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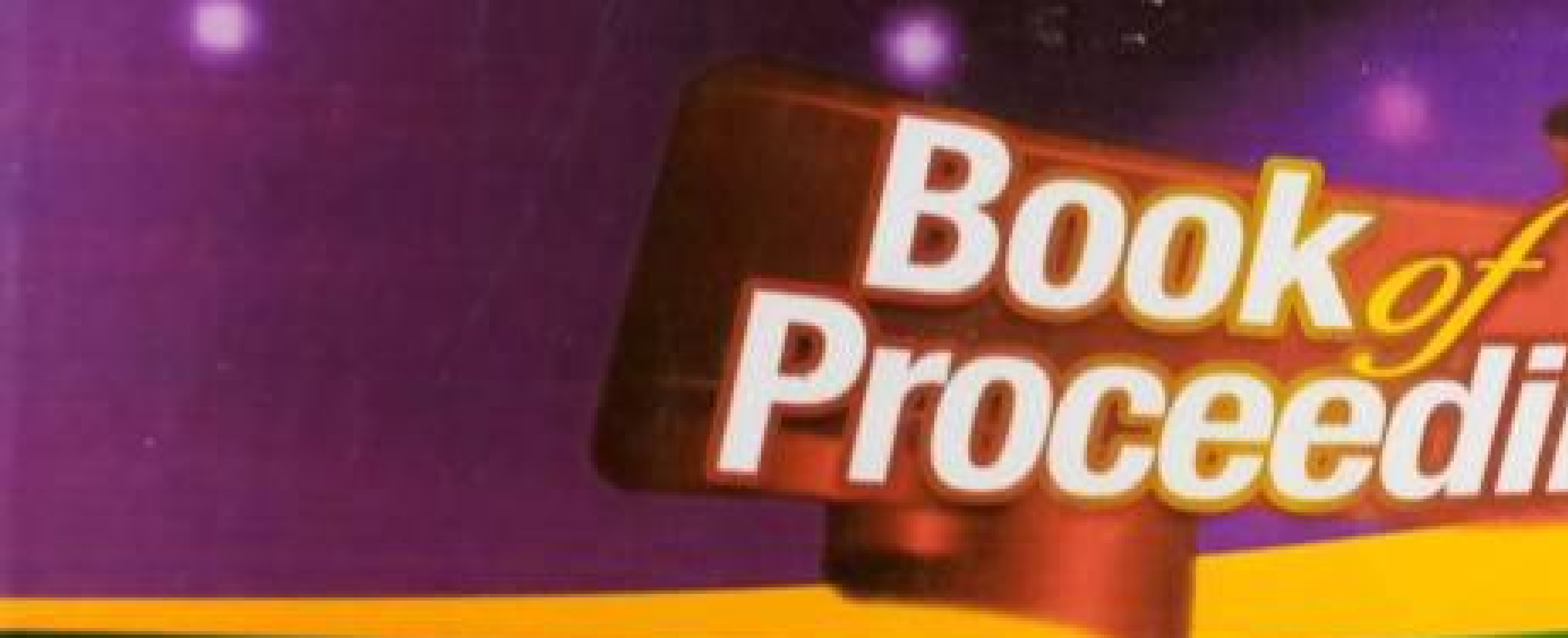

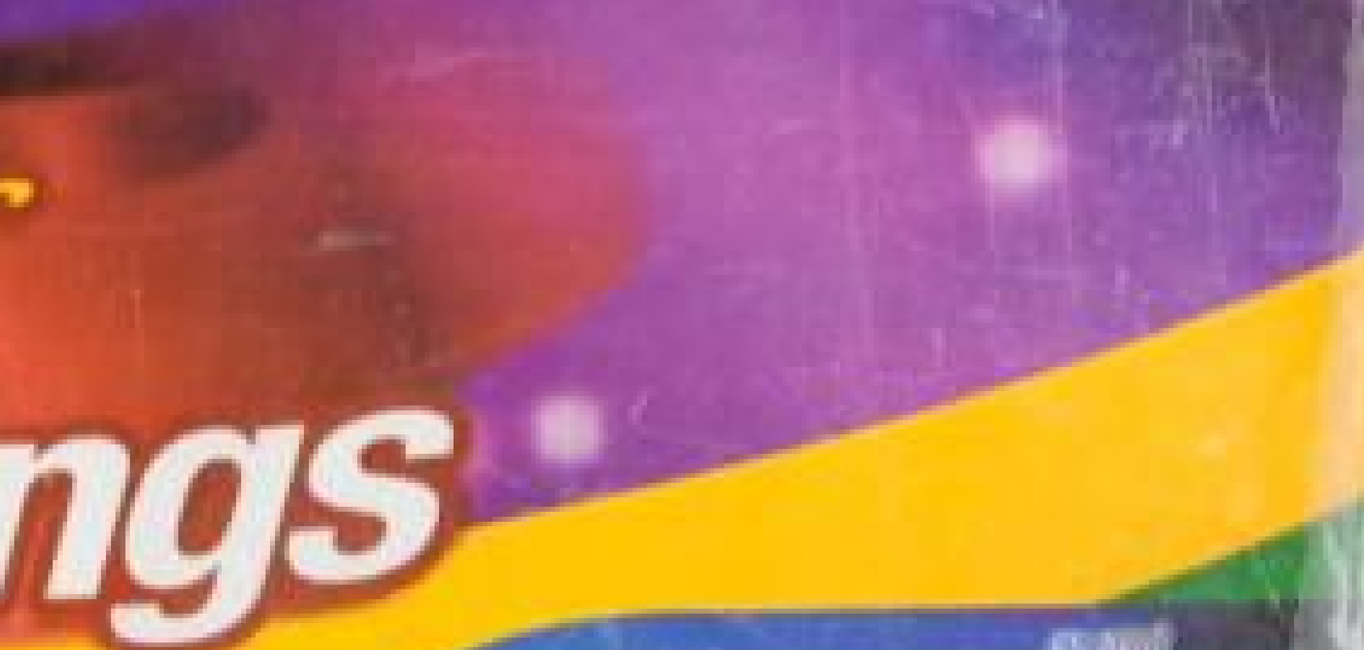

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Characterization of Groundwater Quality using Water Quality Index: A Case Study of Minna City

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ABSTRACT

Groundwater as a form of natural resource is used for domestic, industrial water supply and irrigation all over the world. Its regular assessment, therefore, should be encouraged so as to guarantee its safe consumption in terms of quality. This study is aimed at characterizing the groundwater in Minna city with water quality index (WQI) using weighted arithmetic index method. 180 groundwater samples from four sub-areas within Minna city and subjecting them to comprehensive physicochemical analyses using APHA standard methods of analysis. For the characterization, 12 parameters were considered which included pH, total hardness, calcium, magnesium, bicarbonate, chloride, nitrate, sulphate, total dissolved solids, iron, and manganese. Correlation matrix using SPSS 22 was conducted on the parameters to check the relationships among the water quality parameters. The WQI for these samples ranges from 334.27 to 535.88, with Chanchaga wells having the highest value of 535.88 while Kpakungu recorded the lowest value of 334.27. The high values of WQI has been attributed to the higher values of Manganese, sulphate, total hardness, total alkalinity, and particularly total dissolved solids in the groundwater. Significant correlation was observed in all sampling areas between electrical conductivity, chloride, magnesium, sodium, and total hardness at 0.01 level and with manganese at 0.05 level. The results of analyses have been used to suggest the most critical parameter in groundwater quality. The analysis also reveals that the groundwater of the area needs some degree of treatment before consumption, and it also needs to be protected from the perils of contamination.

Keywords: *Groundwater, Minna, Water quality index, weighted arithmetic index*

1 INTRODUCTION

Minna is endowed with a rich and vast diversity of natural resources, among which are surface water, fertile soil and most importantly, groundwater. As a result of vulnerability of surface water to contamination by industrial waste and other degredational factors by humans, groundwater which is an alternative has been greatly overexplored over the decades. Ground water is an important natural source of water supply all over the world. According to Mariappan et al (2005), its use in irrigation, industries and domestic function continues to increase where perennial surface water source are absent. But rapid urbanization, especially in developing countries like Nigeria, has influenced the accessibility and quality of groundwater as a result of its overexploitation and inappropriate waste disposal, especially in urban areas (Ramakrishnaiah et al., 2009). The monitoring of groundwater quality is therefore a necessity due to its susceptibility to contamination so as to ensure its safe consumption.

The development of water quality index (WQI) for groundwater characterization has been described in several studies (Jiya and Jimoh, 2010; Khalid, 2011; Rao and Nageswararao, 2013; Kumar et al., 2015; Saleem et al., 2016). The WQI to represent gradation in water quality was first proposed by Horten (1965). Water quality index gives an indication of a single number that expresses the overall water quality at a certain area and time based on several water quality parameters (Gupta and Roy, 2012). WQI reflects a composite influence of contributing factors on the quality of water for any water system. Ramakrishnaiah et al (2009) described WQI as one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers. Water quality index, according to Dohare et al. (2014), is an important technique for demarcating groundwater quality and its suitability for drinking purpose. WQI is thus computed to reduce the large amount of water quality data to a simple numerical value that articulates the whole water quality based on different water quality parameters. The aim, therefore, is to turn complex water quality data in to information that is easily understandable and useable by the public.

The present study is divided into three objectives: collecting of groundwater samples from four different areas within Minna city and to analyze a few groundwater quality parameters in terms of their physico-chemical characteristics. The third objective is to characterize the groundwater quality in the study areas using water quality index and provide information on their suitability for human consumption based on computed water quality index values.

2 MATERIALS AND METHOD

2.1 STUDY AREA

Minna, a capital city of Niger State of Nigeria, is located about 138 km from Abuja, a Federal Capital Territory of Nigeria. Minna is located between Latitude 9°37" and Longitude 6°33" as shown in Figure 1 and covers a total landmass of approximately 1300 km^2 (Adeniyi 1984). Minna falls within the larger northwestern Nigerian basement complex, which is made up of crystalline rocks consisting of gneisses and migmatatites, and meta sedimentary schists. Minna has a mean annual rainfall of 1334 mm with the highest mean monthly rainfall in September which is around 300 mm. The mean monthly temperature is highest in March at 30.5°C and lowest in August at 25.1°C.

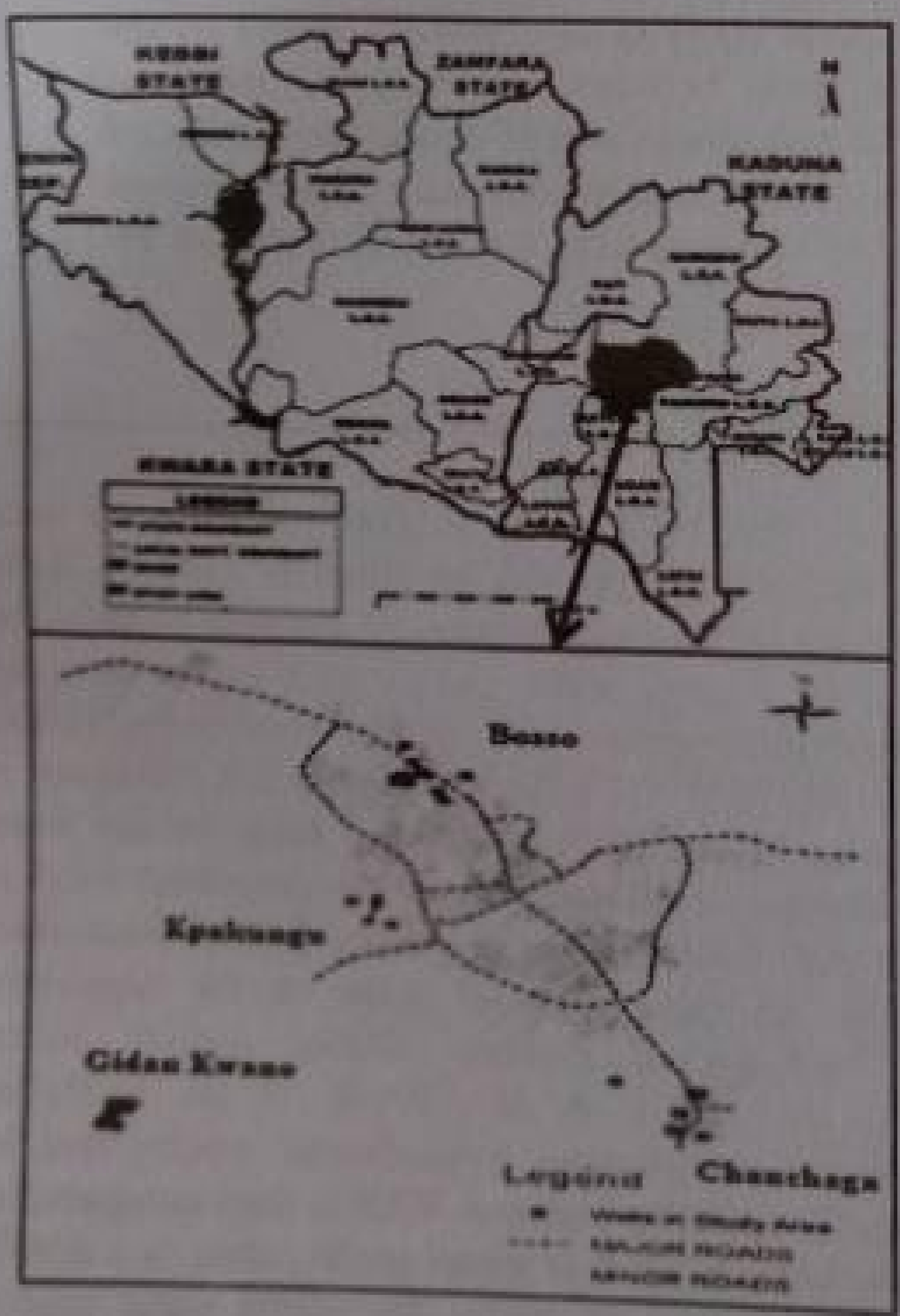

Figure 1: Map of Minna showing the sampling locations

2.2 SAMPLING METHOD

The study area was divided into 4 sub-areas from where sampling was done. The 4 sub-areas are; Chanchaga, Bosso, Kpakungu, and Gidan Kwano where Federal University of Technology, Minna Permanent site is located. In each of the sub-areas under study, fifteen hand dug wells were sampled making a total number of 90 samples collected for analysis. The depth of the wells sampled ranges between 4m to 16m. The groundwater samples were collected early in the morning in labelled 75cl plastic bottles and kept in ice packs before being transported to the laboratory for analysis.

2.3 EXPERIMENTAL METHODS

The analysis of various physico-chemical parameters analyzed namely pH, total alkalinity, chlorides, sulphate, total hardness, calcium, magnesium, electrical conductivity, and total dissolved solids were carried out as per methods described in APHA (1992) and WHO (1992).

Water quality index (WQI) is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers. It thus, becomes an important parameter for the assessment and management of surface water. Water quality index which was first developed by Horton in the early 1970s is basically a mathematical; Means of Calculating a Single value from multiple test results (Basavaraddi et al, 2012). The WQI, which was developed in the early 1970s, can be used to monitor water quality changes in a particular water supply over time. WQI is calculated from the point of view of the suitability of surface water for human consumption. Table 1 gives the summary of the parameters, apparatus and methods used to determine the values of the parameters used in WQI analysis.

In this study, three steps of water quality index were followed. In the first step each of the parameters (Calcium, Magnesium, Chloride, Sulphate, Total Hardnes, Nitrate, Total Dissolved Solids, Alkalinity) was assigned a weight (*wi*) according to its relative importance on the comprehensive quality of water which range from 1 to 5. The maximum weight of 5 were assigned to the parameter which influence more significantly the water quality and minimum weight of 1 is selected to the least regnant the water Quality.

2.4 CALCULATION OF WQI

The Water Quality Index (WQI) was calculated using the Weighted Arithmetic Index method in (1). The quality rating scale for each parameter qi was calculated by using this expression:

$$qi = (Ci/Si) \times 100 \quad (1)$$

A quality rating scale (qi) for each parameter is assigned by dividing its concentration (Ci) in each water sample by its respective standard (Si) and the result multiplied by 100. Relative weight (Wi) was calculated by a value inversely proportional to the recommended standard (Si) of the corresponding parameter as in (2):

$$Wi = 1/Si \quad (2)$$

The overall Water Quality Index (WQI) in was calculated by aggregating the quality rating (Qi) with unit weight (Wi) linearly as shown in (3):

$$WQI = \left(\sum_{I=1}^{I=n} W_i q_i \right) \quad (3)$$

Generally, WQI is discussed for a specific and intended use of water. In this study the WQI for drinking purposes is considered and permissible WQI as represented in (4) for the drinking water is taken as 100:

$$\text{Overall WQI} = \frac{\sum q_i w_i}{\sum w_i} \quad (4)$$

The suitability of WQI values for human consumption according to Table 1, developed by Asuquo and Etim (2012).

TABLE 1: WATER QUALITY INDEX AND WATER QUALITY STATUS

Water Quality Index	Water Quality Status
<50	Excellent
50-100	Good water
100-200	Poor water
200-300	Very poor water
>300	Water unsuitable to drink

Source: Etim *et al* (2013)

2.5 STATISTICAL ANALYSIS

The statistical analysis was carried out using correlation matrix with IBM SPSS 22 to check the relationships between the water quality paramters. Water quality index was calculated from the point of view of suitability of the water for human consumption as seen below.

3 RESULTS

Tables 2 to 5 show the calculation of water quality index with 12 parameters used in the analysis using weighting arithmetic index. From Tables 2 to 5, the WQI for the groundwater samples ranges from 334.27 to 535.88, with Kpakungu wells having the lowest value of 334.27 while Chanchaga wells recorded the highest of 535.88. In Table 5, for Bosso sampling area, total dissolved solids (TDS), sulphate, magnesium and total hardness values were observed to be higher than the standards in the sampled wells which the higher values of WQI are attributed to. The same applied to Chanchaga study area where sulphate and magnesium were observed to be higher than the standards. This thus explains that sulphate and magnesium values dictate the values of WQI in groundwater.

Table 6 shows the range of WQI obtained for the whole study areas. The values obtained for all the study areas were all within the limit of 'Water unsuitable for drinking' status as shown in Table 1.This shows the level of pollution the groundwater has been subjected to.

Results obtained for pH in all the study areas varied between 6.81 and 7.69 as shown in the Tables 2 to 5 with the highest average pH value of 7.69 recorded in Gidan Kwano sampling area as opposed to the lowest value of 6.81 in Bosso study area. This, in other words, means the mean pH values obtained in all the study areas are within limit. of both Standard Organization of Nigeria (SON) and World Health Organization (WHO) values of 6.5–8.5 (World Health Organization, 1998). Analytical observation revealed that the pH value in the study areas was said to have been influenced by the levels of concentration of calcium, magnesium and total alkalinity. The mean total alkalinity value in all the study area range from 97.24 mg/L in Chanchaga study area to 164. 84 mg/L in Bosso study area. In other words, the total alkalinity values obtained in Bosso and Kpakungu study areas are above the permissible limits of 120 mg/L. For sulphate values, the results obtained range from the lowest in Kpakungu as 212.53 mg/L to the highest in Chanchaga as 293.41 mg/L. In all the study areas, the sulphate values obtained were all above the permissible limit of 100 mg/L. Magnesium values obtained also fell above the permissible limit of 0.2 mg/L in all the study areas. Iron (Fe) values obtained from the study areas range between 0.24 mg/L in Bosso to 0.59 mg/L in Gidan Kwano which is above the permissible limit of 0.3 mg/L.

The total hardness varies from 131.64 mg/L in Kpakungu study area to 155.49 mg/L in Bosso study area. In all the study areas except in Bosso study area, the values of total hardness were found to be within the tolerable limit of NSDWQ (Nigerian Standard for Drinking Water Quality) of 150 mg/L (NIS, 2007) and WHO specifications of 300 mg/L (World Health Organization, 1998). Total dissolved solids (TDS) values range from 218.81 mg/L in Kpakungu to 627.77 mg/L in Bosso study area. This, in other words, means all the samples from study areas are within the permissible limit of 500 mg/L except that of Bosso study area.

Tables 7-10 shows the correlation coefficients and interrelationship between all the parameters of water quality. Significant correlations were observed in all sampling areas between electrical conductivity, chloride, magnesium, sodium, total dissolved solids, and total alkalinity at 0.01 level and with total hardness and manganese at 0.05 level. pH values strongly correlated with total alkalinity and calcium at 0.01 level only at Chanchaga study area. No correlation was observed among other parameters with pH in other study areas. Correlation also existed between magnesium and sulphates at 0.05 level only at Chanchaga study area.

TABLE 3: COMPUTED WQI FOR WATER QUALITY OF KPAKUNGU WELLS

WELL	E.C	PH	TH	TA	CL-	Ca	Mg	SO4-2	Na	TDS	Fe	Mn	
W1	244.33	7.18	97.67	117.00	11.90	27.47	7.09	259.05	7.45	156.37	0.39	0.13	
W2	256.33	6.99	94.67	133.33	9.00	24.39	8.24	240.96	6.94	164.05	0.12	0.07	
W3	316.67	7.39	126.33	136.33	21.23	42.89	4.70	144.71	7.93	202.67	0.19	0.13	
W4	430.67	7.59	110.67	172.67	27.37	30.00	8.73	207.57	11.14	275.63	0.30	0.07	
W5	344.33	7.31	129.00	129.67	19.94	38.27	8.16	297.48	8.82	220.37	0.25	0.11	
W6	277.33	7.42	100.00	104.00	20.91	26.35	8.34	188.31	6.65	177.49	0.32	0.10	
W7	272.67	7.14	117.33	97.67	24.92	30.70	9.93	196.06	7.43	174.51	0.40	0.22	
W8	442.67	6.99	196.67	131.00	61.59	49.90	17.58	250.65	14.88	283.31	0.48	0.11	
W9	264.67	7.08	103.67	106.33	21.06	29.72	7.19	238.37	7.75	169.39	0.37	0.10	
W10	374.00	7.31	150.33	117.67	41.17	45.56	8.93	285.21	10.07	239.36	0.52	0.08	
W11	505.00	7.25	152.67	170.67	64.16	21.73	24.01	171.19	15.79	323.20	0.55	0.09	
W12	305.67	7.58	137.67	170.33	10.13	38.55	10.11	170.54	8.57	195.63	0.27	0.13	
W13	193.33	7.03	87.00	107.33	7.40	24.25	6.45	205.75	6.25	123.73	0.25	0.10	
W14	553.00	7.35	231.67	156.33	94.23	52.42	24.59	149.55	14.25	353.92	0.66	0.07	
W15	347.67	7.26	139.33	83.33	28.94	39.95	9.66	182.50	8.27	222.51	0.28	0.11	
AVERAGE	341.89	7.26	131.64	128.91	30.93	34.81	10.91	212.53	9.48	218.81	0.36	0.11	
Lab Value(Ci)	341.89	7.26	131.64	128.91	30.93	34.81	10.91	212.53	9.48	218.81	0.36	0.11	
S. Value (Si)	1000	8.5	150	120	250	200	0.2	100	250	500	0.3	0.2	
Weight (wi)	4.00	4.00	2.00	3.00	5.00	2.00	2.00	4.00	3.00	5.00	4.00	3.00	
Relative Weight (Wi)	0.10	0.10	0.05	0.07	0.12	0.05	0.05	0.10	0.07	0.12	0.10	0.07	1.00
Qty Rating qi	34.19	85.38	87.76	107.43	12.37	17.41	5456.89	212.53	3.79	43.76	119.26	53.78	

$$\frac{\sum q_i w_i}{\sum w_i} = \frac{334.27}{1.0} = 334.27$$

TABLE 5: COMPUTED WQI FOR WATER QUALITY OF BOSSO WELLS

sample	E.C	PH	TH	TA	CL-	Ca	Mg	SO4-2	Na	TDS	Fe	Mn	
W1	672	6.81	176.00	84.00	104.93	58.71	11.34	138.08	11.55	430.08	0.13	0.02	
W2	891	6.66	115.67	196.00	81.08	43.73	11.41	261.62	18.11	570.24	0.31	0.11	
W3	374	6.68	77.67	133.33	27.82	41.35	8.54	264.90	6.34	239.15	0.19	0.01	
W4	1945	6.62	370.00	235.00	193.64	35.75	68.50	186.68	44.87	1244.80	0.14	0.18	
W5	1391	7.13	158.00	151.33	67.86	54.53	15.92	293.54	21.43	890.24	0.20	0.05	
W6	1494	7.38	211.67	218.00	62.56	57.19	33.76	238.18	9.11	956.16	0.16	0.02	
W7	1437	6.92	127.00	260.00	46.66	43.87	20.85	189.90	40.83	919.47	0.09	0.05	
W8	997	7.17	134.67	179.00	76.47	54.40	6.56	231.75	29.04	638.29	0.10	0.01	
W9	986	6.95	87.33	224.67	66.37	23.84	11.53	167.69	25.34	631.25	0.19	0.04	
W10	1175	6.66	140.33	152.00	74.81	28.59	16.82	169.30	27.87	752.00	0.10	0.04	
W11	1062	6.59	158.33	117.33	65.04	39.99	13.25	236.57	14.49	679.47	0.25	0.13	
W12	1152	6.75	206.67	115.33	48.49	63.93	25.77	214.69	9.96	737.49	0.45	0.12	
W13	436	7.36	150.67	142.67	30.29	40.67	12.00	211.14	17.77	279.25	0.71	0.17	
W14	336	6.77	104.00	94.67	26.81	30.54	6.76	279.38	11.17	215.25	0.43	0.16	
W15	365	6.63	114.33	169.33	21.19	24.96	12.69	332.81	11.26	233.39	0.20	0.02	
Lab Value(Ci)	980.89	6.87	155.49	164.84	66.27	42.80	18.38	227.75	19.94	627.77	0.24	0.07	
S. Value (Si)	1000	8.5	150	120	250	200	0.2	100	250	500	0.3	0.2	
Weight (wi)	4.00	4.00	2.00	3.00	5.00	2.00	2.00	4.00	3.00	5.00	4.00	3.00	
Relative Weight (Wi)	0.10	0.10	0.05	0.07	0.12	0.05	0.05	0.10	0.07	0.12	0.10	0.07	1.00
Qty Rating qi	98.09	80.86	103.66	137.37	26.51	21.40	9189.50	227.75	7.98	125.55	80.96	36.72	

$$\frac{\sum q_i w_i}{\sum w_i} = \frac{533.81}{1.0} = 533.81$$

TABLE 6: SUMMARY OF WQI WITH THE SAMPLING AREAS

Sampling Area	Average WQI
Gidan Kwano	361.53
Bosso	533.81
Chanchaga	535.88
Kpakungu	334.27

Results obtained for pH in all the study areas varied between 6.81 and 7.69 as shown in the Tables 2 to 5 with the highest average pH value of 7.69 recorded in Gidan Kwano sampling area as opposed to the lowest value of 6.81 in Bosso study area. This, in other words, means the mean pH values obtained in all the study areas are within limits of both Standard Organization of Nigeria (SON) and World Health Organization (WHO) values of 6.5–8.5 (World Health Organization, 1998). Analytical observation revealed that the pH value in the study areas was said to have been influenced by the levels of concentration of calcium, magnesium and total alkalinity. The mean total alkalinity value in all the study area range from 97.24 mg/L in Chanchaga study area to 164. 84 mg/L in Bosso study area. In other words, the total alkalinity values obtained in Bosso and Kpakungu study areas are above the permissible limits of 120 mg/L. For sulphate values, the results obtained range from the lowest in Kpakungu as 212.53 mg/L to the highest in Chanchaga as 293.41 mg/L. In all the study areas, the sulphate values obtained were all above the permissible limit of 100 mg/L. Magnesium values obtained also fell above the permissible limit of 0.2 mg/L in all the study areas. Iron (Fe) values obtained from the study areas range between 0.24 mg/L in Bosso to 0.59 mg/L in Gidan Kwano which is above the permissible limit of 0.3 mg/L.

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Tables 7 and 8 show the correlation coefficients and interrelationship between all the parameters of water quality. Significant correlations were observed in all sampling areas between electrical conductivity, chloride, magnesium, sodium, total dissolved solids, and total alkalinity at 0.01 level and with total hardness and manganese at 0.05 level. pH values strongly correlated with total alkalinity and calcium at 0.01 level only at Chanchaga study area. No correlation was observed among other parameters with pH in other study areas. Correlation also existed between magnesium and sulphates at 0.05 level only at Chanchaga study area.

TABLE 7: CORRELATION COEFFICIENT MATRIX OF WATER QUALITY PARAMETERS OF CHANCHAGA WELLS

		EC	PH	TH	TA	Cl	Ca	Mg	SO_4^{2-}	Na	TDS	Fe	Mn
EC	Pearson Correlation	1	-.009	.827**	.494	.758**	.439	.842**	.457	.724**	1.000**	-.418	-.577*
	Sig. (2-tailed)		.975	.000	.061	.001	.101	.000	.086	.002	.000	.121	.024
PH	Pearson Correlation	-.009	1	.407	.721**	-.326	.600*	.093	-.051	.292	-.009	.132	.126
	Sig. (2-tailed)	.975		.132	.002	.235	.018	.743	.855	.290	.975	.639	.655
TH	Pearson Correlation	.827**	.407	1	.731**	.486	.724**	.857**	.290	.703**	.827**	-.266	-.461
	Sig. (2-tailed)	.000	.132		.002	.066	.002	.000	.294	.003	.000	.338	.084
TA	Pearson Correlation	.494	.721**	.731**	1	-.008	.655**	.526*	.144	.555*	.494	-.195	-.396
	Sig. (2-tailed)	.061	.002	.002		.977	.008	.044	.609	.032	.061	.486	.144
Cl	Pearson Correlation	.758**	-.326	.486	-.008	1	.235	.522*	.377	.548*	.758**	-.330	-.250
	Sig. (2-tailed)	.001	.235	.066	.977		.399	.046	.166	.034	.001	.229	.369
Ca	Pearson Correlation	.439	.600*	.724**	.655**	.235	1	.270	-.146	.374	.439	-.044	-.260
	Sig. (2-tailed)	.101	.018	.002	.008	.399		.330	.604	.170	.101	.876	.350
Mg	Pearson Correlation	.842**	.093	.857**	.526*	.522*	.270	1	.536*	.676**	.842**	-.330	-.456
	Sig. (2-tailed)	.000	.743	.000	.044	.046	.330		.039	.006	.000	.229	.088
SO_4^{2-}	Pearson Correlation	.457	-.051	.290	.144	.377	-.146	.536*	1	.318	.457	-.290	.040
	Sig. (2-tailed)	.086	.855	.294	.609	.166	.604	.039		.248	.086	.295	.888
Na	Pearson Correlation	.724**	.292	.703**	.555*	.548*	.374	.676**	.318	1	.724**	-.142	-.292
	Sig. (2-tailed)	.002	.290	.003	.032	.034	.170	.006	.248		.002	.615	.291
TDS	Pearson Correlation	1.000**	-.009	.827**	.494	.758**	.439	.842**	.457	.724**	1	-.418	-.577*
	Sig. (2-tailed)	.000	.975	.000	.061	.001	.101	.000	.086	.002		.121	.024
Fe	Pearson Correlation	-.418	.132	-.266	-.195	-.330	-.044	-.330	-.290	-.142	-.418	1	.484
	Sig. (2-tailed)	.121	.639	.338	.486	.229	.876	.229	.295	.615	.121		.068
Mn	Pearson Correlation	-.577*	.126	-.461	-.396	-.250	-.260	-.456	.040	-.292	-.577*	.484	1
	Sig. (2-tailed)	.024	.655	.084	.144	.369	.350	.088	.888	.291	.024	.068	

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

TABLE 8: CORRELATION COEFFICIENT MATRIX OF WATER QUALITY PARAMETERS OF KPAKUNGU WELLS

		EC	PH	TH	TA	Cl	Ca	Mg	SO_4^{2-}	Na	TDS	Fe	Mn
EC	Pearson Correlation	1	.302	.847**	.593*	.908**	.507	.846**	-.240	.934**	1.000**	.699**	-.386
	Sig. (2-tailed)		.273	.000	.020	.000	.054	.000	.388	.000	.000	.004	.155
PH	Pearson Correlation	.302	1	.103	.502	.026	.185	-.018	-.375	.078	.302	-.002	-.106
	Sig. (2-tailed)	.273		.715	.056	.927	.510	.950	.168	.782	.273	.994	.708
TH	Pearson Correlation	.847**	.103	1	.355	.909**	.796**	.806**	-.213	.811**	.847**	.729**	-.185
	Sig. (2-tailed)	.000	.715		.195	.000	.000	.000	.445	.000	.000	.002	.508
TA	Pearson Correlation	.593*	.502	.355	1	.347	.088	.476	-.265	.596*	.593*	.191	-.374
	Sig. (2-tailed)	.020	.056	.195		.205	.754	.073	.339	.019	.020	.494	.170
Cl	Pearson Correlation	.908**	.026	.909**	.347	1	.545*	.907**	-.247	.885**	.908**	.857**	-.287
	Sig. (2-tailed)	.000	.927	.000	.205		.036	.000	.374	.000	.000	.000	.299
Ca	Pearson Correlation	.507	.185	.796**	.088	.545*	1	.283	-.027	.404	.507	.382	-.054
	Sig. (2-tailed)	.054	.510	.000	.754	.036		.307	.923	.135	.054	.160	.849
Mg	Pearson Correlation	.846**	-.018	.806**	.476	.907**	.283	1	-.312	.890**	.846**	.782**	-.241
	Sig. (2-tailed)	.000	.950	.000	.073	.000	.307		.258	.000	.000	.001	.387
SO_4^{2-}	Pearson Correlation	-.240	-.375	-.213	-.265	-.247	-.027	-.312	1	-.137	-.240	-.062	-.113
	Sig. (2-tailed)	.388	.168	.445	.339	.374	.923	.258		.625	.388	.827	.689
Na	Pearson Correlation	.934**	.078	.811**	.596*	.885**	.404	.890**	-.137	1	.934**	.737**	-.328
	Sig. (2-tailed)	.000	.782	.000	.019	.000	.135	.000	.625		.000	.002	.232
TDS	Pearson Correlation	1.000**	.302	.847**	.593*	.908**	.507	.846**	-.240	.934**	1	.699**	-.386
	Sig. (2-tailed)	.000	.273	.000	.020	.000	.054	.000	.388	.000		.004	.155
Fe	Pearson Correlation	.699**	-.002	.729**	.191	.857**	.382	.782**	-.062	.737**	.699**	1	-.098
	Sig. (2-tailed)	.004	.994	.002	.494	.000	.160	.001	.827	.002	.004		.729
Mn	Pearson Correlation	-.386	-.106	-.185	-.374	-.287	-.054	-.241	-.113	-.328	-.386	-.098	1
	Sig. (2-tailed)	.155	.708	.508	.170	.299	.849	.387	.689	.232	.155	.729	

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

4 DISCUSSIONS

The higher value of WQI observed in the groundwater is attributed to the TDS observed to range from 218.81 mg/L to 627.77 mg/L. Thus, the WQI values obtained categorizes the groundwater in all the study areas as 'water unsuitable for drinking' (Table 1). The high values of WQI has been attributed to the higher values of Manganese, sulphate, total hardness, total alkalinity, and total dissolved solids in the groundwater (Rupal et al., 2012). The higher values of Fe observed in Kpakungu, Chanchaga, and Gidan Kwano may cause decolourisation of clothes washed in such areas (Balakrishnan et al., 2008). The higher total hardness recorded in Bosso study area might be due to atmospheric deposition of acid-forming substances which found its way to groundwater body and leaching of calcium, magnesium and other polyvalent within the study area (Ikomi and Emuh, 2000). Using this water for cooking untreated might result to formation of scales in boilers leading to wastage of fuel and the danger of overheating of boilers (Egereonu, 2004; Yisa and Jimoh, 2010).

Higher total dissolved solids in Bosso study areas can be attributed to dense residential area obtainable in Bosso community (Egereonu and Nwachukwu, 2005). Total dissolved solids refer mainly to the inorganic substances that are dissolved in water and its value in groundwater depends on individual components of groundwater. The higher value in groundwater could also be attributed to intense anthropogenic activities along the course of the river and run-off with high suspended matter content in the study area (Chapman, 1996; Yisa and Jimoh, 2010). Use of these water for irrigation will harm the crops and reduce crop yields which is consistent with Sreedevi et al., (2016).

The sulphate values in the study areas are all above the permissible limit of 200 mg/L. Contaminated water are said to contain high sulphate concentrations which is responsible for gastro intestinal irritation in humans (Saleem et al., 2016). Sulphates is naturally present in surface water as SO_4^{2-}. Industrial discharges and atmospheric precipitation can also add significant amounts of sulphate to surface waters. The mean concentration of the sulphate value is 9.97 mg L−1 which is within the tolerable limits of 500 mg L−1 (Ikomi and Emuh, 2000; Egereonu, 2004).

5 CONCLUSIONS

The WQI for 180 samples of groundwater collected from four different areas in Minna city have been obtained. The values of WQI obtained range from 334.27 in Kpakungu study area to 535.88 Chanchaga study area. This shows that in all the study areas, the groundwater is unsafe for consumption. The high values of WQI has been attributed to the higher values of Manganese, sulphate, total hardness, total alkalinity, and particularly total dissolved solids in the groundwater. Significant correlation was observed in all sampling areas between electrical conductivity, chloride, magnesium, sodium, and total hardness at 0.01 level and with manganese at 0.05 level. The results of analyses have been used to suggest the most critical parameters in groundwater quality. The analysis also reveals that the groundwater of the study area needs serious degree of treatment before consumption, and it also needs to be protected from the perils of contamination. Meanwhile, the study could be extended to some other parts of the city so as to have a broader picture of groundwater quality in Minna as a whole.

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