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SEASONAL CHARACTERIZATION OF GROUNDWATER QUALITY IN MINNA METROPOLIS USING WATER QUALITY INDEX

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Abstract
This study is aimed at assessing and characterization of groundwater seasonally in Minna metropolis using water quality index (WQI) with the aid of weighted arithmetic index method. 90 groundwater samples from four sub-areas within Minna metropolis were collected and subjected to comprehensive physicochemical analyses during dry and wet seasons. Parameters considered included pH, total hardness, calcium, magnesium, bicarbonate, chloride, nitrate, sulphate, total dissolved solids, iron, manganese and fluorides. Correlation analysis was used to check the relationships among all the parameters for both the dry and wet seasons. In all the study areas, the WQI of the samples ranged from 334.27 to 535.88 and 242.51 to 404.19 in both dry and wet seasons respectively which 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 analysis of the results showed non-compliance with World Health Organization (WHO) and Nigerian Industrial Standard (NIS) standards which reveals that the groundwater of the study areas is not safe for consumption and therefore needs serious degree of treatment before consumption. This present study thus suggests the use of water quality index as a very helpful tool that will enable the public and stakeholders to evaluate the quality of groundwater.

Key Words: *Water quality index, groundwater, weighted arithmetic index, Minna*

Introduction

Minna is endowed with a vast diversity of natural resources such as water, fertile soil and groundwater (Kuta *et al*., 2014). As a result of surface water contamination by industrial waste and other degredational factors groundwater has been greatly over explored over the decades. According to Mariappan *et al*. (2005), its use in irrigation, industries and domestic function continues to increase where perennial surface water is absent. Butrapid urbanization, especially in developing countries like Nigeria, has influenced the accessibility and quality of groundwater as a result of its over-exploitation and inappropriate waste disposalin 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 (Yisa and Jimoh, 2010; Khalid, 2011; Rao and Nageswararao, 2013; Kumar *et al*., 2015; Saleem *et al*., 2016). The WQI representing gradation in water quality was first proposed by Horten (1965). WQI 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. It has been described as one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers (Ramakrishnaiah *et al*., 2009) and an important technique for demarcating groundwater quality and its suitability for drinking purpose (Dohare *et al*., 2014). WQI is 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 with the aim of turning complex water quality data into information that is easily understandable by the public.

The objectives of this study are (1) to analyze few groundwater quality parameters in terms of their physico-chemical characteristics and (2) 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.

Materials and Method

Study Area

Minna, a capital city of Niger State of Nigeria is located between Latitude 9^{o}37″N and Longitude 6^{o}33″E (Figure 1) and covers a total landmass of approximately 1300 km^2 (Adeniyi, 1984). 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^{o}C and lowest in August at 25.1^{o}C.

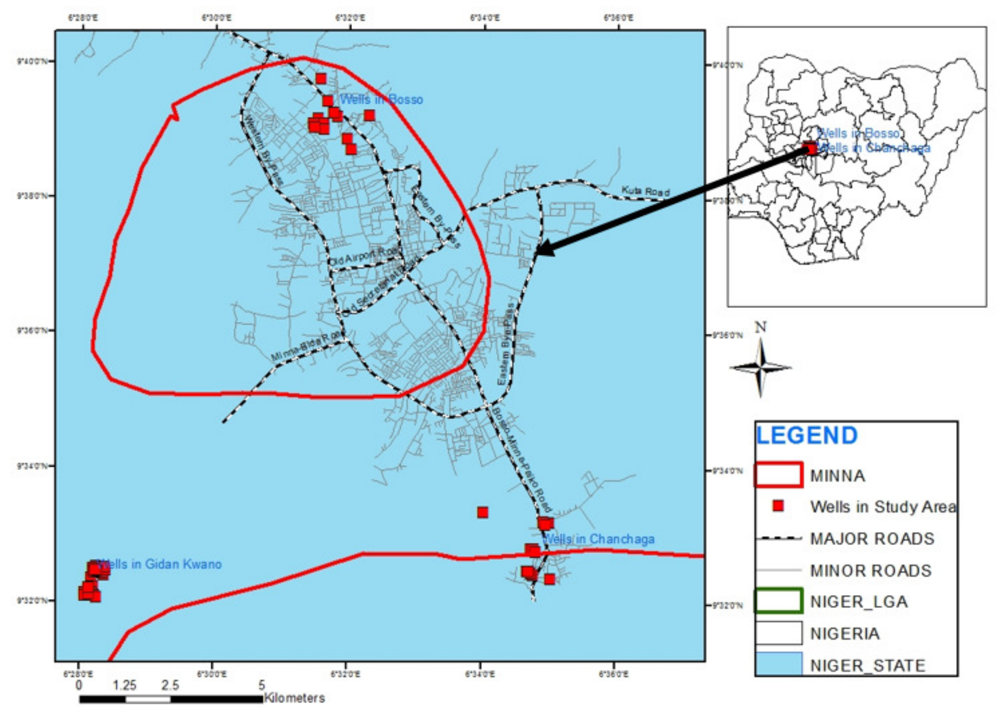

Fig. 1: Map of Minna showing the sampling locations

Sampling Method

Minna metropolis was divided into 4 sub-areas for sampling purposes. The 4 sub-areas are Chanchaga, Bosso, Kpakungu, and Gidan Kwano. Samples were taken during both the dry and wet seasons of the year 2017. Fifteen wells were sampled and 90 samples of water were collected for analysis during the sampling periods. The groundwater samples were collected early in the morning in labelled plastic bottles and kept in ice packs before being transported to the laboratory for analysis.

Analysis of Samples

Physico-chemical parameters analyzed were pH, total alkalinity, chlorides, sulphate, total hardness, calcium, magnesium, electrical conductivity, and total dissolved solids (APHA, 1992 and WHO, 1992).

Calculation of WQI

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

$$qi = (Ci/Si)\times 100 \qquad [1]$$

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:

$$Wi = 1/Si \qquad [2]$$

The overall Water Quality Index (WQI) was calculated by aggregating the quality rating (*Qi*) with unit weight (Wi) linearly (Equations 3 and 4);

$$\text{WQI} = \left(\sum_{I=1}^{i=n} W_i q_i \right) \qquad [3]$$

$$\text{Overall WQI} = \frac{\sum q_i w_i}{\sum w_i} \qquad [4]$$

Statistical Analysis

The statistical analysis was carried out using correlation matrix with IBM SPSS 22 to check the relationships among the water quality parameters.

Dry Season Sampling

Tables 1 to 2 present the calculations of WQI of the groundwater in two of the study areas for the dry season. The two study areas represent the lowest and highest values of the WQI for the groundwater samples which range from 334.27 in Kpakungu study area to 546.23 in Bosso study area.

Results and discussions

Table 1: Computed Dry Season 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	
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	
Rel 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 2: Computed Dry Season 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	
Rel 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	
Wnqn	9.8	8.7	5.18	9.62	3.2	1.07	459.5	22.8	0.56	15.1	8.1	2.6	**546.23**

$$\frac{\sum q_i w_i}{\sum w_i} = \frac{546.23}{1.0} = 546.23$$

Results obtained for pH in all the study areas varied between 6.81 and 7.69 which are within the limits of World Health Organization (WHO) values of 6.5–8.5 (WHO, 1998). This was attributed to the levels of concentration of calcium, magnesium and total alkalinity. The results obtained for sulphates range from 212.53 mg/L in Kpakungu to 293.41 mg/L in Chanchaga all of which were above the permissible limit of 100 mg/L.

The total hardness varies from 131.64 mg/L in Kpakungu study area to 155.49 mg/L in Bosso study area which are within the limits of Nigerian Standard for Drinking Water Quality (NIS, 2007) of 150 mg/L and WHO specifications of 300 mg/L (World Health Organization, 1998), except in Bosso study area. TDS values range from 218.81 mg/L to 627.77 mg/L in the study areas. The values are within the permissible limit of 500 mg/L except in Bosso study area. The high WQI values are due to high concentration of iron, electrical conductivity, total hardness and sulphate. This could be attributed to the seepage of wastes either from septic tanks or from decaying organic matter into the ground water system.

Wet Season Sampling

The calculations of WQI for the wet season are presented in Tables 3 and 4 for two of four study areas. The WQI for the groundwater samples ranges from 242.51 recorded in Chanchaga study area to 404.19 recorded in Gidan Kwano study area which follows the same trend as recorded during the dry season

Table 3: Computed Wet Season WQI for Water Quality of Gidan Kwano Wells

Sample	E.C	PH	TH	TA	Cl^-	Ca	Mg	SO_4^{-2}	Na	TDS	Fe	Mn	
W1	324.00	6.75	100.67	83.00	18.87	31.40	5.43	164.15	8.11	207.36	0.05	0.25	
W2	249.00	6.65	102.50	75.50	5.46	24.60	10.02	136.64	9.74	159.36	0.22	0.25	
W3	284.67	7.06	102.00	73.00	15.06	34.76	3.71	186.68	10.96	182.19	0.10	0.25	
W4	256.33	6.84	109.67	67.67	11.92	32.94	6.69	155.14	10.42	164.05	0.07	0.06	
W5	771.33	6.80	148.33	99.67	41.31	41.35	11.00	140.01	7.94	493.65	0.18	0.03	
W6	311.33	7.00	108.33	92.00	16.55	25.65	10.81	114.59	11.02	199.25	0.22	3.04	
W7	376.33	6.70	131.67	68.33	24.99	31.40	13.00	121.34	10.93	240.85	0.22	0.16	
W8	1079.33	7.00	250.67	217.67	69.85	49.34	31.10	157.07	16.93	690.77	0.34	0.13	
W9	629.00	6.99	238.67	208.67	24.99	25.51	42.69	270.37	20.16	402.56	0.13	0.02	
W10	234.00	7.09	84.67	71.67	11.75	26.21	4.69	193.76	15.25	149.76	0.05	0.03	
W11	360.67	6.73	105.33	74.00	22.84	34.34	4.78	167.05	8.89	230.83	0.05	0.03	
W12	496.33	6.71	147.67	62.67	36.08	34.06	15.28	128.10	9.29	317.65	0.14	0.02	
W13	403.33	6.51	121.33	80.33	26.81	35.04	8.26	183.46	7.99	258.13	0.34	0.18	
W14	483.33	6.73	139.00	99.33	44.03	37.43	11.11	141.62	9.72	309.33	0.36	0.23	
W15	436.33	6.72	188.00	82.67	31.45	34.48	24.86	164.79	14.21	279.25	0.19	0.05	
LabValue(Ci)	446.36	6.82	138.57	97.08	26.80	33.24	13.56	161.65	11.44	285.67	0.18	0.31	
S. Value (Si)	1000	8.5	150	120	250	200	0.2	100	250	500	0.3	0.2	
Weight (wi)	4	4	2	3	5	2	2	4	3	5	4	3	
R.Wt (Wi)	0.1	0.1	0.05	0.07	0.12	0.05	0.05	0.1	0.07	0.12	0.1	0.07	**1**
Qty Rating qi	44.64	80.22	92.38	80.90	10.72	16.62	6780.96	161.65	4.57	57.13	58.96	157.44	
Wiqi	4.46	8.02	4.62	5.66	1.29	0.83	339.05	16.17	0.32	6.86	5.90	11.02	**404.19**

$$\frac{\sum q_i w_i}{\sum w_i} = \frac{404.19}{1.0} = 404.19$$

Table 4: Computed Wet Season WQI for Water Quality of Bosso wells

Sample	E.C	PH	TH	TA	CL-	Ca	Mg	SO4-2	Na	TDS	Fe	Mn	
W1	672.00	6.88	109.00	91.00	34.51	59.78	4.79	159.45	6.98	371.20	0.17	0.05	
W2	891.00	6.83	134.33	93.67	45.36	76.94	5.23	144.84	8.23	509.44	0.22	0.03	
W3	373.67	7.27	124.00	122.00	28.63	77.64	7.02	144.39	6.02	360.96	0.31	0.04	
W4	1945.00	6.94	193.67	182.00	133.90	73.44	13.44	132.29	4.75	1272.96	0.35	0.02	
W5	1391.00	7.20	112.40	172.33	96.00	40.64	8.34	147.09	7.12	752.85	0.28	0.02	
W6	1494.00	7.16	181.80	246.67	93.52	66.72	8.44	139.69	9.12	1098.24	0.17	0.08	
W7	1436.67	7.20	183.73	120.67	108.58	46.09	14.14	124.89	6.96	935.68	0.28	0.07	
W8	997.33	7.33	129.33	123.00	53.79	48.08	13.38	122.95	5.39	795.09	0.24	0.04	
W9	986.33	7.26	113.33	161.33	46.68	45.97	3.42	128.42	5.17	674.56	0.28	0.17	
W10	1175.00	6.99	184.20	132.67	83.75	75.96	1.87	131.64	5.11	891.52	0.38	0.08	
W11	1061.67	6.94	124.33	77.33	57.43	59.15	4.75	108.15	5.69	587.09	0.33	0.05	
W12	1152.33	6.78	143.00	74.00	70.84	66.79	11.98	100.42	6.02	452.27	0.24	0.06	
W13	436.33	6.99	69.67	67.33	21.85	43.59	6.43	102.35	8.44	352.85	0.27	0.12	
W14	336.33	7.22	75.67	69.00	6.95	25.36	10.23	81.11	5.84	245.55	0.33	0.06	
W15	364.67	7.18	73.33	89.00	21.68	32.93	4.67	116.84	5.98	343.89	0.24	0.10	
LabValue(Ci)	980.89	7.08	130.12	121.47	60.23	55.94	7.87	125.64	6.45	642.94	0.27	0.06	
S.Value(Si)	1000	8.5	150	120	250	200	0.2	100	250	500	0.3	0.2	
Weight(wi)	4	4	2	3	5	2	2	4	3	5	4	3	
R.Wt (Wi)	0.1	0.1	0.05	0.07	0.12	0.05	0.05	0.1	0.07	0.12	0.1	0.07	1
QtyRatingqi	98.09	83.28	86.75	101.22	24.09	27.97	3937.3	125.64	2.58	128.59	91.04	32.44	
Wiqi	9.81	8.33	4.34	7.09	2.89	1.40	196.87	12.56	0.18	15.43	9.10	2.27	270.27

$$\frac{\sum q_i w_i}{\sum w_i} = \frac{270.27}{1.0} = 270.27$$

In Table 4, total alkalinity (TA), sulphates and TDS values were above the limits which dictate the high concentration of WQI obtained in Bosso study area. From Tables 3 and 4, total dissolved solids (ranging from 218.81 mg/L to 627.77 mg/L), sulphates, and total hardness (TH) values were above the limits compared to other parameters in Bosso study area which explained the higher value of WQI recorded in all these study areas. This thus explains that TDS, sulphate and magnesium values determine the values of WQI in groundwater.

Thus, the WQI values obtained categorizes the groundwater in all the study areas as 'water unsuitable for drinking' (Table 5). 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 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).

The higher value of TDS 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 this water for irrigation will harm the crops and reduce crop yields (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 $SO4^{2-}$. 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 mgL^{-1} (Ikomi and Emuh, 2000; Egereonu, 2004).

The suitability of WQI values for human consumption is as presented in Table 5, according to Asuquo and Etim (2012).

Table 5: 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 for drinking

Source: Asuquo and Etim (2012)

Table 6 shows the summary of the WQI values for both the dry and wet seasons. Apart from Gidan Kwano study areas, the values of WQI recorded during the dry season are higher than the values obtained during the wet season. This could be attributed to the reduction in the concentration of these parameters in the groundwater as a result of rise in groundwater table during the wet season. In other words, during the wet season, contamination of groundwater is less as a result of excess water from both the surface runoff and percolated water recharging the groundwater, thereby resulting in rise in piezsometric surface.

Table 6: Summary of WQI with the sampling areas

	Average WQI	
Sampling Area	**Dry season**	**Wet season**
Gidan Kwano	361.53	404.19
Bosso	546.23	270.27
Chanchaga	535.88	242.51
Kpakungu	334.27	323.28

From the tables 5 and 6, it is clearly shown that in both dry and wet seasons, groundwater in all the study areas are very poor and unsafe for human consumption.

Tables 7 and 8 show the correlation coefficients and interrelationships among the water quality parameters for dry and wet seasons for Chanchaga and Kpakungu study areas respectively.

During the dry season, 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.

Table 7: Correlation coefficient matrix of water quality parameters of Chanchaga wells for dry season

		EC	**PH**	**TH**	**TA**	Cl^-	**Ca**	**Mg**	$SO4^{2-}$	**Na**	**TDS**	**Fe**	**Mn**
EC	Pearson Correlation	1											
	Sig. (2-tailed)												
PH	Pearson Correlation	-.009	1										
	Sig. (2-tailed)	.975											
TH	Pearson Correlation	.827**	.407	1									
	Sig. (2-tailed)	.000	.132										
TA	Pearson Correlation	.494	.721**	.731**	1								
	Sig. (2-tailed)	.061	.002	.002									
Cl^-	Pearson Correlation	.758**	-.326	.486	-.008	1							
	Sig. (2-tailed)	.001	.235	.066	.977								
Ca	Pearson Correlation	.439	.600*	.724**	.655**	.235	1						
	Sig. (2-tailed)	.101	.018	.002	.008	.399							
Mg	Pearson Correlation	.842**	.093	.857**	.526*	.522*	.270	1					
	Sig. (2-tailed)	.000	.743	.000	.044	.046	.330						
$SO4^{2-}$	Pearson Correlation	.457	-.051	.290	.144	.377	-.146	.536*	1				
	Sig. (2-tailed)	.086	.855	.294	.609	.166	.604	.039					
Na	Pearson Correlation	.724**	.292	.703**	.555*	.548*	.374	.676**	.318	1			
	Sig. (2-tailed)	.002	.290	.003	.032	.034	.170	.006	.248				
TDS	Pearson Correlation	1.000**	-.009	.827**	.494	.758**	.439	.842**	.457	.724**	1		
	Sig. (2-tailed)	.000	.975	.000	.061	.001	.101	.000	.086	.002			
Fe	Pearson Correlation	-.418	.132	-.266	-.195	-.330	-.044	-.330	-.290	-.142	-.418	1	
	Sig. (2-tailed)	.121	.639	.338	.486	.229	.876	.229	.295	.615	.121		
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).

There were no significant correlations observed in all sampling areas between electrical conductivity, chloride, magnesium, and sodium during the wet season. However, total hardness and total alkalinity were strongly correlated with calcium at 0.01 level in Chanchaga study area while in Kpakungu study area calcium showed strong correlation with total hardness, total alkalinity and total dissolved solids at 0.01 level. The results of correlation analysis for Kpakungu study area is presented in Table 8.

Table 8: Correlation coefficient matrix of water quality parameters of Kpakungu wells for wet season

		EC	PH	TH	TA	Cl^-	Ca	Mg	$SO4^{2-}$	Na	TDS	Fe	Mn
EC	Pearson Correlation	1											
	Sig. (2-tailed)												
pH	Pearson Correlation	-.049	1										
	Sig. (2-tailed)	.862											
TH	Pearson Correlation	.974**	-.176	1									
	Sig. (2-tailed)	.000	.530										
TA	Pearson Correlation	.931**	-.272	.958**	1								
	Sig. (2-tailed)	.000	.327	.000									
Cl^-	Pearson Correlation	.955**	.124	.908**	.858**	1							
	Sig. (2-tailed)	.000	.659	.000	.000								
Ca	Pearson Correlation	.878**	.194	.813**	.701**	.883**	1						
	Sig. (2-tailed)	.000	.488	.000	.004	.000							
Mg	Pearson Correlation	.721**	-.587*	.804**	.852**	.565*	.377	1					
	Sig. (2-tailed)	.002	.021	.000	.000	.028	.166						
$SO4^{2-}$	Pearson Correlation	.265	-.141	.267	.306	.310	.178	.306	1				
	Sig. (2-tailed)	.340	.617	.336	.267	.261	.527	.267					
Na	Pearson Correlation	.958**	-.220	.966**	.944**	.893**	.743**	.808**	.315	1			
	Sig. (2-tailed)	.000	.430	.000	.000	.000	.002	.000	.252				
TDS	Pearson Correlation	.988**	-.058	.957**	.922**	.949**	.866**	.708**	.206	.945**	1		
	Sig. (2-tailed)	.000	.838	.000	.000	.000	.000	.003	.461	.000			
Fe	Pearson Correlation	-.037	-.087	-.131	.004	-.033	.078	-.043	.014	-.159	.015	1	
	Sig. (2-tailed)	.897	.758	.641	.987	.908	.782	.878	.961	.571	.958		
Mn	Pearson Correlation	-.029	.073	-.125	-.051	.012	.170	-.111	-.013	-.149	.014	.827**	1
	Sig. (2-tailed)	.917	.796	.657	.856	.965	.544	.693	.962	.595	.961	.000	

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

Conclusions

The WQI for 180 samples of groundwater collected from four different areas in Minna metropolis have been obtained. The values of WQI obtained range from 334.27 to 535.88 in all the study areas. 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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