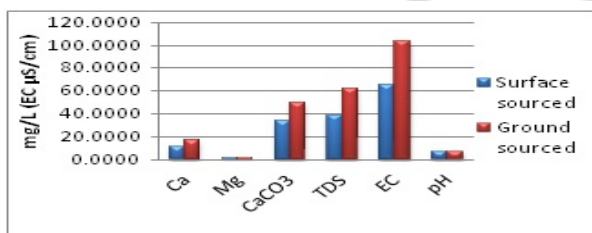

Figure 2 (a)   Mean concentration of chemical parameters of the surface and ground sourced sachet water in Sokoto metropolis

Figure 2 (a and b) compared the mean chemical concentrations for the two sources of sachet water used for this research. While Fe^{+2}, Mn^{+2} and Zn were higher in surface sourced sachet water samples compared with their concentration in the ground sourced sachet water samples. In contrast, SO_4^{2-}, Cl^-, Ca^{+2}, $CaCO_3$, TDS and Electrical conductivity (EC) were higher in the ground sourced sachet water samples. However concentrations of Cr^{6+}, Ni, Pb, Na^+, Mg^{2+} and pH values were almost the same for the two sources.

According to [14] and [16] ground water contain more dissolved salts, hardness, iron etc. than surface water. Therefore the concentrations of SO_4^{2-}, Cl^-, Ca^{2+}, $CaCO_3$ in ground sourced sachet water is not unexpected. Better still the geological formation in the study area is not unconnected with these elements [24], [16], [52]. However concentration of iron in the surface sourced sachet water than the ground sourced sachet water in the study area is atributed to the use of iron removal techniqe (use of iron resin) by some sachet water companies that use ground water sources [16] (Preliminary survey). On the other hand, high proportion of zinc on the surface water could be as a result of urban runoff. Mean while almost equal proportion of Cr^{6+}, Ni, Pb, Na^+, & Mg^{2+} in both surface and ground sources can be an indication of surface-ground water interaction (base flow) and short resident time for the ground water. It could also resulted from the use of shallow bore holes by sachet water companies. According to [16], only insignificance differences may occur between surface and ground water where for example surface water are recharged by adjacent aquifer (base flow), where intensive irrigation practice lead to leaching, where kast develop in limestone formation etc.

Previous studies reported different levels of chemical parameters at different places across Nigeria and Ghana: [1], [3], [4], [5], [6], [7] [8], [9], [20], [25], [35], [37], [38], [42], [43], [46], [50]; to mention but few.

Microbial analysis
By far the most serious public health risk associated with drinking water is microbial contamination [53]. In this study, only 16 samples (19.3%) showed positive presumptive test. The remaining 67 samples (80.7%) showed negative presumptive test (Table 2). However, only 15 samples show positive completed result. This means one of the positive presumptive results was negative at the completed stage (Table 2).

Table 2   Result of presumptive test

Samples	MPN (per 100ml)	Group %	Overall %
12323	3		
13535	3		
13838	3	10.2	
14646	3		
14848	3		
14949	3		
20160	4		18.1
20261	3		
20968	3		
21271	3		
21675	3	37.5	
21776	3		
22281	3		
22382	9		
22483	3		
*15353	4		81.9
Others	-		

* Negetive completed test

For more than 100 years, the microbial safety of drinking water has primarily been determined by testing for bacterial 'indicators' of fecal pollution [21], mainly *Escherichia coli* (*E coli*) and other coliform count. Therefore the 15 (18.1%) samples detected with coliforms can not be safe by all standards. This is because their presence is considered to represent the presence of fecal pollution and is used to indicate that pathogenic bacteria, viruses and protozoa may also be present. However Coliforms are relatively sensitive to disinfection; hence their presence in drinking water can be an indication of inadequate disinfection/disinfection residuals.

Theoretically, microbial contamination would be less [16], [51] or totally absent [14] in ground water as when compared to surface water [28]. Therefore it is surprising that the percentage samples detected with Coliforms bacteria is significantly higher for ground sourced samples as when compared with the surface sourced sachet water samples used for this study (Table 2). This could have resulted from two factors: possible sewage contamination through base flow, leaching/infiltration from the surface [16], [43], and inadequate treatment by the sachet water companies using groundwater sources, because they thought groundwater required no much treatment [14]. According to [41], some sachet water companies in Nigeria only do some minor treatment for water from springs, open wells and deep boreholes.

Previous studies in Nigeria reported elevated levels of microbial contamination among Sachet waters produced in different locations; viz: [2], [9], [17], [19], [28], [33], [34], [42], [44], [54]. However [3] reported about 94% Coliforms free in the municipal area of Ibadan city. Similarly, [43] and [50] reported 100% Coliforms free in FUT, Owerri and Abeokuta metropolis respectively.

Principal components analysis

Table 3   Extracted components

| Component	Initial Eigenvalues			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.423	20.137	20.137	3.271	19.241	19.241
2	3.227	18.983	39.120	2.448	14.399	33.640
3	1.589	9.348	48.468	2.112	12.421	46.062
4	1.412	8.305	56.774	1.501	8.829	54.891
5	1.194	7.026	63.800	1.362	8.014	62.905
6	1.037	6.100	69.900	1.189	6.995	69.900
7	.948	5.575	75.475			
8	.792	4.661	80.137			
9	.731	4.299	84.436			
10	.725	4.267	88.703			
11	.612	3.597	92.300			
12	.477	2.805	95.105			
13	.340	2.002	97.107			
14	.316	1.861	98.968			
15	.173	1.020	99.988			
16	.002	.012	100.00			
17	0.00	0.00	100.00			

Principal Component Analysis (PCA) was applied to the 17 parameters used for this study, and it yielded 17 Principal components (PCs) (Table 3), but only PCs with eigenvalues greater than one were considered to be the most important [48]; thus only six components appeared to be significance (Table 4), and the higher the eigenvalue of a PC the greater the contribution of that particular PC to the variability of water quality in the study area.

Table 4   Components extracted after varimax rotation

Parameters	Component					
	1	2	3	4	5	6
Ca	.934					
CaCO3	.928					
Na	.800	.327				
SO4	.662	.504				
Cu		.791				
Mn		.732				
Pb		.644				.454
EC		-.461	-.686		.359	
TDS		-.456	-.685		.364	
Zn			.675			.333
Fe			.671			
Mg				.687		
Coliforms	.305		.629			
pH	.407			-.575		
Cr					.711	-.314
Cl			.359		.668	
Ni						.752

There fore PCA result consists of six PCs that cumulatively accounting for 69.9% of the total variance in the sachet water quality in the study area. The first component (PC 1), which normally accounts for the most significance process, explains 19.24% of the total variance with an eigenvalue of 3.4. The PC 1 consist of all the major ions (Ca^{2+}, Na^+, and SO_4^{2-}) and $CaCO_3$, except the Mg^{2+} and Cl^-. The presence of these ions in water is not unexpected [49] because they are common inorganic solutes which occurred naturally in drinking water, and are usually loaded in accordance with their abundance [24], just as they were loaded in this component. According to [52] Ca^{2+} and Na^+ are common cations in water (especially groundwater) from sedimentary formation, where corresponding anions include HCO_3^- and SO_4^{2-}.

Similarly, the strong positive loading of Ca^{2+} with $CaCO_3$ and weak positive loading of pH is indication of weathering of calcite (calcium carbonate mineral), which is comparatively soluble and also the major mineral in limestone formation [16]. According to [49], when calcite comes in to contact with water, some portion of that mineral will be dissolved as show in the following equation:

$$CaCO_3 + H_2O = Ca^{2+} + HCO_3^- + OH^-   (1)$$
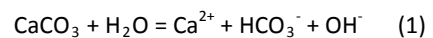
In this reaction, one molecule of calcium carbonate dissolved in water to yield one molecule of calcium ion, one bicarbonate ion and one hydroxide ion. Since pH of natural water is determined by proportion of hydrogen ions (H^+) against that of hydroxide (OH^-), the dissolution of carbonates rocks or sedimentary cemented by carbonates is one of the most widespread and

common mineral reaction that will influence the pH [49]. However, the solubility of $CaCO_3$ is a function of pH [12].

On the other hand, moderate positive loading of SO_4^- with strong positive loading of Ca^{2+} and $CaCO_3$ is not unconnected with the presence of gypsum ($CaSO_4$) in the study area [31]. According to [16] and [24] $CaSO_4$ is the major source of SO_4^{2-} especially in ground water. Dissolution/Precipitation reaction for gypsum is illustrated in the following equation

$$CaSO_4 \cdot 2H_2O \leftrightarrow Ca^{2+} + SO_4^{2-} + 2H_2O \quad (2)$$
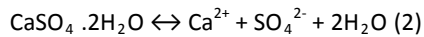
It should be noted at this juncture that Ca^{2+} is also released in this and the previous equations, which explained why the loading of Ca^{2+} is higher than that of SO_4^{2-} in this PC. However positive loading of Ca^{2+}- Na^+ - SO_4^{2-} with $CaCO_3$ shows that hardness depend on the contribution of these ions [51].

Lastly, the weak but positive loading of coliform in this PC indicates sensitivity of bacteria and other biochemical reaction to pH [49]. However positive loading of coliform with strong positive loading of SO_4^{2-} Ca^{2+} and $CaCO_3$ indicate relative availability of dissolved oxygen in shallow aquifer and water-soluble calcite rock, which is characterized by high permeability, porosity and sometimes, development of Karst and sink holes [16], [24]. It can also indicate availability of dissolved oxygen in surface water. However, it should be recalled that apart from Na^+ all the parameters loaded in this PC (PC 1) show higher concentrations in ground sourced sachet water samples than the surface sourced (Figure 2). this means chemical weathering is more pronounced in groundwater than surface water.

The second component (PC 2) explains 14.40% of the total variance with an eigenvalue of 3.2. This component shows strong positive loading of Cu^{2+} and Mn^{2+}, moderate positive loading of Pb and SO_4^{2-}, weak positive loading of Na^+ as well as Moderate negative loading of EC and TDS. This component indicates weathering < atmospheric deposition < mining < corrosion < water treatment. According to [48], it is possible to have single PC with multiple processes. This is the case with PC 2, which indicates five processes, even though water treatment is dominant. Presence of Sodium, sulfate and manganese in natural water is not unexpected; they naturally occur in rocks and soils where they are dissolved into the water bodies [15], [55]. However higher loading of SO_4^{2-} over the Na^+ and strong loading of Cu^{+2} and moderate loading of Pb suggested for other source of SO_4^{2-} in to the water apart from weathering. According to [12] sulfur compounds (mostly SO_2) that arise from the burning of fossils fuels come back to the earth in the form of sulfuric acids dissolved in the rain water after undergoing further oxidation in the atmosphere; the sulfuric acid according to [49], will react in water to form two hydrogen ions and one sulfate ion, thus:

$$H_2SO_4 = 2H^+ + SO_4^{2-} \quad (3)$$
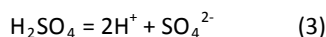
High sulfate levels in water can increase corrosion of cupper from plumbing [55], and lead can corrode more rapidly when it is coupled with copper [53], [55]. Thus a positive loading of these parameters in this PC indicates possible corrosion from plumbing. However the above reaction will increase acidity, and according to the [49] acid water will generally tends to have more dissolved trace elements at higher concentration.

At best, the PC 2 would be seen as an indicator of water treatment processes, particularly coagulation and disinfection. Normally, the reaction that resulted from the use of aluminium sulphate (commercial alum) as coagulant is complex one, but (according to [51] it is often simplified as

$$Al_2(SO_4)_3 + 3Ca(HCO_3)_2 \rightarrow 2Al(OH)_3 + 3CaSO_4 + 6CO_2 \quad (4)$$
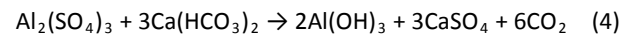
Since coagulation is pH dependent [51] insufficient alkalinity (as $CaCO_3$) can lead to release of sulfuric acid, which react with water and form two hydrogen ions and one sulfate ion [49], thus

$$Al_2(SO_4)_3 + 6H_2O \rightarrow 2Al(OH)_3 + 3H_2SO_4 \quad (5)$$
$$H_2SO_4 = 2H^+ + SO_4^{2-}$$
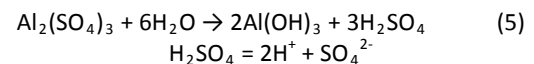
Chlorine, which is widely used for the disinfection of water, is a powerful oxidizing agent which will rapidly combine with reducing agents and unsaturated organic compounds [51], e.g.

$$H_2S + 4Cl_2 + 4H_2O \rightarrow H_2SO_4 + 8HCl \quad (6)$$

According to the [51] this immediate chlorine demand must be satisfied before chlorine becomes available for disinfection. However super-chlorination/de-chlorination [55] is express as

$$Cl_2 + SO_2 + H_2O \rightarrow H_2SO_4 + HCl \quad (7)$$
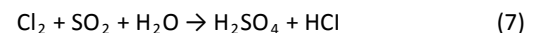
These further dismissed the impact of weathering in this PC, and uphold the role of artificial water treatment in the quality of sachet water samples in review. Better still the positive loading of sodium in this PC may not be unconnected with the use of sodium chloride and sodium chlorate in the production of chlorine dioxide, which is used for water treatment [51], [55]. Chlorine dioxide is unstable, and rapidly decomposes into chlorite, chlorate and chloride ions in treated water. Thus the major route of environmental exposure to chlorine dioxide, sodium chlorite and sodium chlorate is through drinking water [55]. Another debate that will arise from this PC is the possible impact of mining activities on the water quality in the study area; this is informed by moderate loading of Pb with strong Mn and Cu^{2+}, all of which are connected to mining activities [12], [49]. According to [49], the mining activities taking place in the up-stream may exert impact on water quality in the down-stream. Negative loading of electrical conductivity and TDS in this PC indicate strong relationship between the two parameters where EC has been used as surrogate for TDS [24], [51], [53].

The third PC (PC3) has 1.6 eigenvalues, accounting for 12.4% of the variability, and consisting of a moderate positive loading of Zn with Fe^{2+}, as well as a moderate positive loading of EC with TDS. Because limonite and other iron-bearing rocks are nearly universal, dissolved iron is a very common constituent in water [12], [16]. Zn on the other hand is released to water as a result of the dissolution from zinc plated pipes [55], runoff from road, industrial waste and landfills. However the positive loading of Zn with Fe^{2+} suggested for corrosion from galvanized pipe that is made of iron; zinc is used intensively in galvanizing iron to prevent rust [12].

Generally, the negative loading of EC-TDS in this PC and the previous PC (PC 2) is not only indicating the natural relationship between the two parameters [24], [51], [53], but it is also indicating precipitation of one of the most important component of TDS, the Ca^{2+}, during coagulation. Thus:

$$Al_2(SO_4)_3 + 3Ca(HCO_3)_2 \rightarrow 2Al(OH)_3 + 3CaSO_4 + 6CO_2 \quad (8)$$
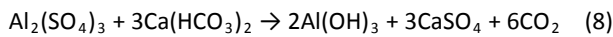
According to [51] when using commercial alum $Al_2(SO_4)_3.14H_2O$, it is found that 1mg/l alum destroys 0.5 alkalinity as $CaCO_3$, and TDS and the EC of a solution depend on the quantity of dissolved salt or dissolved materials present. It should be recalled that in this research Zn and Fe are significantly higher in surface sourced samples respectively as when compared with the ground sourced Figure 2 (a) and opposite is the case for EC and TDS (Figure 2 (b).This means that most of the treatment were carried out for surface water [14].

Therefore, the third PC like PC 2, also indicates multiple processes, which include water treatment and corrosion, where corrosion is dominant.

The forth PC has 1.4 eigenvalues, accounting for 8.8% of the variability, and consisting of moderate positive loading of Mg^{2+} and Coliforms, weak positive loading of Cl^- and moderated negative loading of pH. Magnesium is extremely common in natural water system with dolomite $(CaMg(CO_3)_2$ being the widespread natural source [12]. However, the positive loading of Mg^{2+} with weak negative loading of pH (slightly acidic) in this PC indicates the role of Mg^{2+} on acidity [49]. The weak positive loadings of Cl^- - Coliform on the other hand indicates sewage pollution, where both Cl^- and coliform were used as indicators of sewage pollution [51], [52], [55]. This PC therefore partially indicates weathering and largely indicates sewage contamination. However, since both Cl^- and Coliform are higher in ground than surface sourced samples (Figures 2 (a) and Table 2), possibility of sewage contamination of ground water in the study area is a matter of concern.

The fifth PC with 1.2 eigenvalues, controlling 8.0% of the total variability, consists of weak positive loading of EC and TDS as well as strong and moderate positive loading of Cr^{2+} and Cl^-

respectively. The positive loadings of EC-TDS in this PC further indicates correlation between the two parameters, where EC has been used as surrogate for TDS [24], [53]. Positive loading of Cl^- on the other hand indicates significant contribution of Cl^- to TDS; according to the [24] and [53] Cl^- is one of the principal components of TDS. Both TDS and Cl^- found in drinking water usually come from natural sources, sewage, urban runoff and industrial activities [55]; similarly the Cr^{2+} also arises from natural sources, industrial activities [12], [53] and domestic waste. Since industrial activities are not significant in the study area, the factors that are contained in this PC can be summarized as Urban runoff > sewage pollution > industrial activities.

The last (but not the least) PC (the PC 6) has 1.04 eigenvalues, accounting for 7.0% of the variability, and consisting of strong positive loading of Ni, weak positive loading of Pb and Zn as well as weak negative loading of Cr. The positive loadings of Ni-Pb-Zn is an indication of corrosion in the plumbing system and urban runoff; this is because Ni and Zn usually found their way into water system as result of their dilution from plated pipes [12], [55]; or burning/combustion of fossil fuels, from which these elements enters water through surface runoff [12]. Similarly, though the use of lead (Pb) as additive in gasoline has been baned, Pb could be carried in urban runoff into the water bodies from waste (like batteries), just as it could come from lead pipes and solder in old plumbing [12], [55].

The six principal components analysed so far indicated that sachet water quality in the study area is influenced by eight factors, which can be presented in decending order of priority as weathering > water treatment > corrosion of plumbing system > sewage polution > atmospheric deposition > urban runoff > mining > industrial activities.

Student's "t" test

Table 5   Paired Samples Test for surface and ground sourced Sachet water in Sokoto metropolis

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Surface sourced – Ground sourced	-5.2899824	10.7741183	2.6131075	-10.8295228	.2495581	-2.024	16	.060

Going by Table 5 0.060 is greater than α value (0.05) therefore the H_0 is accepted. Thus: "Paired sample t test failed to reveal a statistical mean difference between surface (M = 9.28, s = 18.69) and ground (M = 14.57, s = 29.33) sourced sachet water in Sokoto metropolis, t(16) = 2.024, p = .060, α = .05. This means "there is no significance difference between sachet water samples produced from surface water sources in Sokoto metropolis and those produced from groundwater sources in the area.

As mentioned earlier, this insignificance different between the two sources in review must have been resulted from significant interaction between the ground and surface water in the study area and the probability that most sachet water companies using ground water are using boreholes that are less than 50 meters deep or tube wells.

Conclusion

Having analyzed the data obtained from laboratory analysis of the 17 parameters used for this research, it is concluded that only 18.1% of sachet water in the study area were not safe for drinking, and the quality differences between the sachet water produced using ground water sources and those produced using surface water source is not significant. Lastly it is concluded that the quality of sachet water in Sokoto metropolis is affected in descending order, by weathering, water treatment, corrosion of plumbing system, sewage pollution, atmospheric deposition, urban runoff, mining, and industrial activities. Thus sachet water quality in the study area is affected by both natural and anthropogenic process.

Recommendations

Both ground and surface water sources used for sachet water production need to be fully protected from sewage contamination and other pollutants that are associated with urban runoff and anthropogenic activities; use of deep boreholes (50 – 100 meters) for sachet water companies that use groundwater sources should be ensured. However, while location of borehole needs to be far from the location of septic tank, indiscriminate digging of septic tanks at indiscriminate depths must be controlled; effective filtration must be ensured, through the use of appropriate filters, regular back-wash of the filters and due replacement of expired ones; Adequate chlorination needed to be ensured so as to provide free chlorine residuals that could prevent microbial re-growth; There is need for replacement of old plumbing systems (that were made from metals) with PCV pipes; The qualities of the environment in which sachet water are produced in the study area needs to be improved; Lastly strict adherence to water policy should be ensured.

Mean while, futher research is recommended on the rate of contamination of ground water from sewage, the health implications of water treatment technique in public water supply, the relationship between mining activities in the up-stream and surface water pollution with lead, the impact of air quality on the quality of surface water sources, and the role of urban runoff as contributor of water contaminants in the study area.

REFERENCES

[1] Abubakar, U and Nasir M.K (2010) "Statistical process and control: A case study of some basic chemicals used in pure water production" *Pakistan Journal of Nutrition,* 9(4): 387-391.

[2] Adegoke, O.A, Bamigbowu E.O, Oni E.S, ugbaja K.N (2012) "Microbiological examination of sachet water sold in Aba, Abia state, Nigeria". *Global Research Journal of Microbiology,* 2(1):062-066.

[3] Adekunle, L.V, Sridhar M, Ajayi A.A, Oluwade P.A, Olawuyi J.F (2004) "An assessment of health and social economic implications of sachet water in Ibadan Nigeria: a public health challenge" *African Journal of Biomedical Research,* 7: 5-8.

[4] Ahimah, J.K and Ofosu S.A (2012) "Evaluation of the quality of sachet water vended in the New Juaben municipality of Ghana". *International Journal of Water Resources and Environmental Engineering,* 4(5): 134-138.

[5] Ajayi, A.A, Sridhar M.K.C, Adekunle L.V,Oluwade P.A, (2008) "Quality of packed water sold in Ibadan, Nigeria" *African Journal of Biomedical Research,* 11:251-258.

[6] Ajayi, O.S and Adesida G (2009) "Radioactivity in some sachet drinking water samples produced in Nigeria" *Iran J. Radiat Res.* 7(3): 151-158.

[7] Alhassan, A.J, Imam A.A, Yakasai H.M (2008) "Quality assessment of sachet water packaged around Kano metropolis, Nigeria" *Bayero Journal of Pure and Applied Sciences,* 1(1): 83-87.

[8] Amori, R, Nana D.A (2010) "Assessment of the quality of bottled/sachet water in the Tarkwa-Nsuaem municipality (TM) of Ghana". *Research Journal of Applied Sciences, Engineering and Technology*, 3(5): 377-385.

[9] Anuoye, J.C, Maxwell O.M, Caleb M.Y (2012) "Quality of sachet water produced and marketed in Minna metropolis, North Central Nigeria". *African Journal of Food Science,* 6(24): 583-588.

[10] Arnold, E.G, Rhodens R.T, Lenore S.C (1985) *"Standard Methods for the Examination of Water and Wastewater"* 16th Edition, American Public Health Association (APHA), American Water Works Association (AWWA), and Water Pollution Control Federation (WPCF).

[11] Azika, N (2006) *"Research Methodology in Behavioral Scinces"* Longman Pub. Nigeria.

[12] Bailey, R.A, Clark H.M, Ferris J.P, Krause S, Strong R (2002) *"Chemistry of the Environment"* (Second edition), Elsevier Inc.

[13] Bartrand, T.A, Weir M, Haas C.N (2007) "Advancing the quality of drinking water: Expert workshop to formulate a research agenda". *Environmental Engineering Science,* 24(7): 863-872.

[14] Bhatia, S.C (2008) *Environmental Chemistry* C.B.S Publishers, New Delhi (India).

[15] Chamley, H. (2003) *"Development in the Earth and Environmental Sciences, VOL. 1: Geosciences Environment and Man"* Elsevier B.V

[16] Cheremissinoff, N.P (1998) *"Groundwater Remediation and Treatment Technologies"* Willams Andrew Inc.

[17] Chinelu, M, Ojiegbe G.C, Ihenyi O.O, Ngozi N.O, John A.A, Jonathan C.N, Charles C.O (2011) "Bacteriological evaluation of some sachet water on sales in Owerri metropolis, Imo state, Nigeria". *Malaysian Journal of Microbiology,* 7(4): 217-225.

[18] Dada, C.A (2009) "Towards a successful packaged water regulation in Nigeria". *Scientific Research and Assay,* 4(9): 921-928.

[19] Edema, M.O, Atayese A.O, Bankole M.O (2011) "Pure water syndrome: Bacteriological quality of sachet water sold in Nigeria". *African Journal of Food Agriculture Nutrition and Development,* 11(1): 4595-4609.

[20] Edu, I, Kyoung-Woong K, Godwin E, Ubong E (2010) "Trace elements in ground and packaged water in Akwa Ibom state, Nigeria". *Geosystem Engineering,* 13(2): 57-68.

[21] EPA (2006) "*Distribution System Indicators of Drinking Water Quality*" Environmental Protection Agency, USA

[22] Ezeugwunne, I.P, Agbakoba N.R, Nnamah N.K (2009) "The prevalence of bacteria in packaged sachet water sold in Nnewi, South East, Nigeria". *World Journal of Dairy and Food Sciences,* 4(1): 19-21.

[23] Fawola, M.O, Oso B.A (1995) *"Laboratory Manual of Microbiology"* Spectrum Books Limited, Ibadan, Nigeria.

[24] Fitts, C (2012) *"Groundwater Science"* (Second Edition) Elsevier Inc.

[25] Jatto, E.O And Asia I.O, (2010) "Quality assessment of domestic water in Epoma" *Report and Opinion,* 2(12): 86-93.

[26] Johnson, T, Case C (2010) *"Laboratory Experiment in Microbiology"* San Francisco

[27] Joseph, N.A, Celestine A.A, Wilberforce O (2012) "Determination of Calcium, Magnesium and Total Hadness concentrations in drinking water supply in Ebonyi state, Nigeria". *Continental Journal of Water, Air and Soil Pollution,* 3(1): 12-16.

[28] Kalpana, S, Bagudo A.I, Aliero A.A (2011) "Microbiological analysis of sachet drinking water marketed at two sites in Aliero, Kebbi state, Nigeria". *Continental Journal of Microbiology*, 5(1):29-36.

[29] Kumar, N.V, Mathew S, Swaminathan G. (2010) "A Hybrid Apporoach towards the assessment of groundwater quality for potability: A fuzzy logic and GIS based case study of Tiruchirapalli city, India". *Journal of Geographic Information System,* 2: 152-162.

[30] Maduabuchi, C.M (2002) "Case studies on transboundary aquifers in Nigeria". Proceedings of the International Workshop, Tripoli, Libya", (2-4 June): 135-141.

[31] Mamman, A. B (2000) *"Nigeria; Giant in the Tropics"* Vol. 2 Abuja: Gabumo Publishing company.

[32] Marghade, D, Malpe D.B, Zade A.B (2011) "Geochemical characterization of groundwater from northeastern part of Nagpur urban, central India" *Environmental Earth science,* 62: 1419-1430.

[33] Martin, E.O, Iniekong P.U, Clara I.E (2012) "Microbial Analysis of Sachet and Tap Water in Enugu State of Nigeria". *Scientific Reseach Journal of Advances in Microbiology*, 2: 547-551.

[34] Muazu, J, Muhammad-Biu A, Muhammad G.T (2012) "Microbial quality of packaged sachet water Marketed in Maiduguri Metropolis, North Eastern Nigeria" *British Journal of Pharmacology and Toxicology*, 3(1): 33-38.

[35] Muhammad, M. A, Ujoh F (2012) "Assessment of the quality of potable water sources In Abuja, Nigeria" *British Journal of Applied Science and Technology*, 2(2): 146-172.

[36] NPC (2010) *"Population Distribution by Sex, State, Local government and Senetorial district, 2006 Population and Housing Census"* National Population Commission, Abuja, Nigeria; Vol. 3

[37] Ogbonna, O, Jimoh W.L, Awagu E.F, Bamishaiye E.I (2011) "Determination of some trace elements in water samples within Kano metropolis" *Advanced in Applied Science research,* 2(2): 62-68.

[38] Ogontona, T.S, Adedeji O.O, Matins O.C (2012) "Contamination of sachet water produced within industrial area of Ikeja, Lagos Nigeria" *Transnational Journal of Science and Technology,* 2(10): 69-74.

[39] Okioga, (2005) "Water Quality and Business Aspects of Sachet-Vended Water in Tamale, Ghana" Unpublished thesis, submitted to the Department of Civil and Environmental Engineering, in partial fulfillment of the requirements of the Degree of Master of Engineering in Civil and Environmental Engineering at the Massachusetts Institute of Technology.

[40] Omezuruike, O.I, Damilola A.O, Adeola O.T, Fajobi E.A, Shittu O.B (2008) "Microbiological and physicochemical analysis of different water samples used for domestic purposes in Abeokuta and Ojota, Lagos state, Nigeria" *African Journal of Biotechnology,* 7(5): 617-621.

[41] Onemano, J.I and Otum J.A (2003) "Problems on water quality standards and monitoring in Nigeria"; a paper presented at the 29th WEDC International Conference, Abuja, 22-26 September 2003.

[42] Onweluzo, J.C and Akuagbazie C.A (2010) "Assessment of the quality of Bottle and sachet water sold in Nsukka town" *Journal of Tropical Agriculture, Food, Environmental and Extension,* 9(2):104-110.

[43] Oparaocha, E.T, Iroegbun O.C, Obi R.K (2010) "Assessment of quality of drinking water sources in the Federal University of Technology, Owerri, Imo state, Nigeria". *Journal of Applied Biosciences,* 32: 1964-1976.

[44] Oyedeji, O, Olutiola P.O, Moninuola M.A (2010) "Microbiological quality of packaged drinking water brands marketed in Ibadan metropolis and Ile-Ife city in South Western Nigeria". *African Journal of Microbiological Research,* 4(1): 096-102.

[45] Ramon, J.S, Evans T.M, Lechvallier C.E (1981) "Coliform Species Recovered from Untreated Surface Water and Drinking Water by Membrane Filter, Standard, and Modified Most-Probable-Techniques" *Applied and Environmental Microbiology,* 41(3): 657-663.

[46] Shalom, N.C, Obinna C.N, Adetayo Y.O, Vivienne N.E (2011) "Assessment of water quality in Canaanland, Ota, Southwest Nigeria". *Agriculture and Biology Journal of North America,* 2(4): 577-583.

[47] SON (2007) "Nigerian Industrial Standard (NIS 554:2007); The Nigerian standard for Drinking Water Quality" Standard Ognization of Nigeria.

[48] Sulaiman, W.N.A, Kura N.U, Ramli M.F, Ibrahim S, Aris A.Z, Mustapha A (2013) "evaluation of factors influencing the ground water chemistry in a small tropical Island of Malaysia". *International Journal of Research and Public Health,* 10: 1861-1881.

[49] Sullivan, P.J, Agardy F.J, Clark J.J. (2005) *"The Environmental Science of Drinking Water"* Elsevier Inc.

[50] Taiwo, A.A, Idowu O, Lanre-lyanda Y.A, Jolaoso A.A, Jiboku O.O, Ijaola T.O, Taiwo A.G (2012) "Physico-chemical and bacterialogical analysis of

sachet water samples in Abeokuta metropolis". *Global Advanced Research Journal of Agricultural Science,* 1(1): 001-006.

[51] Tebbutt, T.H.Y (1998) *"Priciples of Water Quality Control : Fifth Edition"* Elsevier Ltd.

[52] Todd, D.K and Mays L.W (2005) *"Groundwater Hydrology"* John Wiley & Sons, Inc.

[53] UNICEF (2008) "Unicef Hand Book on Water Quality" United Nations Children's Fund, New York.

[54] Waziri, M. (2012) "Assessment of the microbial quality of sachet water in Damaturu-Yobe state, Nigeria" *Journal of Asian Scientific Research,* 2(2): 76-80.

[55] WHO (2006) *"Guidelines for Drinking Water Quality"* 3rd Edition, Vol. 1

[56] Weber, S.G (1996)*"Comprehensive Analytical Chemistry; Vol.3: (Spectrochemical Trace Analysis For Metals and Metalloids)"* Elesevier B.V

APPENDIX 1   SON Standard and WHO Guidelines for Drinking Water Quality respectively

Maximum permissible limit for Inorganic Constituents

Parameter	Unit	SON	WHO
Aluminum (Al)	Mg/L	0.2	0.2
Arsenic (As)	mg/L	0.01	0.01
Barium	mg/L	0.7	0.7
Cadmium (Cd)	mg/L	0.003	0.003
Chloride (Cl)	mg/L	250	-
Chromium (Cr^{6+})	mg/L	0.05	0.05
Conductivity	µS/cm	1000	-
Copper (Cu^{+2})	mg/L	1	2
Cyanide (CN^-)	mg/L	0.01	0.07
Fluoride (F)	mg/L	1.5	1.5
Hardness (as $CaCO_3$)	mg/L	150	-
Hydrogen Sulphide (H_2S)	mg/L	0.05	-
Iron (Fe^{+2})	mg/L	0.3	0.3
Lead (Pb)	mg/L	0.01	0.01
Magnesium (Mg^{+2})	mg/L	0.20	-
Manganese (Mn^{+2})	mg/L	0.2	0.4
Mercury (Hg)	mg/L	0.001	0.006
Nickel (Ni)	mg/L	0.02	0.07
Nitrate (NO_3)	mg/L	50	50
Nitrite (NO_2)	mg/L	0.2	3
pH	-	6.5-8.5	-
Sodium (Na)	mg/L	200	-
Sulphate (SO_4)	mg/L	100	-
Total Dissolved Solids (TDS)	mg/L	500	-
Zinc (Zn)	mg/L	3	-

Maximum permitted limit for Microbiological Parameters

Parameter	Unit	SON	WHO
Total Coliform count (TCC)	cfu/mL	10	10
Thermo tolerant Coliform or *E.coli*	cfu/100mL	0	0
Faecal streptococcus	cfu/100mL	0	0
Clostridium perfringens spore	cfu/100mL	0	0

Source: SON (2007) &WHO (2006)

APPENDIX 2   Mean, Maximum, Minimum and Standard deviation from chemical analysis of sachet water samples obtained from Sokoto metropolis (mg/L)

Samples from surface water																
Samples	Cr	Cu	Fe	Mn	Ni	Pb	Zn	Ca	Mg	CaCO3	Na	SO4	Cl	TDS	EC	pH
Mean	0.014	0.112	0.046	0.021	0.015	0.007	0.134	11.121	1.472	33.837	0.051	0.030	0.231	38.812	65.056	6.8
Max.	0.051	0.391	0.343	0.067	0.029	0.013	1.188	26.070	4.491	69.306	0.115	0.100	0.600	97.400	165.20	7.6
Min	0.010	0.009	0.000	0.005	0.007	0.004	0.003	2.807	0.749	10.088	0.007	0.002	0.100	29.200	49.100	5.8
STDV.	0.007	0.098	0.068	0.012	0.006	0.003	0.214	4.964	0.773	12.221	0.027	0.020	0.091	11.549	19.871	0.3

Samples from groundwater																
Samples	Cr	Cu	Fe	Mn	Ni	Pb	Zn	Ca	Mg	CaCO3	Na	SO4	Cl	TDS	EC	pH
Mean	0.014	0.089	0.028	0.016	0.014	0.006	0.026	16.962	1.778	49.693	0.050	0.041	0.263	61.946	103.40	6.9
Max.	0.031	0.323	0.115	0.062	0.029	0.013	0.193	70.588	3.743	191.82	0.265	0.135	0.400	182.00	305.00	8.0
Min	0.010	0.009	0.000	0.005	0.007	0.004	0.003	0.802	0.749	8.143	0.007	0.009	0.100	31.700	52.700	4.8
STDV.	0.006	0.102	0.028	0.013	0.007	0.003	0.042	15.920	0.849	40.748	0.055	0.039	0.082	31.738	53.281	0.8

Both surface and ground sourced samples																
Samples	Cr	Cu	Fe	Mn	Ni	Pb	Zn	Ca	Mg	CaCO3	Na	SO4	Cl	TDS	EC	pH
Mean	0.014	0.106	0.041	0.020	0.015	0.007	0.103	12.810	1.560	38.422	0.051	0.032	0.240	45.501	76.142	6.9
Max.	0.051	0.391	0.343	0.067	0.029	0.013	1.188	70.588	4.491	191.82	0.265	0.135	0.600	182.00	305.00	8.0
Min	0.007	0.099	0.041	0.013	0.006	0.003	0.103	9.778	0.803	24.973	0.037	0.024	0.090	22.096	37.167	0.5
STDV.	0.007	0.099	0.059	0.013	0.006	0.003	0.188	9.778	0.803	24.973	0.037	0.024	0.090	22.096	37.167	0.5

NB: **EC = µS/cm**   **pH = pH meter**