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Evaluation of the Water Quality of River Kaduna, Nigeria Using Water Quality Index

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ABSTRACT: Twelve (12) water quality parameters (turbidity, TDS, pH, Cl^-, EC, DO, BOD_5, COD, total nitrogen, total phosphorus, Fe and Mn) were analyzed in River Kaduna, Nigeria on a monthly basis for a period of one year in 15 sampling locations using standard methods. The data obtained were used to develop Water Quality Index (WQI) across the 15 sampling locations. The WQI revealed that the water quality of 4 sampling locations were poor as their index values ranged between 17.77 to 25.47. On the other hand, the generalized water quality of the remaining 11 sampling locations was marginal as the index values ranged between 44.95 to 60.80. The index values of the various sampling locations were thereafter used as weights in mapping the WQI of the entire sampled portion of the river using Inverse Distance Weighted (IDW) interpolation method. The WQI of the entire river was suggestively ranked marginal as 11 sampling locations out of 15 (73.3%) fell into the marginal category. Hence, regulatory agencies were advised to check the anthropogenic activities along the watershed with more emphasis at the hot spot areas or locations that recorded poor WQI. © JASEM

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***Key Words*:** WQI, Canadian, Mapping, Sampling, Locations.

Proper documentation of the water quality in a given catchment is important because it will suggest the level of treatment to be given to the water when the need for using such water for a particular purpose arises. This is because the cost of treating raw water per unit volume is a function of the quality status of the raw water. Therefore, a strategic means of cutting down the cost of treatment of raw water is to manage the pollution load of the rivers serving as source of raw water.

An integral part in any environmental monitoring program is the reporting of results to both managers and the general public. However, most water quality researchers report results by comparing the different analyzed parameters with their respective permissible limits set by regulating bodies (local or international). For instance, over the years, several researchers such as Mohammed *et al.* (2015), Mohammed (2013) and Yusuf *et al.* (2008) have reported the water quality of River Kaduna by describing the trends and compliance with official stated guidelines. However, Carlos and Alejandra (2014) stated that in many cases, managers and the general public rather prefer statements concerning the general health or status of the system concern. Hence, the Canadian Council of Ministers of Environment (2001) reported that one possible solution to this problem is by employing an index that will mathematically combine all water quality measures and provide a general and readily understood description of the water. In other words, developing Water Quality Index (WQI) for River Kaduna will summarize the various analyzed water ingredients (parameters) and rank the overall quality of the water. The ranking could be excellent, good, fair, marginal or poor.

MATERIALS AND METHOD

Description of Study Area: River Kaduna is a tributary of the River Niger with its source from Kujama Hill in Plateau State and flow for 210km before reaching Kaduna town. It crosses the city dividing it into north and south areas. Beyond Kaduna, the river flows for about 100km into the Shiroro Dam. It continues to flow for 100km and finally discharges into River Niger at the northern shores of Pategi (Ekiye and Luo, 2010). However, the portion of the river considered was 32.7km stretch that cut across four Local Government Areas of Kaduna State which are parts of Igabi, Kaduna North, Chikun and Kaduna South (Figure 1). This stretch of the river falls between Latitudes 10^o 28 00" – 10^o 36' 00" North and longitude 07^o 21' 00" – 07^o 35' 00" East (ArcGIS 10.5).

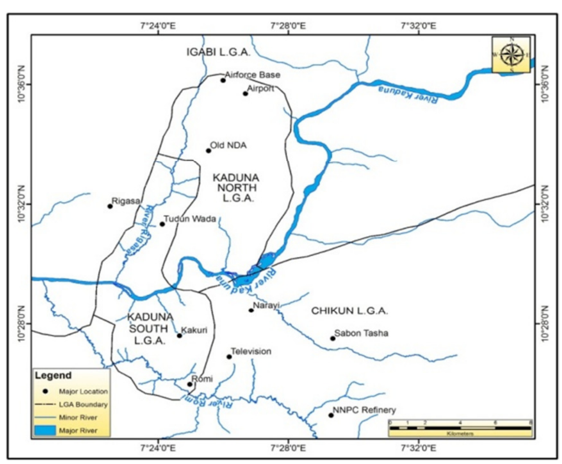

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Fig 1: Map of River Kaduna within Kaduna metropolis.

Sampling Locations: The sampling locations comprises of 8 along River Kaduna and 7 (at about 30m away from the confluence points) along the major tributaries, making a total of 15 sampling sites. These stations correspond to flow routs and inflow from discharge point. The justification for selecting these locations as sampling points is that, they represented the best point for gaining access to the rivers and also suitable for easy sampling of the current water quality status and have a more progressive pollution load (Adie, 2008).

At each sampling location, a Global Position System (GPS) was used in recording the geographical coordinate of such location. The recorded coordinate of all the sampling locations are shown in Table 1

.

Table 1: Sampling location coordinates

Location Code	Location Name	Geographical Coordinate
L1	Malali	10°36'3.09"N, 7°30'21.91"E
L2	Kwarau	10°36'16.96"N, 7°30'5.43"E
L3	NNPC	10°31'29.23"N, 7°28'14.04"E
L4	Kuyi	10°30'56.02"N, 7°28'28.84"E
L5	Barnawa	10°29'44.46"N, 7°26'56.86"E
L6	Kutimbi	10°28'53.12"N, 7°27'6.71"E
L7	Living Faith	10°29'36.82"N, 7°26'16.25"E
L8	Kigo	10°29'57.44"N, 7°26'3.32"E
L9	Down Quarters	10°29'6.80"N, 7°24'13.53"E
L10	Breweries	10°28'40.07"N, 7°24'7.42"E
L11	Ungwa Mu'Azu	10°29'17.15"N, 7°22'56.89"E
L12	Rigasa	10°29'42.63"N, 7°22'45.92"E
L13	Maigiginya	10°29'30.84"N, 7°20'48.66"E
L14	Romi	10°29'10.65"N, 7°20'31.50"E
L15	Railway Bridge	10°29'31.67"N, 7°20'13.77"E

Sampling Procedure and Laboratory Analysis: The sampling was done monthly for a period of one year between June 2016 and May 2017 thus, covering two metrological seasons. This sampling frequency and duration is in line with Adebayo (2014) and Esengul *et al.* (2014).

The grab sampling technique was employed in each sampling location. This was done by dipping high density polyethylene (HDPE) plastic bottles below the water surface at the center of the stream and ensuring that the mouth of the bottle faces the water current. Prior to sampling, the sample bottles were disinfected with methylated spirit and then thoroughly rinsed with the sample water before sample collection as recommended by APHA, (2005). The collected samples were stored in a cooler containing ice and delivered on the same day to the laboratory where they were refrigerated until analysis. However, DO, pH, TDS and EC were determined in-situ.

A portable dissolved oxygen meter (DO STARTER300D, ±1% made by OHAUS Corporation, USA) was used for the determination of dissolved oxygen while a Pocket-sized pH meter (pHep®,±0.1 made by HANNA LTD, England) was used in determining pH. TDS and EC were determined via a pocket-sized dissolved solids and conductivity meter with temperature compensation (TDS & EC hold, ±2% made by Griffin Company, USA). However, turbidity, total nitrogen and total phosphorus were analyzed by HACH 2100N turbidimeter (made by HANNA, LTD, England), Kjeldahl auto distillation machine (Kjeltec 8200™ made by FOSS, Sweden) and Phosphorous meter

(Colorimeter 257 made by Sherwood, USA) respectively. Determination of chloride ion (Cl^-) was achieved through Mohr's titrimetric method by using silver nitrate as titrant while heavy metals (Fe and Mn) were analyzed through atomic absorption spectrophotometer (280FS AA made by Agilent Technology, USA). Glassware (BOD bottles, conical flasks, measuring cylinders, pipettes and burets) made by Kimax Company, England were used for titration during the determination of Cl^-, BOD and COD. In addition, a handheld Global Position System navigator (Etrex 20x) made by Garmin, USA was used in determining the geographical locations of the sampled points.

Development of Water Quality Index: The Water Quality Index (WQI) developed was based on the Canadian Council of Ministers of Environment (CCME), which has been adopted by the Global Environmental Monitoring Systems (GEMS, 2007). The index is based on a combination of three factors:

Scope, **F_1** - the number of variables whose objectives are not met

$$F_1 = \frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables} \times 100 \quad (1)$$

Frequency, **F_2**, - the frequency with which the objectives are not met.

$$F_2 = \frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests} \times 100 \quad (2)$$

Amplitude, **F_3**, - the amount by which the objectives are not met. F_3 was calculated in three steps:

a) The number of times by which an individual concentration was greater than (or less than, when the objective is a minimum) the objective was termed an "excursion" and was estimated as follows;

b) $$excursion_i = \frac{Failed\ Test\ Value_i}{Objective_j} - 1 \quad (3)$$

For cases in which the test value must not exceed the objective:

$$excursion_i = \frac{Objective_j}{Failed\ Test\ value_i} - 1 \quad (4)$$

c) The collective amount by which individual tests were out of compliance was calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives). This variable, referred to as the normalized sum of excursions (nse), was calculated as:

$$nse = \frac{\sum_{i=1}^{n} excursion_i}{number\ of\ tests} \quad (5)$$

d) F_3 was thereafter calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a range between 0 and 100 as given in Equation (6)

$$F_3 = \frac{nse}{0.01nse + 0.01} \quad (6)$$

The Canadian Council of Ministers of Environment Water Quality Index (CCME WQI) was then developed by substituting the values of F_1, F_2 and F_3 into the Equation (7) given by CCME, 2001.

$$WQI = 100 - \frac{\sqrt{(F_1{}^2 + F_2{}^2 + F_3{}^2)}}{1.732} \quad (7)$$

Equation (7) was employed in all the sampling locations and their respective results were computed. Thereafter, the results obtained were ranked into five categories as recommended by the Canadian Council of Ministers of Environment (CCME, 2001). These five categories for the assessment and protection of aquatic environment are as follows;

Excellent: (CCME WQI Value 95-100) – Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels.

Good: (CCME WQI Value 80-94) – Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.

Fair: (CCME WQI Value 65-79) – Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.

Marginal: (CCME WQI Value 45-64) – Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.

Poor: (CCME WQI Value 0-44) – Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

Mapping of Water Quality Index: Inverse Distance Weighted Interpolation (IDW) method of the spatial analyst extension (ESRI, 2015) in the ArcGIS 10.5 was used in mapping the WQI within the catchment area. This is because Inverse Distance Weighted interpolation (IDW) assumes that the nearer a sample point is to the cell whose value is to be estimated, the more closely the cell's value will resemble the sample point's value. In other words, the principle underlying IDW is the Waldo Tobler's first law of Geography which states that *"everything is related to everything else, but near things are more related than distant things"*.

IDW uses linear combination of weights at known points to estimate unknown location values (ESRI, 2015). That is, values at unknown locations $\hat{Z}(S_0)$ were determined by the weighting value $\lambda_i(S_0)$ and values at known locations $Z(S_i)$ expressed mathematically as shown in Equation (8), ESRI (2015).

$$\hat{Z}(S_0) = \sum_{i=1}^{n} \lambda_i(S_0).Z(S_i) \quad (8)$$

However, the weights $\lambda_i(S_0)$ were estimated through inverse distance from all points to the new points by applying equation (9), ESRI (2015).

$$\lambda_i(S_0) = \frac{\frac{1}{\beta d(S_0,S_1)}}{\sum_{i=0}^{n}\frac{1}{\beta d(S_0,S_1)}}\ ;\ \beta > 1 \quad (9)$$

Where:

$\boldsymbol{\lambda_i}$ = Weight for neighbor *i* (the sum of weights must be unity to ensure an unbiased interpolator).

$\boldsymbol{d(S_0, S_1)}$ = Distance from the new point to a known sample point.

$\boldsymbol{\beta}$ = Coefficient used to adjust the weights.

$\boldsymbol{n}$ = Total number of points in the neighbourhood analysis.

RESULTS AND DISCUSSION

The in-situ and laboratory results of the concerned water quality parameters in all the sampling sites (i.e sampling location L1 to L15) are shown in Table 2 to Table 13.

Table 2: Monthly variation of turbidity (NTU)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15
Jun	78.4	49.4	150.9	83.4	81.0	95.4	110.1	188.2	109.7	167.5	107.6	111.5	75.9	84.9	55.3
Jul	92.0	58.0	176.5	98.1	95.1	111.8	128.2	221.3	128.5	196.4	126.1	130.5	87.9	99.9	65.1
Aug	74.3	46.2	142.4	77.8	76.0	90.3	103.9	176.6	103.8	158.9	101.2	106.3	70.8	80.7	52.1
Sep	41.4	27.8	79.9	43.3	42.6	50.4	57.7	100.4	58.2	88.9	56.8	59.1	39.3	44.6	28.9
Oct	29.4	18.5	56.2	31.3	30.1	35.7	41.5	71.8	41.2	63.5	41.0	42.1	28.7	31.9	20.8
Nov	26.8	8.7	4.3	9.1	9.4	6.9	4.9	1.8	5.2	2.3	5.5	4.6	17.1	9.1	21.2
Dec	22.8	7.5	3.7	7.8	8.0	5.9	4.2	1.6	4.4	1.9	4.6	3.9	14.6	7.7	18.1
Jan	21.4	7.0	3.4	7.3	7.7	5.5	3.9	1.5	4.1	1.8	4.4	3.7	13.8	7.3	17.1
Feb	18.2	5.9	2.9	6.2	6.4	4.6	3.3	1.2	3.5	1.6	3.7	3.1	116	6.1	14.4
Mar	12.2	3.9	1.9	4.2	4.3	3.1	2.2	0.9	2.3	1.0	2.4	2.1	7.7	4.1	9.6
Apr	8.7	2.8	1.4	2.9	3.0	2.2	1.6	0.6	1.7	0.7	1.7	1.5	5.5	2.9	6.8
May	62.1	38.9	119.5	66.1	63.8	75.3	87.2	149.9	86.9	132.9	85.9	88.2	60.2	67.1	43.8

NTU = Naphelometric Turbidity Unit. L1, L2, L3,…….,L15 = Sampling Locations 1, 2,3,………,15 in that order.

Table 3: Monthly variation of total dissolved solids (mg/L)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15
Jun	81	88	84	83	80	401	93	460	82	525	95	498	80	94	80
Jul	76	85	79	80	75	387	82	408	80	504	88	476	75	89	77
Aug	65	80	62	73	66	345	77	388	69	474	83	454	69	85	71
Sep	60	76	61	70	58	333	68	351	66	470	78	422	67	79	69
Oct	61	75	59	65	59	329	75	392	71	485	81	451	77	84	77
Nov	93	121	94	100	95	389	98	466	91	505	97	468	93	114	94
Dec	105	127	103	113	103	542	103	561	102	562	105	529	104	127	103
Jan	106	123	107	116	107	576	105	598	107	604	107	532	108	132	108
Feb	97	115	97	106	99	550	99	569	97	609	99	524	98	124	99
Mar	100	116	102	108	101	518	100	587	101	600	101	508	102	121	101
Apr	90	110	88	99	93	507	91	529	91	593	89	504	92	116	92
May	79	86	78	86	82	502	91	506	82	547	87	502	81	102	81

L1, L2, L3, L15 = Sampling Locations 1, 2, 3,………,15 in that order.

Table 4: Monthly variation of pH

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15
Jun	7.2	7.3	7.3	6.7	7.3	6.3	7.2	6.4	7.2	8.9	7.2	6.5	7.2	7.4	7.2
Jul	6.8	7.3	6.9	6.7	6.8	6.3	6.8	6.3	6.9	8.8	6.8	6.4	6.7	7.3	6.8
Aug	6.8	6.8	6.8	6.5	6.7	6.2	6.7	6.2	6.8	8.7	6.7	6.4	6.7	7.3	6.7
Sep	6.9	6.7	6.8	6.6	6.8	6.4	6.8	6.3	6.9	8.9	6.9	6.3	6.8	7.4	6.8
Oct	7.2	6.8	7.3	6.8	7.4	6.6	7.3	6.5	6.7	8.9	7.2	6.4	7.2	7.5	7.3
Nov	7.4	6.8	7.5	6.7	7.6	6.8	7.7	6.6	6.9	9.0	7.4	6.7	7.4	7.6	7.5
Dec	7.4	7.4	7.4	6.8	7.4	6.8	7.5	6.8	7.2	9.1	7.5	6.8	7.6	7.5	7.6
Jan	7.5	7.4	7.5	7.3	7.5	6.9	7.4	7.1	7.4	9.2	7.7	7.9	7.8	7.7	7.7
Feb	7.6	7.5	7.5	7.3	7.3	6.8	7.5	7.3	7.4	9.1	7.8	7.2	7.7	7.7	7.7
Mar	7.3	7.6	7.4	7.4	7.4	6.7	7.4	7.4	7.4	9.3	7.9	7.4	7.8	7.8	7.8
Apr	7.5	7.3	7.4	7.2	7.5	6.6	7.6	6.8	7.3	9.2	7.5	6.8	7.3	7.6	7.4
May	7.2	7.3	7.3	6.9	7.4	6.4	7.3	6.3	7.2	9.0	7.3	6.4	7.1	7.5	7.2

L1, L2, L3,……., L15 = Sampling Locations 1, 2,3,………,15 in that order.

Table 5: Monthly variation of chloride ion (mg/L)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15
Jun	13.28	16.65	14.78	14.35	12.88	194.52	19.64	227.64	13.02	265.91	21.14	249.77	12.69	20.52	12.53
Jul	10.28	15.15	12.15	12.84	9.91	186.68	13.65	197.94	12.53	253.88	17.02	237.04	9.91	17.90	10.66
Aug	3.91	12.14	2.42	8.69	4.66	162.80	10.66	187.03	6.16	236.59	14.40	225.05	6.54	15.66	7.28
Sep	0.92	10.26	2.04	7.18	0.17	156.46	5.79	165.98	4.66	234.71	11.40	207.07	5.41	12.66	6.16
Oct	1.67	9.51	0.63	4.16	0.92	154.22	9.91	188.91	7.28	242.98	12.90	223.18	11.03	15.28	11.03
Nov	19.64	35.45	20.39	24.16	20.77	187.80	22.64	230.64	18.52	254.63	21.89	232.92	19.64	32.13	20.39
Dec	26.39	38.45	25.26	31.33	25.64	273.25	25.64	284.40	24.89	286.59	26.39	267.01	26.01	39.25	25.64
Jan	27.13	36.58	27.88	32.84	27.88	292.28	26.76	305.08	27.51	310.27	27.51	268.87	28.26	41.87	28.26
Feb	22.27	31.69	21.89	27.18	23.01	277.35	23.39	288.91	21.89	313.28	23.01	264.38	22.64	37.75	23.01
Mar	23.76	32.44	24.89	28.69	24.51	259.82	23.76	299.06	24.14	308.02	24.51	255.39	24.89	35.88	24.14
Apr	18.15	29.06	17.02	23.40	19.64	253.47	18.90	266.36	18.90	303.88	17.77	252.77	19.27	33.26	19.27
May	12.15	15.53	11.40	15.86	12.53	250.86	18.52	253.20	13.65	278.32	16.27	251.64	12.53	25.02	13.28

L1, L2, L3,…….,L15 = Sampling Locations 1, 2,3,………,15 in that order.

Table 6: Monthly variation of electrical conductivity (μS/cm)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15
Jun	122	131	126	124	120	601	136	690	123	789	143	747	120	140	120
Jul	114	127	119	120	113	580	139	611	120	757	132	713	113	133	115
Aug	97	119	93	109	99	516	123	582	103	711	125	681	104	127	106
Sep	89	114	92	105	87	499	115	526	99	706	117	633	101	119	103
Oct	91	112	88	97	89	493	102	587	106	728	121	676	116	126	116
Nov	139	181	141	150	142	583	113	698	136	759	145	702	139	171	141
Dec	157	189	154	169	155	812	155	841	153	844	157	793	156	190	155
Jan	159	184	161	173	161	863	158	896	160	907	160	798	162	197	162
Feb	146	171	145	158	148	823	149	853	145	915	148	786	147	186	148
Mar	150	173	153	162	152	776	150	880	151	901	152	762	153	181	151
Apr	135	164	132	148	139	759	137	793	137	890	134	755	138	174	138
May	119	128	117	128	120	752	136	758	123	822	130	752	120	152	122

μS/cm = Micro Mohs per centimeter. L1, L2, L3, ………,L15 = Sampling Locations 1, 2,3,………,15 in that order.

Table 7: Monthly variation of dissolved oxygen (mg/L)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15
Jun	7.80	6.85	7.72	6.51	7.27	4.72	7.23	4.80	7.09	4.24	7.01	4.09	7.58	6.88	7.58
Jul	8.18	6.92	8.15	6.68	7.32	4.77	7.19	4.86	7.13	4.37	7.04	4.83	8.02	6.97	8.01
Aug	8.22	6.88	8.23	6.23	6.84	4.56	6.77	4.73	6.81	4.29	6.75	4.52	7.79	6.56	7.76
Sep	8.10	6.32	8.06	5.97	6.50	4.22	6.59	4.39	6.54	4.06	6.42	4.49	7.08	6.39	7.08
Oct	7.96	6.11	7.85	5.46	6.17	3.97	6.14	4.12	6.10	3.71	5.97	4.17	6.48	6.11	6.44
Nov	7.48	5.73	7.52	5.17	5.88	3.66	5.09	3.90	5.07	3.55	4.81	3.91	5.02	5.60	5.04
Dec	7.25	5.28	6.99	4.86	5.69	3.39	4.51	3.44	4.10	3.46	3.77	3.91	4.36	4.81	4.38
Jan	6.11	4.86	6.27	4.39	4.87	3.28	4.12	3.37	4.02	2.61	3.64	3.86	4.05	4.48	4.09
Feb	5.87	4.77	5.93	4.33	4.61	3.23	3.95	3.15	3.56	2.19	3.49	3.54	3.98	4.11	4.01
Mar	5.25	4.50	5.37	4.20	4.48	3.15	3.86	3.11	3.44	2.43	3.16	3.29	3.82	3.93	3.82
Apr	5.18	4.19	5.06	4.05	4.22	3.11	3.67	2.18	3.23	2.29	3.07	3.08	3.64	3.62	3.64
May	6.39	5.04	6.42	5.72	5.96	3.93	5.38	2.97	5.84	3.14	5.33	3.61	5.20	5.09	5.19

L1, L2, L3,…….,L15 = Sampling Locations 1, 2,3,………,15 in that order.

Table 8: Monthly variation of 5-days Biochemical Oxygen Demand (mg/L)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15
Jun	0.43	0.55	1.63	1.01	1.20	1.81	1.85	2.04	1.70	2.16	1.72	1.67	0.41	0.95	0.17
Jul	0.48	0.58	1.37	1.04	1.23	1.84	1.81	2.09	1.75	2.24	1.59	1.96	0.43	0.99	0.18
Aug	0.50	0.59	1.33	1.06	1.30	1.86	1.73	2.05	1.73	2.32	1.46	2.04	0.43	1.08	0.18
Sep	0.59	0.64	1.42	1.17	1.52	2.02	1.72	2.12	1.87	2.41	1.43	2.10	0.47	1.16	0.19
Oct	0.61	0.69	1.68	1.24	1.57	2.07	1.77	2.19	1.85	2.46	1.49	2.19	0.54	1.35	0.22
Nov	0.65	0.74	1.84	1.31	1.65	2.12	1.94	2.55	1.96	2.66	1.54	2.36	0.69	1.47	0.28
Dec	0.66	0.77	1.94	1.44	1.74	2.21	2.08	2.68	1.99	2.88	1.97	2.42	0.76	1.54	0.31
Jan	0.67	0.83	1.98	1.50	1.83	2.34	2.23	2.72	2.41	2.02	2.18	2.49	0.83	1.58	0.34
Feb	0.66	0.84	2.00	1.61	1.96	2.51	2.40	2.71	2.57	2.07	2.25	2.63	0.86	1.68	0.35
Mar	0.63	0.83	1.93	1.57	1.94	2.46	2.44	2.69	2.55	1.99	2.40	2.60	0.81	1.66	0.33
Apr	0.52	0.61	1.91	1.38	1.59	2.51	1.98	1.76	2.93	1.31	2.58	2.66	0.56	1.23	0.23
May	0.42	0.51	1.88	0.97	1.13	2.03	1.91	1.38	1.79	2.02	1.86	1.86	0.39	0.87	0.16

L1, L2, L3,…….,L15 = Sampling Locations 1, 2,3,………,15 in that order.

Table 9: Monthly variation of Chemical Oxygen Demand (mg/L)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15
Jun	35.08	36.49	49.92	40.84	41.94	46.50	53.25	61.72	52.35	58.23	48.33	53.10	37.91	43.00	35.91
Jul	33.79	35.00	47.88	39.18	40.23	44.60	51.08	58.17	50.18	55.82	46.06	50.61	36.13	39.96	33.37
Aug	34.32	35.55	48.64	39.79	40.86	45.30	51.88	59.08	50.97	56.70	46.79	51.41	36.70	40.59	33.90
Sep	36.04	37.33	51.07	41.78	42.91	47.57	54.48	62.05	53.53	59.55	49.13	53.98	38.54	42.62	35.59
Oct	37.99	39.35	53.83	44.04	45.22	50.14	57.42	65.40	56.41	62.76	51.78	56.89	40.62	44.92	37.51
Nov	40.12	41.55	56.84	46.51	47.76	52.95	60.64	69.06	59.58	66.28	54.69	60.09	42.90	47.45	39.63
Dec	41.46	42.95	58.76	48.07	49.36	54.73	62.68	71.38	61.58	68.50	56.53	62.11	44.34	49.04	40.96
Jan	43.26	44.80	61.29	50.15	51.50	57.10	65.39	74.48	64.25	71.47	58.97	64.79	46.26	51.16	42.73
Feb	43.84	45.41	62.13	50.83	51.18	57.93	66.34	75.56	65.18	72.51	59.83	65.74	46.93	51.91	43.35
Mar	44.39	45.98	62.91	51.47	52.85	58.59	67.09	76.42	65.93	73.34	60.51	66.48	47.46	52.49	43.84
Apr	45.07	46.68	63.86	52.25	53.66	59.49	68.13	77.59	66.94	74.46	61.44	67.50	48.19	53.30	44.51
May	36.21	37.51	51.32	41.98	43.11	47.80	54.74	62.35	53.78	59.82	49.37	54.24	38.72	42.83	35.77

L1, L2, L3,……..,L15 = Sampling Locations 1, 2,3,………,15 in that order.

Table 10: Monthly variation of total nitrogen (mg/L)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15
Jun	0.96	0.79	0.73	0.80	0.80	0.67	0.73	0.87	0.74	0.82	0.74	0.74	0.87	0.79	0.91
Jul	0.88	0.73	0.67	0.73	0.74	0.63	0.68	0.82	0.69	0.77	0.69	0.70	0.80	0.73	0.84
Aug	0.85	0.70	0.65	0.71	0.72	0.59	0.65	0.77	0.66	0.72	0.67	0.66	0.78	0.71	0.81
Sep	0.83	0.69	0.64	0.69	0.69	0.64	0.64	0.83	0.65	0.78	0.65	0.71	0.76	0.69	0.79
Oct	0.90	0.75	0.69	0.75	0.76	0.73	0.70	0.95	0.70	0.89	0.71	0.81	0.81	0.75	0.85
Nov	1.11	0.92	0.85	0.92	0.93	0.92	0.85	1.20	0.85	1.12	0.86	1.02	1.00	0.92	1.05
Dec	1.24	1.03	0.95	1.04	1.05	1.22	0.96	1.59	0.96	1.49	0.98	1.36	1.13	1.04	1.18
Jan	1.39	1.15	1.06	1.16	1.16	1.27	1.07	1.66	1.07	1.56	1.08	1.42	1.26	1.15	1.32
Feb	1.77	1.47	1.36	1.48	1.48	1.41	1.36	1.84	1.37	1.72	1.38	1.57	1.61	1.47	1.68
Mar	1.93	1.60	1.48	1.61	1.62	1.46	1.49	1.91	1.50	1.79	1.51	1.63	1.75	1.61	1.83
Apr	2.18	1.80	1.66	1.81	1.82	1.55	1.67	2.02	1.68	1.89	1.70	1.72	1.98	1.81	2.07
May	1.43	1.18	1.09	1.19	1.19	1.02	1.09	1.33	1.10	1.25	1.11	1.13	1.30	1.18	1.36

L1, L2, L3,…….,L15 = Sampling Locations 1, 2,3,………,15 in that order.

Table 11: Monthly variation of total phosphorus (mg/L)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15
Jun	0.140	0.115	0.107	0.117	0.117	0.098	0.107	0.114	0.108	0.120	0.109	0.108	0.127	0.115	0.133
Jul	0.128	0.107	0.098	0.107	0.108	0.092	0.099	0.106	0.101	0.112	0.102	0.102	0.117	0.107	0.123
Aug	0.124	0.102	0.095	0.104	0.105	0.101	0.095	0.119	0.096	0.105	0.096	0.096	0.114	0.104	0.118
Sep	0.121	0.101	0.093	0.101	0.102	0.097	0.093	0.115	0.095	0.114	0.096	0.104	0.111	0.101	0.115
Oct	0.131	0.110	0.100	0.110	0.111	0.107	0.102	0.122	0.103	0.130	0.104	0.118	0.118	0.110	0.124
Nov	0.162	0.134	0.124	0.134	0.136	0.129	0.124	0.148	0.125	0.164	0.126	0.149	0.146	0.134	0.153
Dec	0.181	0.150	0.139	0.152	0.153	0.145	0.140	0.193	0.141	0.218	0.141	0.200	0.165	0.152	0.172
Jan	0.203	0.168	0.155	0.169	0.169	0.161	0.156	0.217	0.156	0.228	0.157	0.207	0.184	0.168	0.193
Feb	0.258	0.215	0.200	0.216	0.216	0.204	0.199	0.236	0.200	0.251	0.201	0.229	0.235	0.215	0.245
Mar	0.282	0.234	0.216	0.235	0.237	0.226	0.218	0.244	0.219	0.261	0.220	0.238	0.256	0.235	0.267
Apr	0.318	0.263	0.242	0.264	0.266	0.251	0.244	0.258	0.245	0.276	0.246	0.251	0.289	0.264	0.302
May	0.209	0.172	0.159	0.174	0.174	0.164	0.159	0.160	0.161	0.183	0.163	0.165	0.190	0.172	0.198

L1, L2, L3,…….,L15 = Sampling Locations 1, 2,3,………,15 in that order.

Table 12: Monthly variation of iron (mg/L)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15
Jun	0.181	0.188	0.257	0.210	0.216	0.239	0.269	0.312	0.265	0.292	0.243	0.265	0.186	0.210	0.175
Jul	0.165	0.172	0.235	0.193	0.198	0.220	0.248	0.287	0.243	0.269	0.222	0.245	0.169	0.194	0.159
Aug	0.208	0.216	0.296	0.242	0.248	0.275	0.310	0.359	0.300	0.337	0.275	0.306	0.213	0.243	0.200
Sep	0.236	0.245	0.298	0.274	0.281	0.312	0.351	0.407	0.345	0.382	0.316	0.346	0.242	0.275	0.228
Oct	0.239	0.249	0.300	0.279	0.286	0.317	0.356	0.413	0.350	0.387	0.320	0.351	0.245	0.280	0.230
Nov	0.241	0.251	0.343	0.281	0.288	0.319	0.359	0.416	0.353	0.390	0.323	0.354	0.247	0.282	0.232
Dec	0.248	0.258	0.353	0.289	0.298	0.330	0.371	0.430	0.365	0.403	0.334	0.366	0.254	0.290	0.239
Jan	0.294	0.306	0.419	0.342	0.351	0.389	0.437	0.507	0.430	0.475	0.394	0.431	0.302	0.343	0.284
Feb	0.399	0.415	0.568	0.464	0.476	0.528	0.594	0.689	0.584	0.646	0.535	0.586	0.409	0.465	0.385
Mar	0.463	0.482	0.659	0.539	0.553	0.613	0.689	0.799	0.662	0.749	0.606	0.680	0.475	0.540	0.447
Apr	0.343	0.357	0.488	0.400	0.411	0.456	0.513	0.595	0.505	0.558	0.462	0.506	0.352	0.401	0.331
May	0.249	0.259	0.291	0.290	0.298	0.311	0.350	0.406	0.344	0.381	0.314	0.345	0.255	0.291	0.240

L1, L2, L3,…….,L15 = Sampling Locations 1, 2,3,………,15 in that order.

Table 13: Monthly variation of manganese (mg/L)

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15
Jun	0.064	ND	0.070	0.074	0.076	0.085	0.095	0.099	0.092	0.103	0.085	0.093	0.066	0.075	0.062
Jul	0.106	ND	0.119	0.123	0.125	0.141	0.157	0.166	0.155	0.172	0.143	0.156	0.110	0.124	0.103
Aug	0.121	ND	0.136	0.140	0.143	0.161	0.179	0.190	0.176	0.196	0.163	0.177	0.126	0.141	0.119
Sep	0.143	0.011	0.155	0.166	0.170	0.190	0.212	0.225	0.209	0.233	0.193	0.211	0.150	0.167	0.141
Oct	0.168	0.019	0.186	0.195	0.214	0.247	0.275	0.291	0.271	0.301	0.250	0.272	0.176	0.200	0.166
Nov	0.192	0.025	0.200	0.254	0.260	0.292	0.326	0.345	0.321	0.357	0.296	0.323	0.197	0.256	0.185
Dec	0.246	0.028	0.255	0.285	0.291	0.326	0.364	0.386	0.359	0.399	0.331	0.361	0.257	0.286	0.242
Jan	0.285	0.037	0.312	0.331	0.338	0.380	0.424	0.449	0.417	0.464	0.385	0.419	0.298	0.333	0.280
Feb	0.310	0.043	0.346	0.359	0.366	0.412	0.459	0.486	0.451	0.502	0.417	0.454	0.323	0.362	0.304
Mar	0.364	0.056	0.374	0.422	0.428	0.482	0.537	0.569	0.529	0.588	0.488	0.532	0.377	0.423	0.355
Apr	0.249	0.031	0.322	0.289	0.294	0.330	0.368	0.390	0.362	0.403	0.334	0.364	0.259	0.290	0.244
May	0.139	0.018	0.200	0.161	0.165	0.186	0.207	0.219	0.203	0.226	0.188	0.198	0.145	0.163	0.136

ND = Not Detected. L1, L2, L3,,L15 = Sampling Locations 1, 2,3,………,15 in that order.

The data displayed in Table 3 to 14 were subjected into the Canadian Water Quality Index models across all the sampling locations and the values obtained are shown in Table 14.

Table 14: Summary Canadian WQI of Sampling locations

Location Code	Location Name	WQI	Interpretation
L1	Malali	56.31	Marginal
L2	Kwarau	60.80	Marginal
L3	NNPC	54.00	Marginal
L4	Kuyi	52.83	Marginal
L5	Barnawa	52.91	Marginal
L6	Kutimbi	25.47	Poor
L7	Kigo	46.22	Marginal
L8	Living Faith	20.55	Poor
L9	Down Quarters	44.95	Marginal
L10	Breweries	17.77	Poor
L11	Ungwa Mu'azu	46.58	Marginal
L12	Rigasa	24.11	Poor
L13	Maigiginya	52.80	Marginal
L14	Romi	52.62	Marginal
L15	Railway Bridge	54.04	Marginal

WQI = Water Quality Index

The WQI values of all the sampling locations shown in Table 14 were used in mapping the entire sampled portion of the river via Inverse Distance Weighted (IDW) interpolation method as could be seen in Figure 2.

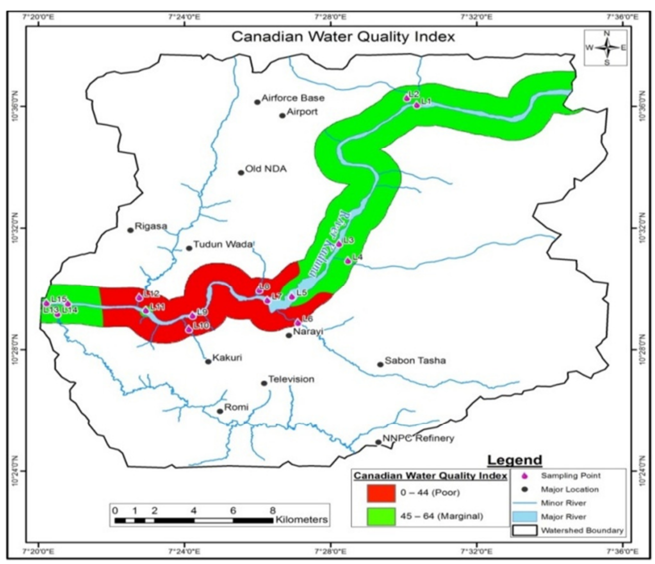

Fig 2: Canadian WQI map of River Kaduna

Table 14 divulge that among the 15 sampling locations, only locations L6 (Kutimbi), L8 (Kigo), L10 (Breweries) and L12 (Rigasa) recorded poor WQI. This could be attributed to the anthropogenic activities within the areas draining to these locations. However, Figure 2 revealed that the communities and towns draining to these sampling locations are Kakuri, Narayi, Sabon Tasha, Tudun Wada and Rigasa. These communities or towns are majorly industrialized and built-up areas within the watershed. The WQI map (Figure 2) also indicates that the water quality of the river upstream of Narayi community was marginal based on the Canadian WQI. Nevertheless, the quality of the river became poor in between Narayi and Rigasa communities and thereafter, the water quality started improving downstream at a point in between River Rigasa and River Romi.

*Conclusion***:** Based on the results obtained in this research, it could be concluded that the WQI of River Kaduna on the Canadian scale is mostly marginal. However, the areas with high impairment level (poor) along the river are located within Sabon Tasha, Narayi, Kakuri, Tudun Wada and Rigasa communities. Hence, Regulatory agencies are advised to check the anthropogenic activities occurring within the watershed with more emphasis at Sabon Tasha, Narayi, Kakuri, Tudun Wada and Rigasa communities.

REFERENCES

Adebayo, OO (2014). Evaluation of Spatio-Temporal Characteristics of River Water Quality in Ogun-Osun River Basin in Nigeria Using Geographical Information System and Multivariate Techniques. A Ph.D Thesis submitted to the Post graduate School of University of Ibadan, Nigeria.

Adie, DB (2008). Multivariate Statistical Analysis of Pollution Characteristics in Rivers of the Middle Galma Basin, Nigeria. A Ph.D Dissertation submitted to the Post graduate School of Ahmadu Bello University, Zaria, Nigeria.

APHA (2005). Standard Methods for Examination of Water and Waste Water. American Public Health Association, Washington, DC.

Carlos, M; Alejandra, VV (2014). Journal of Urban and Environmental Engineering, Vol. 1, No.3, pp18–25.

CCME (2001). Canadian Council of Ministers of Environment: Water Quality Index User's Manual. Canadian Water Quality Guidelines for the Protection of Aquatic Life, pp 1-5.

Ekiye, E; Luo, Z (2010). Water Quality Monitoring in Nigeria; Case Study of Nigeria's Industrial Cities. Journal of American Science, 6(4), pp 22-28.

Esengul, K; Cem, T; Arzu, C (2014). Monitoring Stream Water Quality: A Statistical Evaluation. *Poland Journal of Environmental Studies.* Vol. 23, No. 5, pp 1637-1647.

ESRI, (2015). ArcGIS 10.5: Using ArcGIS Spatial Analyst. Software User Guide ESRI, USA.

Mohammed, AA (2013). Water Quality Study of River Kaduna. *International Journal of Advanced Research* Volume 1, Issue 7, pp 467-474

Mohammed, AE; Ibrahim, I; Badaru, YU; Garba, IK; Kudu, D (2015). Assessment of Effluents Discharged From Textile Industries in Selected Villages in Kaduna State, Nigeria. *African Journal of Environmental Science and Technology*, Vol. 9(5), pp 385-389.

Yusuf, RO; Durojaiye, AO; Salawudeen, TA (2008). Pollution Monitoring Along Kaduna River. *lnternational Journal of Environmental Science,* Vol. 4, No. 4, pp 76-82