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Water Quality Assessment of Dug Wells in Lagos Island, Southwestern Nigeria

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Abstract *Several evidences abound that shallow wells can constitute public health problems if its water is incidentally contaminated. Consequently, physicochemical parameters and metal concentration of groundwater samples from Lagos Island were analysed and compared with WHO (2011) standards. Water samples were taken from dug wells across four clusters within Lagos Island in Nigeria. Standard (AOAC) methods were adopted in the analysis of the physicochemical parameters while heavy metals ions determination was done using Atomic Absorption Spectrophotometer. The results obtained revealed noticeable discrepancy in the levels of some physicochemical properties and metal ion concentration in the water samples when compared with WHO (2011) standards. Though most physicochemical parameters were within safe limits, hardness, conductivity, concentrations of lead, zinc, calcium, manganese and potassium exceeded their permissible limits. Decreasing order for the concentration of the metal ions was Ca > Mg > K > Zn > Fe > Cu > Mn > Pb > Ni > Cd. From the results and findings of the study, it is proposed that if mitigating measures are not implemented, well water within Lagos Island may constitute future environmental threat*

Key Words: *Shallow wells, water, quality, Lagos Island*

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1.0 Introduction

Groundwater pollution is an objectionable change in groundwater quality resulting from anthropogenic activities (Harter,2003;Odoemelam and Eddy, 2009). Contaminated environment has serious hazardous consequence on the health of humans, animal life and vegetation. Water pollution is a consequence of solid and liquid wastes disposal on land and surface water. The most important wastes are sewage, industrial effluent, agricultural produce and chemicals. Sewage consists of substances demanding oxygen for the process of degradation and living matters such as microalgae, bacteria, protozoan and parasites as well as chemicals. The remarkable increase in industrial activities within the last few decades and the release of detestable industrial effluents into the environment have been generated great concern to the populace and environmental scientist. Heavy metal concentration in drinking water is useful in understanding the role of pollutant and nutrient elements (Tamasi and Cini, 2004; Ogoko and Emeziem, 2018).

Groundwater is an essential natural resource that has immense benefit to mankind globally (Soladoye *et al*, 2014). Previously there was a very high demand for surface water as an alternative option for urban water supply. According to estimation, over 269 million urban dwellers depend on dug wells as their principal source of drinking water in Nigeria (Gronwall *et al.,* 2010). Inability of the various tiers of government to meet the demand for portable water supply and the cost of drilling boreholes, there is an increase in the number of surfaces well in several cities in Nigeria. The unfortunate development is that most of these wells are shallow and may not be deeper than 5 m. Consequently, several sources of pollution ranging from microbial, heavy metals and physicochemical factors (Foster and Chilton, 2013; Soladoye *et al*, 2014).

In an effort to establish the portability of borehole water samples in Obolo local government area of Akwa Ibom state, Itah and Akpan (2005) investigated the physicochemical and microbiological properties of borehole water within the studied zone. Their study indicated that iron and mercury were above the permissible limits of World Health Organisation (WHO, 2011) for portable water. Rutkoviene *et al*. (2005) established pollution of shallow well depends on seasons while Saito *et al*. (2016) observed strong increase in B, Si, Li, dissolved organic carbon, Mg^{2+}, NH_4^+, Na^+, and K^+) between 4% and 31% for a temperature change of 7 °C. According to Shakya *et al*. (2019), nitrogen contamination was observed in shallow wells within Kathmandu in Nepal and the contamination was linked to agricultural activities. Isah *et al*. (2015) also observed significant level of coliform contamination in wells dug around toilets in Bauchi state. In Southwestern Nigeria, Etim (2017) reported contamination of shallow groundwater by antimony and predicted future danger. In Ibadan, out of 100 wells studied, mean concentrations of manganese, iron, total dissolved solids, pH and bacterial population were outside the WHO permissible limit in more than 50% of the sampled wells. Wells with poor locational characteristics had high turbidity and bacterial population ($P < 0.05$). In assessing hazards generated by shallow well water in Abeokuta, Orebiyi *et* al. (2010) found that measured as Fe, Pb, NO_3, electrical conductivity, bacteria count and total coliform have mean values greater than World Health Organization maximum permissible standards for drinking water. In view of the possibilities of contamination of well water in Lagos state, owing to several and progressive activities within the zone in addition to natural factors, this study is designed to investigate the pollution status of Lagos Island with respect to physicochemical parameters and heavy metals. Literature has revealed that aquifers possess natural potentials to minimize pollution (USGS, 2014), which consequently reduces harmful impact of pollution on groundwater (Thuyet *et al,* 1994). It should also be noted that contamination takes a longer time to manifest in groundwater, when it eventually does, it is difficult and expensive to remediate, (Dan-Hassan, 2012). Aquifers are natural underground reservoirs with huge water loading potentials.

2.0 Materials and methods

2.1 Sample collection and preparation

Triplicate well water samples were collected from each sampling point or station within the same coordinate. The triplicate samples were pooled together to form composite mixtures. Sampling was done on eight different point or stations within four major study blocks from Lagos Island as presented in Table 1. The composite samples were collected in labeled 1 liter polyethylene containers and stored in a refrigerator prior to analysis.

2.2 Study Area

Lagos is the commercial nerve center located in the southwestern Nigeria and one of the most rapidly developing cities in the African continent. Lagos has estimated population of 21 million in 2016 census, which makes it the largest city in Africa, and 7^{th} most populous cities on the planet. The latitude and longitude coordinates are 6.465° **N** and 3.406° **E** respectively. Lagos state has the largest sea port and significant presence of manufacturing companies in Nigeria. The study focuses on four clusters or blocks in Lagos Island which constitutes the sampling sites. The four clusters are Tinubu, Idumota, Adeniji and Obalende. A total of eight composite samples were collected, two each from the four clusters as presented in Table 1.

Table 1: GPS particulars of sampling sites

Study Block	Station	Description	Location Coordinates
Tinubu	Station 1	Water North	6.455^0N, 3.425^0E
	Station 2	Water South	6.433^0N, 3.501^0E
Idumota	Station 3	Water North	6.403^0N, 3.502^0E
	Station 4	Water South	6.414^0N, 3.498^0E
Adeniji	Station 5	Water North	6.454^0N, 3.424^0N
	Station 6	Water South	6.411^0N, 3.320^0E
Obalende	Station 7	Water North	6.458^0N, 3.444^0E
	Station 8	Water South	6.480^0N, 3.300^0E

2.3 Determination of Physicochemical Properties

The pH of the water sample was estimated using Test-2 pH meter. The electrical conductivity and total dissolved solid (TDS) of water samples were measured using electrical conductivity/TDS/Temperature meter (HM Digital COM-100). The turbidity of each water sample was measured using spectrophotometer (HACH DR 2000). The turbidity of the sample was estimated against deionized water as a blank at a wavelength of 450 nm. Nitrate, sulphate and phosphate were determined using Spectrophotometric methods (HACH DR 2000 spectrophotometer). Alkalinity and acidity of the water samples were determined by the acid-base titrimetric method. Hardness of water was determined by EDTA titrimetric method using Erichrome black T indicator. Concentration of chloride was determined argentometrically by titration of 50 ml of sample against silver nitrate indicator. Carbonate ion and hydroxide ions concentration were determined using AOAC method (OMA, 2019).

2.4 Determination of heavy metal ions

Atomic absorption spectrophotometer (HACH DR2) was used in the analysis of metal element concentration according to American Public Health Association (APHA, AWWA, 2001).

Calibration curves were prepared for each metal using serially diluted concentrations of the respective metal stock solution. From the calibration curve, concentration of the metal ion was estimated through graphical extrapolation.

2.5 Pollution index

Pollution index is a geochemical index which was used to evaluate the extent of pollution of groundwater. Pollution index (Pi) is the ratio of the concentration of individual parameter evaluated to that of recommended standard. It describes the comparative contributed by each parameter to the overall pollution (Ogoko and Donald, 2018). Pollution index can be expressed thus:

$$Pollution\ index\ (Pi) = \frac{\text{concentration of individual parameter}}{\text{Recommended standard concentration}} \quad (1)$$

Pollution index has a threshold value of 1.0. Values less than unity (1.0) specifies that pollution has not occurred but values greater than 1.0 demonstrate substantial level of pollution.

3.0 Results and Discussion

3.1 Physicochemical properties

The results of the physicochemical parameters of well water samples from some locations within Lagos Island are presented in Table 2. The results showed differences in the concentration of physicochemical parameters of groundwater samples in Lagos Island. The pH of the water samples ranged from 5.60 ± 0.11 to 7.10 ± 0.12 with a mean value of 6.51. This indicate that the water is mildly acid, with closeness to neutrality. The pH values obtained from the water samples in most of the stations were within recommended maximum limit of 6.50-8.50 (WHO, 2011). Measured turbidity of the water ranged from 0.15 ± 0.20 to 0.16 ± 0.22 NTU. The WHO permissible limit for turbidity is 5 NTU (WHO, 2011). Therefore, the water is not polluted with respect to turbidity. Electric conductivity and total dissolved solid (TDS) ranged from 1040.0 ± 0.50 µs/cm^3 to 1520.00 ± 0.83 µs/cm^3 and 745.00 ± 1.30 mg/L to 1101.00 ± 1.60 mg/L respectively. The values of electrical conductivity were higher than the allowable maximum limit of 1000 µs/cm^3, whereas the values of TDS in most of the water samples were within the recommended maximum limit of 1000 mg/L (WHO, 2011). Therefore, the water is ionic indicating that it rich in soluble salts. This implies that the water may not be useful for certain purposes or could constitute health impact if consumed (Osu and Ogoko, 2012). Water with very low levels of total dissolved solids tend to exhibit characteristic taste while higher levels of total dissolved solids impacts unpleasant mineral taste and causes excessive scaling in electric boilers, heaters and water pipes (Ogoko *et al.,* 2015). Minimum (0.01 ± 0.00 mg/L) and maximum (0.09 ± 0.01 mg/L) levels of total suspended solids (TSS) were recorded in the water samples with a mean value of (0.043 mg/L). Measured salinity of well water samples ranged from 238.40 ± 0.70 mg/L to 635.73 ± 0.99 mg/L. It was observed that both Station 5 and Station 6 from Adeniji had at least twice more salt contents than other stations studied, and have slightly exceeded the recommended upper limit of 600 mg/L. (Manoj and Avinash,2012; CPCB, 2013) . This may be attributed to the close proximity of these locations to the sea. Nitrate and sulphate concentrations in groundwater samples ranged from 1.04 ± 0.03 to 1.46 ± 0.11 mg/L and 35.48 ± 0.12 to 37.6 ± 0.15 mg/L respectively. Nitrate and sulphate concentrations were within permissible limit of 10 mg/L and 250 mg/L respectively (WHO, 2011). Therefore, the water samples are not polluted with respect to nitrate and sulphate and their contribution to the measured salinity and conductivity may be minimal. Chloride ion and phosphate ion concentrations in groundwater samples ranged from 131.96 ± 0.18 to 351.89 ± 0.29 mg/L and 0.17 ± 0.09 to 0.21 ± 0.03 mg/L respectively. Cl^- ion concentrations were within recommended permissible limit of 250 mg/L (WHO, 2011). Hence the water is not polluted with chloride ions. Alkalinity of the water samples ranged from 240.00 ± 0.63 mg/L to 420.00 ± 0.39

mg/L. It was observed that hydrogen carbonate ion concentration varied from 366.00 ± 1.21 mg/L to 671.00 ± 0.61 mg/L with mean value of 518.5 mg/L. Hardness of water varies from 1592.00 ±1.81 mg/L to 2376.00 ± 1.00 mg/L with a mean of 2055 mg/L. Values of hardness of water above 180 mg/L indicates very hard water unsuitable for drinking without further treatment. Therefore, the water is hard. Hard water is cause by the presence of trioxocarbonate (IV) or tetraoxosulphate (VI) ions of calcium and magnesium. Since the measured concentration of trioxocarbonate (IV) is higher thatetraoxosulphate (VI), then temporary harness dominates the hardness. Boiling of the water before use can help to reduce the hardness.

3.2 Metal ions concentrations

Measured concentrations of heavy metals in groundwater samples from some parts of Lagos Island are recorded in Table 3.

Table 2: Physicochemical Parameter of Groundwater samples from Lagos Island

Parameter	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Mean	WHO Maximum LIMIT
pH	6.60±0.10	6.60±0.20	6.80±0.12	6.80±0.15	5.60±0.11	5.60±0.11	7.10±0.12	7.00±0.13	6.51	6.50-8.50
Turbidity (NTU)	0.16±0.01	0.16±0.02	0.15±0.20	0.16±0.21	0.16±0.20	0.16±0.22	0.16±0.21	0.16±0.20	0.16	5.00
EC μs^{cm3}	1040.0±0.50	1040.00±0.80	1040.00±0.60	1040.00±0.70	1520.00±0.80	1520.00±0.83	1260.00±0.40	1250.00±0.50	1214	1000
TDS (mg/L)	746.0±0.40	745.00±1.30	817.00±1.10	818.00±1.20	1101.00±1.60	1098.00±1.50	903.00±1.00	901.00±0.30	891.10	1000
TSS(mg/L)	0.09±0.01	0.08±0.01	0.01±0.00	0.07±0.01	0.03±0.01	0.02±0.01	0.02±0.01	0.02±0.01	0.043	---
Salinity (mg/L)	332.31±0.71	325.09±0.90	238.40±0.70	245.62±0.40	621.27±0.65	635.73±0.99	267.29±0.10	274.52±0.63	367.52	----
NO_3-N (mg/L)	1.12±0.10	1.04±0.03	1.42±0.11	1.27±0.12	1.23±0.13	1.38±0.15	1.42±0.10	1.46±0.11	1.29	10.00
SO4^{2-} (mg/L)	35.88±0.11	36.34±0.10	35.48±0.12	37.6±0.15	36.06±0.11	36.43±0.13	36.11±0.14	36.74±0.16		250-500
Alkalinity (mg/L)	300.00±0.21	320.00±0.51	380.00±0.91	360.00±0.52	240.00±0.63	260.00±0.74	440.00±0.83	420.00±0.39	340	-----
HCO_3^-(mg/L)	457.50±1.20	488.00±1.11	579.50±1.12	549.00±1.19	366.00±1.21	396.50±0.91	671.00±0.61	640.50±0.41	518.5	------
OH^- (mg/L)	127.50±2.10	136.00±2.01	161.50±0.89	153.00±1.18	102.00±0.78	110.50±1.10	187.00±0.58	178.50±0.68	144.5	-----
Acidity(mg/L)	30.00±0.20	30.00±0.01	30.00±0.18	30.00±0.19	30.00±0.21	30.00±0.16	40.00±0.17	40.00±0.19	32.5	------
Chloride (mg/L)	183.94±0.90	179.94±0.30	131.96±0.18	135.96±0.42	343.89±0.35	351.89±0.29	147.95±0.46	151.95±0.65	203.4	250
Hardness (mg/L)	2376.00±1.00	2324.00±2.45	2296.00±2.20	2308.00±1.98	1596.00±0.78	1592.00±1.81	1976.00±2.18	1972.00±1.99	2055	60-180
P-PO_4^{3-}	0.17±0.10	0.18±0.01	0.17±0.09	0.19±0.31	0.19±0.01	0.18±0.02	0.21±0.03	0.19±0.02	0.185	----

** Mean of three ± Standard Deviation

Table 3: Metal concentration in Groundwater samples from Lagos Island

Metal (mg/L)	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Mean	PSQCA	WHO limit
Cu	0.04±0.01	0.04±0.01	0.04±0.01	0.03±0.01	0.03±0.01	0.03±0.01	0.03±0.01	0.03±0.01	0.03	1.00	2.00
Pb	0.02±0.01	0.02±0.01	0.02±0.01	0.02±0.01	0.02±0.01	0.02±0.00	0.02±0.01	0.02±0.01	0.02	0.01	0.01
Fe	0.25±0.02	0.24±0.04	0.03±0.01	0.03±0.01	0.03±0.01	0.03±0.01	0.03±0.01	0.03±0.01	0.08	0.30	0.30
Mn	0.01±0.00	0.01±0.00	0.01±0.00	0.09±0.02	0.02±0.01	0.02±0.01	0.02±0.01	0.02±0.01	0.03	0.10	0.10
Zn	1.97±0.02	1.87±0.02	1.79±0.01	1.78±0.01	2.09±0.03	2.08±0.02	1.77±0.01	1.79±0.02	1.89	0.10	0.10
Cd	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00	0.01	0.003
Ca	952.30±0.20	931.46±0.28	920.24±1.25	925.05±1.20	639.68±0.98	638.07±0.92	791.98±0.50	790.38±0.60	823.64	100	----
Mg	345.95±0.40	338.38±0.52	334.31±0.30	336.05±0.60	232.39±0.52	231.80±0.38	287.71±0.90	287.13±0.25	299.22	50.00	------
K	31.74±0.02	31.04±0.03	30.68±0.01	30.83±0.02	21.32±0.20	21.27±0.50	26.40±0.03	26.35±0.10	27.45	10.00	-----
Ni	0.01±0.00	0.01±0.00	0.01±0.00	0.01±0.00	0.01±0.00	0.01±0.00	0.02±0.01	0.02±0.00	0.013	----	0.07

** Mean of three ± Standard Deviation

Mean concentrations of copper ranged from 0.03 ± 0.01 mg/L to 0.04 ± 0.01 mg/L with mean value of 0.03 mg/L. Therefore, concentrations of copper were within the recommended permissible limit (WHO, 2011). Mean concentration of lead (0.02 mg/L) obtained from the water samples was slightly higher than the permissible limit of 0.01 mg/L (WHO, 2011; SON, 2015). Mean concentration of iron in the water samples ranged from 0.03 ± 0.01 mg/L to 0.25 ± 0.02 mg/L. The measured concentrations are within the recommended maximum limit of 0.3 mg/L (WHO, 2011; SON, 2015). Manganese is essential to all organisms at certain minute concentration, however, at higher concentration it is an undesirable impurity in water because of its tendency to deposit black oxide stains. From Table 3, it is evident that mean concentration of manganese ion in the water ranged from, 0.01 ± 0.00 mg/L to 0.09 ± 0.02 mg/L with overall mean value of 0.03 mg/L. The measured concentrations of manganese ions were within the maximum permissible limit of 0.10 mg/L (WHO, 2011). Measured mean concentrations of zinc ranged from 1.77 ± 0.01 mg/L to 2.09 ± 0.03 mg/L with an overall mean value of 1.89 mg/L. Zinc concentrations were higher than the allowable limit of 0.10 mg/L for portable water (WHO, 2011). Therefore, the water is polluted with zinc. Concentration of cadmium in the water samples was below detectable limit while mean concentration of calcium ions ranged from 638.07 ± 0.92 mg/L to 952.30 ± 0.20 mg/L with an overall mean value of 823.64 mg/L. However, it is recommended that in drinking water the maximum permissible limit of Calcium is 100 mg/L (PSQCA, 2019). According to Sjors and Gunnarsson (2002), calcium concentration in natural groundwater ranged from 1 to 100 mg/L. Nature of the well and composition of the bedrock are the factors that determines the concentration of calcium in water. Magnesium concentrations varied from 231.80 ± 0.38 mg/L to 345.95 ± 0.40 mg/L with mean value of 299.22 mg/L. Magnesium and calcium ions are the primary cations in hard water. They commonly combined with carbonate or sulphate to constitute hardness to water. Potassium is an essential element for both plants and animals and its major source in water is from weathering and erosion of potassium-bearing minerals. Potassium concentration in uncontaminated aquifers is usually below 10 mg/L (PSQCA, 2019). Measured mean concentration of potassium in the groundwater samples ranged from 21.27 ± 0.50 to 31.74 ± 0.02 mg/L with overall mean value of 27.45 mg/L. Therefore, the studied wells are contaminated by potassium. The presence of high concentration of potassium ions in the water samples justified why the water is hard. Potassium exist as a very reactive monovalent metal, hence the high conductivity of the well water samples maybe attributed to the presence of soluble potassium salt.

The concentration of nickel ranged from 0.01 ± 0.00 mg/L to 0.02 ± 0.00 mg/L with mean value of 0.013 mg/L. The World Health Organization and Standard Organization of Nigeria permissible limit of Ni concentration in potable water is 0.07 and 0.02 mg/L respectively and the concentration of nickel in all water samples were within the recommended limit range. Hence, the water is not polluted with respect to nickel.

3.3 Pollution index

Pollution index of metal elements were computed and values presented in Table 4.

Table 4: Pollution index of metal elements for the ten sampling points

Metal (mg/L)	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Mean
Cu	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03
Pb	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Fe	0.83	0.80	0.10	0.10	0.10	0.10	0.10	0.10	0.28
Mn	0.10	0.10	0.10	0.9	0.20	0.20	0.20	0.20	0.25
Zn	0.66	0.62	0.60	0.59	0.70	0.69	0.59	0.59	0.60
Cd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca	6.35	6.21	6.14	6.35	4.27	4.25	5.28	5.27	5.52
Mg	6.92	6.77	6.69	6.72	4.65	4.64	5.75	5.74	5.98
K	3.17	3.10	3.07	3.08	2.13	2.13	2.64	2.64	2.75
Ni	0.14	0.14	0.14	0.14	0.14	0.14	0.29	0.29	0.18

Pollution index of copper, iron, manganese, zinc, cadmium, nickel was less than the threshold value (1.0), indicating that no pollution has occurred. On the other hand, the pollution index of lead, calcium, potassium and magnesium ranged from 2.00 to 5.98, indicating significantly high level of pollution.

3.4 Statistical Analysis

There is correlation among pH, EC, TDS, and Hardness ($p < 0.05$) and stronger significant relationship between pH and salinity, alkalinity, HCO, OH as well as chloride at ($p < 0.01$). Strong significant correlations were observed among HCO_3^-, salinity, acidity, and chloride at the $p< 0.05$ and between HCO_3^- with pH, alkalinity, and OH, at the $p< 0.01$ level of significant. Furthermore, there was strong correlation between copper and iron; copper and magnesium; copper and potassium; copper and nickel metals at the $p< 0.05$ level of significant. Correlation between physicochemical parameters and metal concentrations in groundwater samples was also observed. For instance, electrical conductivity showed strong correlation with magnesium metals at the $p< 0.05$ while TDS displayed strong correlation with copper metals at $p< 0.05$. Salinity showed strong correlation with magnesium, potassium and nickel at $p< 0.05$ while chloride showed strong correlation with magnesium, potassium and nickel at $p< 0.05$. Similarly, nitrate demonstrated stronger correlation with iron only at the $p< 0.01$ level f significant whereas SO_4^{2-} ion shows stronger correlation with zinc metals at $p < 0.01$. Strong correlations were also observed between alkalinity, manganese and calcium metals only at $p < 0.05$ level of significant respectively.

High conductivity of the groundwater samples can therefore be explained in terms of the high levels of the total dissolve solids, ions in solution and the associations between anions and the respective cations. The presence of $MgCl_2$, KCl, and nickel chloride in water sample may have contributed to the overall high salinity and hardness of the well water.

4.0 Conclusion

The physicochemical parameters and metal ion concentrations were within stipulated maximum permissible limits. However, the borehole water samples had very high level of hardness and needs further treatment before drinking. The concentration of lead appeared to be higher than the recommended limit, indicating that the water is not good enough for drinking.

Based on the findings of this work, it is therefore recommended that further research works be carried to determine the effects of the identified pollutants on the consumers of the studied wells in order to forestall future public health challenges. Finally, designed of affordable treatment measures may also help to improve the quality of the water.

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Appendix 1": Pearson correlation coefficients

	pH	Turbidity	EC	TDS	TSS	Salinity	NO_3^-	SO_4^{2-}	Alkalinity	HCO_3^-	OH	Acidity	Cl^-	Hardness	P-PO	Cu	Fe	Mn	Zn	Ca	Mg	K	Ni
pH	1																						
Turbidity	-.197	1																					
EC	-.740*	.333	1																				
TDS	-.747*	.212	.979**	1																			
TSS	.104	.411	-.561	-.623	1																		
Salinity	-.972**	.317	.859**	.836**	-.198	1																	
NO_3^-	.200	-.334	.331	.408	.878**	-.100	1																
SO_4^{2-}	.117	.539	-.047	-.001	.270	-.119	.006	1															
Alkalinity	.917**	-.223	-.444	-.435	-.271	-.834*	.537	.121	1														
HCO_3^-	.917**	-.223	-.444	-.435	-.271	-.834*	.537	.121	1.000**	1													
OH	.917**	-.223	-.444	-.435	-.271	-.834*	.537	.121	1.000**	1.000**	1												
Acidity	.563	.218	.121	.047	-.435	-.362	.591	.092	.766*	.766*	.766*	1											
Cl^-	-.972**	.317	.859**	.836**	-.198	1.000**	-.100	-.119	-.834*	-.834*	-.834*	-.362	1										
Hardness	.709*	-.300	.997**	.984**	.610	-.829*	-.383	.025	.394	.394	.394	-.154	-.829*	1									
P-PO	.232	.463	.339	.309	-.307	-.065	.361	.351	.451	.451	.451	.707*	-.065	-.366	1								
Cu	.217	-.488	-.682	-.712*	.453	-.347	-.533	.559	-.076	-.076	-.076	-.447	-.347	.708*	-.738*	1							
Fe	.092	.218	-.508	-.635	.823*	-.145	-.847**	-.218	-.257	-.257	-.257	-.333	-.145	.563	-.477	.745*	1						
Mn	.563	.218	.121	.047	-.435	-.362	.591	.092	.766*	.766*	.766*	1.000**	-.362	-.154	.707*	-.447	-.333	1					
Zn	.141	.227	-.176	-.055	.234	-.210	.049	.855**	.118	.118	.118	-.115	-.210	.155	.286	-.465	-.346	-.115	1				
Ca	-.946**	.305	.679	.636	.048	.941**	-.320	-.232	-.931**	-.931**	-.931**	-.511	.941**	-.628	-.289	-.096	.130	-.511	-.291	1			
Mg	.709*	-.300	-.997*	-.984**	.610	-.829*	-.383	.025	.394	.394	.394	-.154	-.829*	1.000**	-.366	.708*	.563	-.154	.155	-.628	1		
K	.709*	-.300	-.997**	-.984**	.610	-.829*	-.383	.025	.394	.394	.394	-.154	-.829*	1.000**	-.366	.708*	.563	-.154	.155	-.628	1.000**	1	
Ni	.710**	-.301	-.997**	-.984**	.610	-.830*	-.383	.024	.395	.395	.395	-.154	-.830*	1.000**	-.366	.708*	.562	-.154	.155	-.628	1.00**	1.00**	1