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Research Article

Physico-Chemical Analysis and Modelling of Ground Water Quality Parameters Using Water Quality Index Method (WQI) and Principal Component Analysis (PCA)

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Abstract

Groundwater is one of the major sources of water. It is affected by a number of natural and anthropogenic factors. As groundwater use has increased, issue associated with the quality of groundwater resources have likewise grown in importance. In this study, mathematical modelling technique for water quality index computation and multivariate statistical using Principal Component Analysis (PCA) were employed to evaluate and analyze the variability of ground water quality in parts of Benin City, Edo State, Nigeria. Various ground water quality parameters such as pH, turbidity, total suspended solids (TSS), Electrical Conductivity (EC), Total Dissolved Solids (TDS), Dissolved Oxygen (DO), phosphate, nitrate, sulphate, total solids (TS), sodium, potassium, calcium, magnesium, iron, lead, cadmium, zinc and chloride from twelve boreholes of known coordinates were investigated. Results of the computed water quality index indicate a latent variation in ground water quality of the study area. Although the index revealed an adequate ground water quality in the study area, a variation of 85.610% to 94.204% was observed. In addition, results of the principal component analysis (PCA) revealed that; phosphate, chloride and total dissolved solids are the three most important variables affecting the quality of the borehole water within the study area.

Keywords: Principal component analysis; Water quality index; Ground water; Electrical conductivity; Total dissolved solids

Abbreviations: PCA: Principal Component Analysis; WQI: Water Quality Index; GA: Ground Water; EC: Electrical Conductivity; TDS: Total Dissolved Solids; DO: Dissolved Oxygen; TSS: Total Suspended Solids

Introduction

Groundwater is one of the major sources of water. It is affected by a number of natural and anthropogenic factors. As groundwater use has increased, issue associated with the quality of groundwater resources have likewise grown in importance. For many years, attention has been directed at contamination from point sources. More recently, concerns have increased about nonpoint sources of contaminant and about the overall quality of groundwater resources Faisal [1]; Efe [2]; Oteze & Akujieze [3]. Contaminants in groundwater commonly result from infiltration containing agricultural fertilizers, pesticides, or contaminants from leaking tanks or pipes associated with industry Fryar [4], Debels [5]. Groundwater contamination can be detected by analyzing borehole water for a series of dissolved ion species. Hence water quality data sets typically contain many variables measured at several spatially scattered locations Ilaboya [6]. Water quality parameters which is used to assess the overall quality of ground water are usually adversely affected when untreated waste are discharge directly into water bodies Balakrishnan [7]. Apart from the fact that the pH will be totally altered, parameters such as chemical load, biological load, turbidity, conductivity, total dissolved solids, total suspended solids concentration of heavy metals and a host of other water quality parameters will also be affected. On account of these, it is recommended that monitoring programs be placed on ground that will constantly check and ensure that industries are located far away from water bodies in addition to monitoring the indiscriminate discharge of untreated waste into river and other water bodies Abdalkarim, et al. [8].

Identification of the critical factors affecting the overall quality of groundwater can be made possible through the use of non-parametric statistical techniques such as principal component analysis. In recent years many studies have been done using principal components analysis in the interpretation of water quality parameters. The application of different multivariate statistical techniques, such as cluster analysis (CA), principal component analysis (PCA) and factor analysis (FA) help to identify important components or factors accounting for most of the variation in the overall water quality Mazlum and Mazlum [9]. They are designed to reduce the number of variables to a small number of indices while attempting to preserve the relationships present in the original data. Iyer [10] constructed a statistical model which is based on PCA for coastal water quality data from the Cochin coast in south west India. The authors employed the model to explain the relationships between the various physicochemical variables that have been monitored and also to assess the effects of environmental conditions on the coastal water quality. Lohani [11] utilized principal components technique to provide a quick analytical method for the water quality of Chao Phraya river in Thailand. Also, Shihab [12] used this technique to describe the variation in water quality in Saddam dam reservoir and to reduce the number of water quality parameters needed for monitoring the lake water. In this study, water quality index model and principal component analysis were employed to study the variability in ground water quality from selected boreholes around Benin City.

Description of Study Area

The study area is Benin City in Nigeria. The city serves as the administrative and socio-economic center for both Oredo Local Government Area and Edo State in Nigeria. Benin City is a humid tropical urban settlement which comprises three Local Government Areas namely Egor, Ikpoba Okha and Oredo. It is located within latitudes 6020’N and 6058’N and longitudes 5035’E and 5041’E. It broadly occupies an area of approximately 112.552sq km. This extensive coverage suggests spatial variability of weather and climatic elements. Benin City lies visibly in the southern most corner of a dissected margin: a prominent topographical unit which lies north of the Niger Delta, west of the lower Niger Valley, and south of the Western Plains and Ranges Okhakhu [13]. The Benin City hydrological basin is partitioned into two main units. The first unit consists of the Ikpoba River Basin which drains the whole eastern part of the city while the second unit covers the Ogba River Basin which drains the western part. Although smaller rivers are found in some parts of the peripheral locations of the study area, in general, the hydrological basin clearly shows a north-south direction of flow owing to the high elevation of Nigeria from its northern part Okhakhu [13]. Fishing, irrigation, domestic consumption, industrial utilization, animal husbandry, recreation, environmental sanitation and research activities are some of the functions of rivers found in Benin City.

Rainfall, temperature, wind and relative humidity are the most significant climatic elements in Benin City. The rainfall element strongly determines the occurrence of the wet and dry seasons in the study area. As observed during the assessment of the urban troposphere using sensitive rain gauges of the American origin, the rainfall amount, its intensity, duration as well as its distribution throughout the city are determined by the prevailing maritime winds, changing clouds, temperatures and circulating pressures. Two principal air masses prevail in the City. These are the tropical maritime and tropical continental. The tropical maritime air mass which is essentially humid, warm, moisture-borne, and widely resident in Benin City for almost twelve months, originates from the South Atlantic Zone. It causes rainfall which begins from the late January till its gradual subsidence in mid-November. The arrival of rainfall in the study area brings welcome relief to the urban residents from the prevailing moderately dry and cold wind periods which normally occur between late December and the end of January Okhakhu [13]. Heavy rainfall and the associated floods occur frequently in Benin City and have caused huge economic losses as well as social problems. The Google earth map of Benin City is presented in Figure 1.

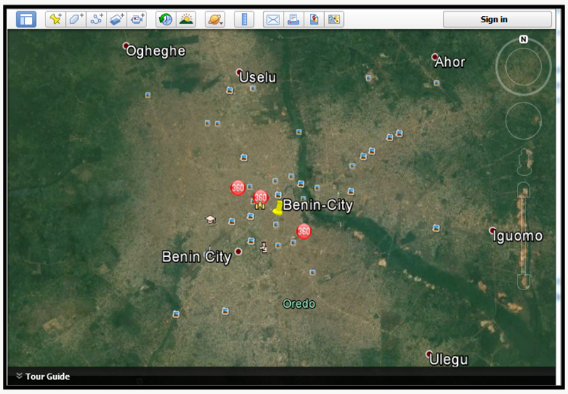

Figure 1: Google Earth Map Showing Benin City

Research Methodology

Sample Collection/Conditioning

Water samples were collected randomly from twelve (12) boreholes within the study area. On the spot (in-situ) test such as pH, conductivity, total dissolved solids and dissolved oxygen was conducted immediately after sample collection. The water samples were then conditioned by storing them in clean dried sample bottles at room temperature before analysis. The need for conditioning was to allow the water to settle properly and give room for the microbial organisms to exhibit their full characteristics behaviour for ease of detection Ilaboya [6].

Physico-Chemical Analyses of Water Samples

The water samples were then subjected to full laboratory analysis in other to determine their physico-chemical properties that was used to compute the overall water quality index of the individual water samples. Some of the methods employed in the analysis are described below:

Turbidity Measurement: The amount of colloidal and residual suspended matter present in the water samples was determined using the Jenway 6035 Turbidimeter.

Hydrogen Ion Concentration (pH): The hydrogen ion concentration (pH) of the water samples was determined using a standard laboratory digital micro-processor pH meter; Hanna pH 210 model.

Dissolved Oxygen Content (DO): The dissolved oxygen content (DO) of the water samples was measured using a standard laboratory sized digital dissolved oxygen analyzer model: DO - 5509.

Conductivity Measurement: The conductivity of the water samples was determined using a digital water/sand quality test kit model SN2209

Total Dissolved Solids (TDS): The amount of total dissolved solids (tds) present in the different water samples was determined using a digital water/sand quality test kit model SN2209

Heavy Metal Determination: The concentration of heavy metals present in the different water samples was determined using Atomic Adsorption Spectrophotometer (AAS). (SOLAAR 969 UNICAM SERIES, using air acetylene flame).

Water Quality Index Modelling

Water quality index was calculated for each of the sample water collected from different boreholes for assessing the variation of the overall quality of the water sample at each specific borehole location. The water quality index modelling was done by considering about fifteen (15) important physico-chemical parameters. The selected physico-chemical parameters include; pH, Nitrate, Electrical conductivity (EC), turbidity, Dissolved Oxygen (DO), Total Dissolved Solids (TDS), alkalinity, chloride, sulphate, Zinc, sodium, Carbonate Hardness, manganese, iron and copper. The basic steps involved in the modeling of water quality index are as follows:

Parameter Weightage Determination: For water quality index calculation, we first have to know the Weightage of each of the parameters identified. Parameters which have higher permissible limits are less harmful because they cannot significantly change the quality of the water sample even when they are present in high concentration. Weightage of tested parameters have an inverse relationship with its permissible limits. Therefore

$$W_n = \frac{1}{S_n} \quad (3.1)$$

Where;

W_n = Unit weight of the different parameters tested

S_n = Standard values of selected parameters (WHO Standard Permissible Limit)

Quality Rating or Sub Index of Selected Parameters: Rating scale was prepared for range of values of each parameter. The rating varies from 0 to 100 and is divided into five intervals. The rating qn = 0 implies that the parameter present in water exceeds the standard maximum permissible limits and water is severely polluted. On the other hand qn = 100 implies that the parameter present in water has the most desirable value. This scale is the modified version of rating scale given by Tiwari and Mishra (1985) and is calculated as follows:

$$q_n = \frac{100(V_n - V_{io})}{(S_n - V_{io})} \quad (3.2)$$

Where:

q_n = Quality rating or sub index

V_n = Laboratory test result for each parameter tested

S_n = Standard value of each parameter tested (WHO standard for drinking water)

V_{io} = ideal value of selected parameters tested (in pure water Vio = 0 for all parameters tested except pH and dissolved oxygen which is 7.0 and 14.6 respectively.

Water Quality Index Calculation: Essentially, a Water Quality Index (WQI) is a compilation of a number of parameters that can be used to determine the overall quality of water sample. pH, Nitrate, Electrical conductivity (EC), turbidity, Dissolved Oxygen (DO), Total Dissolved Solids (TDS), alkalinity, chloride, sulphate, Zinc, sodium, Carbonate Hardness, manganese, iron and copper. The numerical value was then multiplied by a weighting factor that is relative to the significance of the test to water quality. The sum of the resulting values was added together to arrive at an overall water quality index. It is basically a mathematical means of calculating a single value from multiple test results. The WQI result represents the level of water quality in a given borehole location. The following steps were employed in computing the overall water quality.

i. The weightage unit (W_n) for all parameters tested was determined and summed up to obtain

$$\sum W_n$$

ii. The quality rating or sub-index for all parameters tested was determined and summed up to obtain

$$\sum q_n$$

iii. The index W_n*q_n was calculated for each parameter tested and summed up to obtain

$$\sum W_n.q_n$$

iv. Finally, Water Quality Index (WQI) was computed for each borehole location using the mass balance equation of the form:

$$(100) - \left(\frac{\sum W_n.q_n}{\sum W_n}\right) \quad (3.3)$$

Ground Water Quality Analysis Using Principal Component Analysis

Statistical computations involving the application of principal component analysis for ground water modelling was made using statistical package for the social sciences (SPSS 22 software). Principal component analysis (PCA) is a powerful tool that attempts to explain the variance of a large dataset of intercorrelated variables with a smaller set of independent variables. The Principal Components (PC) is the uncorrelated (orthogonal) variables obtained by multiplying the original correlated variables with the eigenvector, which is a list of coefficients (loadings or weightings). Thus, the PCs are weighted linear combinations of the original variables. PC provides information on the most meaningful parameters, which describe the whole data set while affording data reduction with a minimum loss of original information. Application of PCA to ground water analysis was conducted by using the following step by step methodology

a) Collection of groundwater samples

b) Analysis of the water samples

c) Computation of Anti-image correlation matrix

d) Computation of eigen values

e) Extraction of the component matrix

f) Generation of scree plot

g) Extraction of the rotated component matrix

h) Horizontal decentralization of the component matrix

i) Extraction of parameters with critical effects on water quality

Result and Discussion

Results of the detailed physico-chemical analysis of the ground water samples are presented in Appendix while the parameters employed for the water quality index modelling and principal component analysis is presented in Tables 1- 3. Results of the computed water quality index are presented as shown in tables 4 to 15 respectively. Based on the result of Tables 4-15, it was observed that there is a significant variation in the water quality index of the water samples collected from the twelve different boreholes.

Table 1: Ground Water Quality Test Results (BH1, BH2, BH3, and BH4).

S/No	Parameters	WHO (Standard Value)	BH1	BH2	BH3	BH4
1	pH	6.5	7.5	7.4	7.4	7.43
2	Nitrate	10	0	0	0	0.00
3	E.C	1000	3150	3030	3075	3085
4	Turbidity	5	1.9	0.5	0.8	1.07
5	DO	5	4.7	4.4	4.6	4.57
6	TDS	500	2079	1999.8	2030	2036.3
7	Alkalinity	600	106.8	106.8	106.8	106.8
8	Chloride	250	18.1	18.3	18.2	18.20
9	Sulphate	250	3.74	3.75	3.73	3.74
10	Zinc	3.0	0.12	0.13	0.12	0.123
11	Sodium	200	23.4	24.1	23.5	23.67
12	Hardness	200	249.2	249.2	249.2	249.2
13	Manganese	0.05	0.047	0.048	0.048	0.0477
14	Iron	1.0	0.31	0.31	0.31	0.31
15	Copper	2.0	0	0	0	0.00

Table 2: Ground Water Quality Test Results (BH5, BH6, BH7, and BH8).

S/No	Parameters	WHO (Standard Value)	BH5	BH6	BH7	BH8
1	pH	6.5	7.5	7.4	7.4	7.43
2	Nitrate	10	0	0	0	0.00
3	E.C	1000	3320	2987	2960	3087
4	Turbidity	5	0.1	0.13	0.15	0.127
5	DO	5	4.5	4.4	4.4	4.43
6	TDS	500	2191.2	1971.4	1953.6	2038.73

7	Alkalinity	600	106.8	106.8	106.8	106.8
8	Chloride	250	16.4	17.3	17.6	17.1
9	Sulphate	250	0.63	0.61	0.64	0.627
10	Zinc	3.0	0.13	0.14	0.12	0.13
11	Sodium	200	26.1	25.6	26.3	26.0
12	Hardness	200	249.2	249.2	249.2	249.2
13	Manganese	0.05	0.048	0.049	0.048	0.0483
14	Iron	1.0	0.28	0.275	0.28	0.278
15	Copper	2.0	0.02	0.02	0.02	0.02

Table 3: Ground Water Quality Test Results (BH9, BH10, BH11, and BH12).

S/No	Parameters	WHO (Standard Value)	BH9	BH10	BH11	BH12
1	pH	6.5	6.3	6.6	6.6	6.50
2	Nitrate	10	0	0	0	0.00
3	E.C	1000	2840	2900	2840	2860
4	Turbidity	5	0.01	0	0	0.0033
5	DO	5	5.5	5.4	5.4	5.433
6	TDS	500	1874.4	1914	1874.4	1887.6
7	Alkalinity	600	178	178	178	178.0
8	Chloride	250	17.7	17.6	17.8	17.7
9	Sulphate	250	3.51	3.52	3.52	3.517
10	Zinc	3.0	0.15	0.15	0.15	0.15
11	Sodium	200	24.7	24.4	24.3	24.47
12	Hardness	200	249.2	212.3	249.2	236.9
13	Manganese	0.05	0.05	0.051	0.052	0.051
14	Iron	1.0	0.05	0.05	0.05	0.05
15	Copper	2.0	0.021	0.022	0.023	0.022

Table 4: Water Quality Index of BH1.

S/No	Parameters	WHO Limits (Sn)	Test Results (Vn)	Weightage (Wn)	Quality Rating (qn)	[(Wn*qn)]
1	pH	6.5	7.5	0.15385	-100	-15.38462
2	Nitrate	10	0	0.10000	0	0.00000
3	E.C	1000	3150	0.00100	315	0.31500
4	Turbidity	5	1.9	0.20000	38	7.60000
5	DO	5	4.7	0.20000	103.125	20.62500
6	TDS	500	2079	0.00200	415.8	0.83160
7	Alkalinity	600	106.8	0.00167	17.8	0.02967
8	Chloride	250	18.1	0.00400	7.24	0.02896
9	Sulphate	250	3.74	0.00400	1.496	0.00598
10	Zinc	3.0	0.12	0.33333	4	1.33333
11	Sodium	200	23.4	0.00500	11.7	0.05850
12	Hardness	200	249.2	0.00500	124.6	0.62300
13	Manganese	0.05	0.047	20.00000	94	1880.00000
14	Iron	1.0	0.31	1.00000	31	31.00000
15	Copper	2.0	0	0.50000	0	0.00000
	∑ = 22.50985		∑ = 1927.066			
WQI = [∑(Wn*qn)]/[(∑Wn)] = 85.60993334%						

Table 5: Water Quality Index of BH2.

S/No	Parameters	WHO Limits (Sn)	Test Results (Vn)	Weightage (Wn)	Quality Rating (qn)	[(Wn*qn)]
1	pH	6.5	7.4	0.15385	-80	-12.30769
2	Nitrate	10	0	0.10000	0	0.00000
3	E.C	1000	3030	0.00100	303	0.30300
4	Turbidity	5	0.5	0.20000	10	2.00000
5	DO	5	4.4	0.20000	106.25	21.25000
6	TDS	500	1999.8	0.00200	399.96	0.79992
7	Alkalinity	600	106.8	0.00167	17.8	0.02967
8	Chloride	250	18.3	0.00400	7.32	0.02928
9	Sulphate	250	3.75	0.00400	1.5	0.00600
10	Zinc	3.0	0.13	0.33333	4.333333333	1.44444
11	Sodium	200	24.1	0.00500	12.05	0.06025
12	Hardness	200	249.2	0.00500	124.6	0.62300
13	Manganese	0.05	0.048	20.00000	96	1920.00000
14	Iron	1.0	0.31	1.00000	31	31.00000
15	Copper	2.0	0	0.50000	0	0.00000
				∑ = 22.50985		∑ = 1965.238
WQI = [∑(Wn*qn)]/[(∑Wn)] = 87.30569971%						

Table 6: Water Quality Index of BH3.

S/No	Parameters	WHO Limits (Sn)	Test Results (Vn)	Weightage (Wn)	Quality Rating (qn)	[(Wn*qn)]
1	pH	6.5	7.4	0.15385	-80	-12.30769
2	Nitrate	10	0	0.10000	0	0.00000
3	E.C	1000	3075	0.00100	307.5	0.30750
4	Turbidity	5	0.8	0.20000	16	3.20000
5	DO	5	4.6	0.20000	104.1666667	20.83333
6	TDS	500	2030	0.00200	406	0.81200
7	Alkalinity	600	106.8	0.00167	17.8	0.02967
8	Chloride	250	18.2	0.00400	7.28	0.02912
9	Sulphate	250	3.73	0.00400	1.492	0.00597
10	Zinc	3.0	0.12	0.33333	4	1.33333
11	Sodium	200	23.5	0.00500	11.75	0.05875
12	Hardness	200	249.2	0.00500	124.6	0.62300
13	Manganese	0.05	0.048	20.00000	96	1920.00000
14	Iron	1.0	0.31	1.00000	31	31.00000
15	Copper	2.0	0	0.50000	0	0.00000
				∑ = 22.50985		∑ = 1965.925
WQI = [∑(Wn*qn)]/[(∑Wn)] = 87.33622458%						

Table 7: Water Quality Index of Sample BH4.

S/No	Parameters	WHO Limits (Sn)	Test Results (Vn)	Weightage (Wn)	Quality Rating (qn)	[(Wn*qn)]
1	pH	6.5	7.43	0.153846154	-86	-13.2307692
2	Nitrate	10	0.00	0.1	0	0
3	E.C	1000	3085	0.001	308.5	0.3085
4	Turbidity	5	1.07	0.2	21.4	4.28
5	DO	5	4.57	0.2	104.4791667	20.89583333
6	TDS	500	2036.3	0.002	407.26	0.81452
7	Alkalinity	600	106.8	0.001666667	17.8	0.029666667

8	Chloride	250	18.20	0.004	7.28	0.02912
9	Sulphate	250	3.74	0.004	1.496	0.005984
10	Zinc	3.0	0.123	0.333333333	4.1	1.366666667
11	Sodium	200	23.67	0.005	11.835	0.059175
12	Hardness	200	249.2	0.005	124.6	0.623
13	Manganese	0.05	0.0477	20	95.4	1908
14	Iron	1.0	0.31	1	31	31
15	Copper	2.0	0.00	0.5	0	0
				∑ = 22.50985		∑ = 1954.182
WQI = [∑(Wn*qn)]/[(∑Wn)] = 86.815%						

Table 8: Water Quality Index of BH5.

S/No	Parameters	WHO Limits (Sn)	Test Results (Vn)	Weightage (Wn)	Quality Rating (qn)	[(Wn*qn)]
1	pH	6.5	7.5	0.15385	-100	-15.38462
2	Nitrate	10	0	0.10000	0	0.00000
3	E.C	1000	3320	0.00100	332	0.33200
4	Turbidity	5	0.1	0.20000	2	0.40000
5	DO	5	4.5	0.20000	105.2083333	21.04167
6	TDS	500	2191.2	0.00200	438.24	0.87648
7	Alkalinity	600	106.8	0.00167	17.8	0.02967
8	Chloride	250	16.4	0.00400	6.56	0.02624
9	Sulphate	250	0.63	0.00400	0.252	0.00101
10	Zinc	3.0	0.13	0.33333	4.333333333	1.44444
11	Sodium	200	26.1	0.00500	13.05	0.06525
12	Hardness	200	249.2	0.00500	124.6	0.62300
13	Manganese	0.05	0.048	20.00000	96	1920.00000
14	Iron	1.0	0.28	1.00000	28	28.00000
15	Copper	2.0	0.02	0.50000	1	0.50000
				∑ = 22.50985		∑ = 1957.955
WQI = [∑(Wn*qn)]/[(∑Wn)] = 86.98216447%						

Table 9: Water Quality Index of BH6.

S/No	Parameters	WHO Limits (Sn)	Test Results (Vn)	Weightage (Wn)	Quality Rating (qn)	[(Wn*qn)]
1	pH	6.5	7.4	0.15385	-80	-12.30769
2	Nitrate	10	0	0.10000	0	0.00000
3	E.C	1000	2987	0.00100	298.7	0.29870
4	Turbidity	5	0.13	0.20000	2.6	0.52000
5	DO	5	4.4	0.20000	106.25	21.25000
6	TDS	500	1971.4	0.00200	394.28	0.78856
7	Alkalinity	600	106.8	0.00167	17.8	0.02967
8	Chloride	250	17.3	0.00400	6.92	0.02768
9	Sulphate	250	0.61	0.00400	0.244	0.00098
10	Zinc	3.0	0.14	0.33333	4.666666667	1.55556
11	Sodium	200	25.6	0.00500	12.8	0.06400
12	Hardness	200	249.2	0.00500	124.6	0.62300
13	Manganese	0.05	0.049	20.00000	98	1960.00000
14	Iron	1.0	0.275	1.00000	27.5	27.50000
15	Copper	2.0	0.02	0.50000	1	0.50000
	∑ = 22.50985					∑ = 2000.850
WQI = [∑(Wn*qn)]/[(∑Wn)] = 88.88778858%						

Table 10: Water Quality Index of BH7.

S/No	Parameters	WHO Limits (Sn)	Test Results (Vn)	Weightage (Wn)	Quality Rating (qn)	[(Wn*qn)]
1	pH	6.5	7.4	0.15385	-80	-12.30769
2	Nitrate	10	0	0.10000	0	0.00000
3	E.C	1000	2960	0.00100	296	0.29600
4	Turbidity	5	0.15	0.20000	3	0.60000
5	DO	5	4.4	0.20000	106.25	21.25000
6	TDS	500	1953.6	0.00200	390.72	0.78144
7	Alkalinity	600	106.8	0.00167	17.8	0.02967
8	Chloride	250	17.6	0.00400	7.04	0.02816
9	Sulphate	250	0.64	0.00400	0.256	0.00102
10	Zinc	3.0	0.12	0.33333	4	1.33333
11	Sodium	200	26.3	0.00500	13.15	0.06575
12	Hardness	200	249.2	0.00500	124.6	0.62300
13	Manganese	0.05	0.048	20.00000	96	1920.00000
14	Iron	1.0	0.28	1.00000	28	28.00000
15	Copper	2.0	0.02	0.50000	1	0.50000
				∑ = 22.50985		∑ = 1961.201
WQI = [∑(Wn*qn)]/[(∑Wn)] = 87.12634766%						

Table 11: Water Quality Index of BH8.

S/No	Parameters	WHO Limits (Sn)	Test Results (Vn)	Weightage (Wn)	Quality Rating (qn)	[(Wn*qn)]
1	pH	6.5	7.43	0.153846154	-86	-13.23076923
2	Nitrate	10	0.00	0.1	0	0
3	E.C	1000	3087	0.001	308.7	0.3087
4	Turbidity	5	0.127	0.2	2.54	0.508
5	DO	5	4.43	0.2	105.9375	21.1875
6	TDS	500	2038.73	0.002	407.746	0.815492
7	Alkalinity	600	106.8	0.001666667	17.8	0.029666667
8	Chloride	250	17.1	0.004	6.84	0.02736
9	Sulphate	250	0.627	0.004	0.2508	0.0010032
10	Zinc	3.0	0.13	0.333333333	4.333333333	1.444444444
11	Sodium	200	26.0	0.005	13	0.065
12	Hardness	200	249.2	0.005	124.6	0.623
13	Manganese	0.05	0.0483	20	96.6	1932
14	Iron	1.0	0.278	1	27.8	27.8
15	Copper	2.0	0.02	0.5	1	0.5
				∑ = 22.50985		∑ = 1972.079
WQI = [∑(Wn*qn)]/[(∑Wn)] = 87.60963463%						

Table 12: Water Quality Index of BH9.

S/No	Parameters	WHO Limits (Sn)	Test Results (Vn)	Weightage (Wn)	Quality Rating (qn)	[(Wn*qn)]
1	pH	6.5	6.3	0.15385	140	21.53846
2	Nitrate	10	0	0.10000	0	0.00000
3	E.C	1000	2840	0.00100	284	0.28400
4	Turbidity	5	0.01	0.20000	0.2	0.04000
5	DO	5	5.5	0.20000	94.79166667	18.95833
6	TDS	500	1874.4	0.00200	374.88	0.74976
7	Alkalinity	600	178	0.00167	29.66666667	0.04944

8	Chloride	250	17.7	0.00400	7.08	0.02832
9	Sulphate	250	3.51	0.00400	1.404	0.00562
10	Zinc	3.0	0.15	0.33333	5	1.66667
11	Sodium	200	24.7	0.00500	12.35	0.06175
12	Hardness	200	249.2	0.00500	124.6	0.62300
13	Manganese	0.05	0.05	20.00000	100	2000.00000
14	Iron	1.0	0.05	1.00000	5	5.00000
15	Copper	2.0	0.021	0.50000	1.05	0.52500
				∑ = 22.50985		∑ = 2049.530
WQI = [∑(Wn*qn)]/[(∑Wn)] = 91.05039359%						

Table 13: Water Quality Index of BH10.

S/No	Parameters	WHO Limits (Sn)	Test Results (Vn)	Weightage (Wn)	Quality Rating (qn)	[(Wn*qn)]
1	pH	6.5	6.6	0.15385	80	12.30769
2	Nitrate	10	0	0.10000	0	0.00000
3	E.C	1000	2900	0.00100	290	0.29000
4	Turbidity	5	0	0.20000	0	0.00000
5	DO	5	5.4	0.20000	95.83333333	19.16667
6	TDS	500	1914	0.00200	382.8	0.76560
7	Alkalinity	600	178	0.00167	29.66666667	0.04944
8	Chloride	250	17.6	0.00400	7.04	0.02816
9	Sulphate	250	3.52	0.00400	1.408	0.00563
10	Zinc	3.0	0.15	0.33333	5	1.66667
11	Sodium	200	24.4	0.00500	12.2	0.06100
12	Hardness	200	212.3	0.00500	106.15	0.53075
13	Manganese	0.05	0.051	20.00000	102	2040.00000
14	Iron	1.0	0.05	1.00000	5	5.00000
15	Copper	2.0	0.022	0.50000	1.1	0.55000
				∑ = 22.50985		∑ = 2080.422
WQI = [∑(Wn*qn)]/[(∑Wn)] = 92.42273794%						

Table 14: Water Quality Index of BH11.

S/No	Parameters	WHO Limits (Sn)	Test Results (Vn)	Weightage (Wn)	Quality Rating (qn)	[(Wn*qn)]
1	pH	6.5	6.6	0.15385	80	12.30769
2	Nitrate	10	0	0.10000	0	0.00000
3	E.C	1000	2840	0.00100	284	0.28400
4	Turbidity	5	0	0.20000	0	0.00000
5	DO	5	5.4	0.20000	95.83333333	19.16667
6	TDS	500	1874.4	0.00200	374.88	0.74976
7	Alkalinity	600	178	0.00167	29.66666667	0.04944
8	Chloride	250	17.8	0.00400	7.12	0.02848
9	Sulphate	250	3.52	0.00400	1.408	0.00563
10	Zinc	3.0	0.15	0.33333	5	1.66667
11	Sodium	200	24.3	0.00500	12.15	0.06075
12	Hardness	200	249.2	0.00500	124.6	0.62300
13	Manganese	0.05	0.052	20.00000	104	2080.00000
14	Iron	1.0	0.05	1.00000	5	5.00000
15	Copper	2.0	0.023	0.50000	1.15	0.57500
				∑ = 22.50985		∑ = 2120.517
WQI = [∑(Wn*qn)]/[(∑Wn)] = 94.20397979%						

Table 15: Water Quality Index of BH12

S/No	Parameters	WHO Limits (Sn)	Test Results (Vn)	Weightage (Wn)	Quality Rating (qn)	[(Wn*qn)]
1	pH	6.5	6.50	0.153846154	100	15.38461538
2	Nitrate	10	0.00	0.1	0	0
3	E.C	1000	2860	0.001	286	0.286
4	Turbidity	5	0.0033	0.2	0.066	0.0132
5	DO	5	5.433	0.2	95.48958333	19.09791667
6	TDS	500	1887.6	0.002	377.52	0.75504
7	Alkalinity	600	178.0	0.001666667	29.66666667	0.049444444
8	Chloride	250	17.7	0.004	7.08	0.02832
9	Sulphate	250	3.517	0.004	1.4068	0.0056272
10	Zinc	3.0	0.15	0.333333333	5	1.666666667
11	Sodium	200	24.47	0.005	12.235	0.061175
12	Hardness	200	236.9	0.005	118.45	0.59225
13	Manganese	0.05	0.051	20	102	2040
14	Iron	1.0	0.05	1	5	5
15	Copper	2.0	0.022	0.5	1.1	0.55
				∑ = 22.50985		∑ = 2083.490
WQI = [∑(Wn*qn)]/[(∑Wn)] = 92.55906243%						

Table 16a: Anti-Image Correlation Matrix

		pH	Electrical Conductivity	Turbidity	Dissolved Oxygen	TDS	Alkainity	Chloride	Sulphate	Zinc
Correlation	pH	1.000	.813	.516	-.965	.813	-.985	-.073	-.436	-.887
	Electrical Conductivity	.813	1.000	.464	-.710	.999	-.777	-.352	-.353	-.707
	Turbidity	.516	.464	1.000	-.339	.498	-.498	.536	.391	-.669
	Dissolved Oxygen	-.965	-.710	-.339	1.000	-.702	.980	.115	.544	.825
	TDS	.813	.999	.498	-.702	1.000	-.775	-.333	-.335	-.714
	Alkainity	-.985	-.777	-.498	.980	-.775	1.000	.045	.443	.896
	Chloride	-.073	-.352	.536	.115	-.333	.045	1.000	.794	-.179
	Sulphate	-.436	-.353	.391	.544	-.335	.443	.794	1.000	.195
	Zinc	-.887	-.707	-.669	.825	-.714	.896	-.179	.195	1.000
	Sodium	.155	.134	-.629	-.303	.111	-.174	-.825	-.934	.041
	Hardness	.480	.345	.278	-.522	.346	-.555	.031	-.247	-.497
	Manganese	-.884	-.781	-.659	.851	-.789	.923	-.066	.254	.925
	Iron	.979	.773	.571	-.960	.774	-.994	.050	-.340	-.918
	Copper	-.555	-.433	-.844	.455	-.448	.569	-.682	-.484	.694
	Chromium	.477	.343	.743	-.402	.353	-.492	.728	.546	-.602
	Phosphate	.951	.704	.337	-.984	.699	-.971	-.189	-.617	-.796
	Total Hydrocarbon Content	.518	.440	-.331	-.618	.421	-.525	-.778	-.994	-.275

Principal component analysis (PCA) was performed to:

a) Study the combined influence (correlation) of some selected water quality parameters on the overall quality of borehole water within the study location.

b) Identify the most critical water quality parameter (s) that significantly influenced the overall water quality of ground water within the study area

Results of the factor analysis are presented as follows

Anti- Image Correlation Matrix

The anti-image correlation matrix presented in Tables 16a & 16b was employed to test the capacity of principal component analysis (PCA) in explaining the underlying correlation between some selected water quality parameters. Results of Tables 16a & 16b shows that principal component analysis is suitable for this analysis. The suitability of PCA is based on the fact that; the off diagonal matrix in Tables 16a & 16b are less than unity with a host of them very close to 1.

Table 16b: Anti-Image Correlation Matrix

Sodium	Hardness	Manganese	Iron	Copper	Chromium	Phosphate	Total Hydrocarbon Content
.155	.480	-.884	.979	-.555	.477	.951	.518
.134	.345	-.781	.773	-.433	.343	.704	.440
-.629	.278	-.659	.571	-.844	.743	.337	-.331
-.303	-.522	.851	-.960	.455	-.402	-.984	-.618
.111	.346	-.789	.774	-.448	.353	.699	.421
-.174	-.555	.923	-.994	.569	-.492	-.971	-.525
-.825	.031	-.066	.050	-.682	.728	-.189	-.778
-.934	-.247	.254	-.340	-.484	.546	-.617	-.994
.041	-.497	.925	-.918	.694	-.602	-.796	-.275
1.000	.116	-.024	.067	.684	-.705	.357	.904
.116	1.000	-.512	.551	-.316	.273	.539	.291
-.024	-.512	1.000	-.938	.678	-.581	-.843	-.335
.067	.551	-.938	1.000	-.657	.585	.941	.427
.684	-.316	.678	-.657	1.000	-.981	-.382	.399
-.705	.273	-.581	.585	-.981	1.000	.304	-.464
.357	.539	-.843	.941	-.382	.304	1.000	.684
.904	.291	-.335	.427	.399	-.464	.684	1.000

Computation of Communalities

It is also important in the extraction phase to examine the communualities. The communualities is represented by the sum of the square loading for a variable across factor. Communality can range from 0 to 1. A communality of 1 means that all of the variation in the ground water quality is explained by the component factors. The computed communualities is presented in Table 17. It was observed from the result of Table 4.17 that the initial communualities was 1.000 for all the ground water quality parameters employed for this analysis. Communualities of 1.000 is good since it indicates that the variation in ground water quality around the study area can be explained with the aid of principal component analysis. Extraction communualities are estimates of the variance in each variables accounted for by the factors. High extraction indicates that the extracted components represents the variables well. If any extraction is very low (< 0.3), then one may need to extract another component factor.

Table 17: Computed Communalities of Ground Water Quality Parameters

Communalities

	Initial	Extraction
pH	1.000	.926
Nitrate	1.000	.926
EC	1.000	.982
DO	1.000	.958
TDS	1.000	.982
Sodium	1.000	.878
Lead	1.000	.979
Sulphate	1.000	.902
Zinc	1.000	.794
Copper	1.000	.861
Chloride	1.000	.869
Iron	1.000	.882
Carbonate	1.000	.796
Nickel	1.000	.870
Phosphate	1.000	.968
Alkalinity	1.000	.965
Calcium	1.000	.897

Extraction Method: Principal Component Analysis.

Table 18: Extraction of Compoent Factors Using Principal Componet Analysis Method

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	9.535	56.086	56.086	9.535	56.086	56.086	6.660	39.179	39.179
2	5.263	30.957	87.043	5.263	30.957	87.043	5.276	31.038	70.217
3	1.023	6.019	93.062	1.023	6.019	93.062	3.884	22.845	93.062
4	.612	3.600	96.662						
5	.302	1.778	98.440						
6	.157	.925	99.365						
7	.086	.507	99.872						
8	.021	.126	99.999						
9	.000	.001	100.000						
10	1.105E-5	6.501E-5	100.000						
11	1.050E-6	6.176E-6	100.000						
12	1.37E-15	8.084E-15	100.000						
13	3.15E-16	1.856E-15	100.000						
14	7.12E-18	4.191E-17	100.000						
15	-5.81E-17	-3.420E-16	100.000						
16	-9.20E-17	-5.412E-16	100.000						
17	-3.29E-16	-1.936E-15	100.000						

Extraction Method: Principal Component Analysis.

Table 19: Rotated Component Matrix Showing the Three Component Factors

Rotated Component Matrix[a]

	Component		
	1	2	3
pH	.801	-.010	.567
Electrical Conductivity	.402	-.074	.893
Turbidity	.338	.709	.455
Dissolved Oxygen	-.881	.130	-.405
TDS	.398	-.051	.899
Alkainity	-.865	.007	-.493
Chloride	.143	.909	-.352
Sulphate	-.411	.891	-.157
Zinc	-.773	-.232	-.484
Sodium	.207	-.959	-.016
Hardness	.743	.008	-.067
Manganese	-.756	-.167	-.565
Iron	.855	.104	.500
Copper	-.466	-.810	-.337
Chromium	.425	.832	.245
Phosphate	.873	-.205	.404
Total Hydrocarbon Content	.467	-.852	.225

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 5 iterations.

Extraction of Component Factors

The next step in the factor analysis was to extract the component factor using principal component analysis method (PCA). Result of the component factor extracted is presented in Table 18. The extraction analysis determines how well the component factors explains the variation in the overall water quality from the twelve boreholes using the total varianced explained as presented in Table 19. Factors with eigen values greater than one represent the number of component factors needed to describe the underlying variation of the ground water quality. This are the component factors that contributes an adequate amount to the variation in the ground water quality. The eigen value is normally used as cutoff in factor analysis since it is the sum of the squared factor loadings of all variables. Factors with eigen value less than unity means that such factor do not have any influence on the overall ground water quality. From the results of Table 18, it was observed that three component factors had eigen value greater than one. These component factors contributed to change in the quality of the ground water aroung the study area. This claim was further supported using the scree plot presented in Figure 2. From the result of Figure 3, it was again observed that three component factors possess very strong influence on the overall quality of the ground water around the study location.

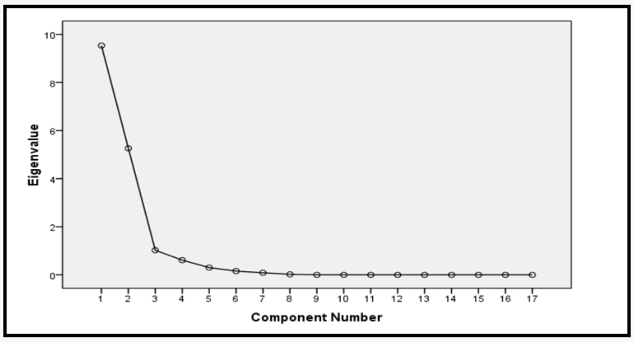

Figure 2: Scree Plot Showing Factors with High Significant Influence

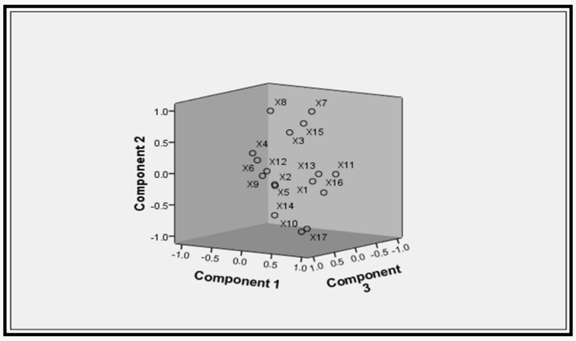

Figure 3: Component plot in rotated space

Extraction of Rotated Component Matrix

In other to identify the ground water quality parameters that make up the members of each component factors, the rotated component matrix was generated as presented in Table 19. The extracted rotated component matrix was employed to understand the correlation between ground water quality parameters in each component group. In regression terms, the rotated component matrix is the standardized regression coefficient between the observed values and the component factors. Higher factor loading indicates that a parameter is closely associated with the component factor. To determine the water quality parameters that make up each of the component factors, horizontal decentralization of the rotated component matrix was done and the best favoured parameters was selected as member of that particular component factor. Result of the horizontal decentralization of the rotated component matrix is presented in Table 20

Table 20: Makeup of the Component Factors.

Variables		Componet Factors		
Variable Code	Variable Name	1	2	3
X1	pH	0.801		
X2	Electrical conductivity			0.893
X3	Turbidity		0.709	
X4	Dissolved Oxygen		0.130	
X5	TDS			0.899
X6	Alkalinity		0.007	
X7	Chloride		0.909	
X8	Sulphate		0.891	
X9	Zinc			
X10	Sodium	0.207		
X11	Hardness	0.743		
X12	Manganese			
X13	Iron	0.855		
X14	Copper			
X15	Chromium		0.832	
X16	Phosphate	0.873		
X17	THC	0.467		

Results of Table 20 revealed that the first component factor is most highly correlated with pH, concentration of sodium, iron, total hardness, phosphate and total hydrocarbon content with phosphate having the strongest influence. The second component factor is most highly correlated with turbidity, dissolved oxygen, alkalinity, chloride, chromium, and sulphate concentration with chloride concentration having the strongest influence. The third component factor is most highly correlated with electrical conductivity and total dissolved solids with Tds having the strongest influence. It is also observed from the result of Table 20 that zinc, manganese and copper do not have any influence on the overall quality of the different borehole water tested. In addition, phosphate, chloride and total dissolved solids are the three most important variables affecting the quality of the borehole water within the study area. The component plot in rotated space is presented as shown in Figure 2. Based on the results of the factor analysis using the principal component analysis (PCA), it was observed that phosphate, chloride and total dissolved solids are the three most important variables affecting the quality of the borehole water within the study area. Therefore, the treatment units to be design must be capable of addressing the effects of high posphate, chloride and total dissolved solid observed with the borehole water.

Treatment Unit for Chloride Removal

Chemical precipitation involving the use of quick lime (calcium oxide) or soda lime can be employed. The quick lime will react with the chloride present in the water to form precipitate of calcium chloride which can then be removed either by gravimetric analysis or sedimentation under the influence of gravity. For effective design computation, the following assumptions were made:

a) Daily water demand = 2 million Liters (2 x 10^6L)

b) Volume of water to be treated = Daily water demand

c) Maximum chloride concentration = 18.3mg/L

For molecular weight, we find that 100parts of $CaCO_3$ requires 56 parts of pure lime (CaO) for treatment or

100mg/L of $CaCO_3$ requires = 56mg/L of quick lime

18.3mg/L of $CaCO_3$ will require

$$56/100 \times 18.3mg / L\ of\ CaO = 10.248mg / L\ of\ CaO$$

Hence quick lime needed = 10.248 mg/L

Since two million liters of water is to be treated, total quick lime required.

= 10.248mg/L x 2 x 106L

= 20.498kg

The quantity of soda required to react with non-carbonate hardness of 18.3mg/L (as calcium carbonate) is computed as follows;

From molecular weight we have

100parts of $CaCo_3$ requires = 106 parts of Na_2CO_3

18.3mg/L of $CaCo_3$ will require

Total soda lime required to treat two million liters of water

= 19.398mg/L x 2 x 106L

= 19.398 x 2 x 106mg

= 38.796kg

Dimension of Dosing Tank

Daily water demand = $2000m^3/d$

Hourly water demand = $2000/24 = 83.33m^3/hr$

a. Since Pumping Is For 20hrs Per Day, Discharge Into The Tank Will Be

$$\frac{83.33 \times 24}{20} = 100m^3 / hr$$

b. Assume A Detention Period Of 8 Hours Then

i. Capacity of tank = $100m^3 / 8 = 800m^3$

c. Assume Effective Tank Depth Of 3.0m Then

ii. Area of tank = $\frac{Volume}{depth} = \frac{800m^3}{3m} = 266.67m^2$

d. Assume Length To Breadth Ratio Of 2.5:1

$$2.5\beta \times \beta = 266.67$$

$$\beta^2 = \frac{226.67}{2.5} = 106.668$$

$$\beta = \sqrt{106.668}$$

$$\beta = 10.328m$$

Length = 2.5β = 2.5 x 10.325

L = 25.820m

e. Assume A Free Board of 0.5m, Hence Actual Depth of Tank = 3.5m

Hence tank dimension = L x β x h = 25.820m x 10.328m x 3.5m

Treatment Option for Phosphate and Total Dissolved Solids

The fixed bed adsorption treatment method offers the best treatment options of water containing high concentration of phosphate and total dissolved solids. Fixed bed column can be operated singly in series, or in parallel. Treatment with a granular activated carbon involves carbon held in a reactor (sometimes called a contactor). The water to be treated is applied to the top of the column and withdrawn at the bottom. The activated carbon is held in place with an under dram system at the bottom of the column. The advantage of a down flow design is that adsorption of organics and filtration suspended solids are accomplished in a single step.

a. Volume of Water Treatment per Gram of Granular Activated Carbon Specific Throughput.

Assumption

i. Let Empty Bed Contact Time (EBCT) = 10min

ii. Let effective contact time (t) = 7min

iii. Density (ℓ) of GAC = 350g/L

Then

Specific throughput = $t/(EBCT)(\ell_{GAC}) = 7/10 \times 350 = 0.00286L / g$

b. GAC - Granular Activated Carbon Usage Rate (g/m³)

$$1/Specific\ throughput = 1/0.00286 = 349.65g / m^3$$

c. Does of Gac Required for 10min Ebct

= EBCT x Q x ℓ_{GAC}

Where EBCT = Empty Bed Contact Time = 10min

Q = Daily flow rate of water

$$= \frac{2.0\times10^{6} L}{24hrs} = 83,333.33L/hr = 1,388.89L/\min$$

Mass = $10\min \times 1,388.89\, {}^{L}\!/\!_{\min} \times {}^{350g}\!/\!_{L} = 10\times 1,388.89\times 350g$

= 4,861,115g

= 4,861.115kg

= 4.861 x 106g

d. Volume Of Water Treated

$$= \frac{Mass\ of\ GAC\ for\ a\ given\ EBCT}{GAC\ Usage\ rate} = \frac{4.861\times10^{6} g}{349.65\, {}^{g}\!/\!_{m^3}} = 13,902.80m^{3}$$

e. Bed Life of Gac

$$= \frac{Volume\ of\ water\ treated}{Q} = \frac{13,902.80m^{3}}{2000m^{3}/d} = 6.95days$$

Conclusion

Analytical tools employed in this study which include; physico-chemical characterization, water quality index modeling and principal component analysis where found effective in providing suitable information on:

i. The quality of ground water witnin the study location.

ii. Understanding the contributions of each water quality parametrs to the overall quality of ground water within the study area

Information derived from the analysis was therefore employed as baseline for the design of the treatment unit. The design was targeted to solving the basic issues derived from the principal component analysis which revealed that phosphate, chloride and total dissolved solids are the three most important variables affecting the quality of the borehole water within the study area.

Appendix

Appendix 1: Water quality Assessment of Borehole 1, 2, 3, and 4.

(Module 1-4)

Appendix 2: Water quality Assessment of Borehole 5, 6, 7, and 8.

(Module 1-4)

Appendix 3: Water quality Assessment of Borehole 9, 10, 11, and 12.

(Module 1-4)

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