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Canadian Water Quality Index of Port Harcourt Groundwater

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ABSTRACT

The quality of groundwater in Port Harcourt was investigated in order to understand the status at different points within the city. This was achieved by obtaining water samples from thirty (30) boreholes evenly distributed within the city at a frequency of three months for a period of one year. The water samples were analyzed for turbidity, total dissolved solids (TDS), pH, electrical conductivity (EC) chloride (Cl), sulphate (SO_4), nitrate (NO_3) and phosphate (PO_4). Others include biochemical oxygen demand (BOD), chemical oxygen demand (COD), total coliform (TC), iron (Fe), lead (Pb) and manganese (Mn). The laboratory results associated with the various sampled boreholes were subjected to Canadian Water Quality Index (CWQI) and it was noted that the groundwater quality of the sampled boreholes ranged between 76.73 – 35.60 on the Canadian index. The index values at the non-sampled boreholes were obtained by mapping the groundwater quality of the entire city using Inverse Distance Weighted (IDW) interpolation technique. The generated map revealed that the quality of groundwater in Port Harcourt deteriorate towards the southern part of the city. Notwithstanding, it was concluded that the groundwater quality within the entire city were either occasionally, frequently or always threatened by anthropogenic and (or) geogenic factors based on the range of the Canadian index values determined.

1. Introduction

It is essential that water quality is ascertained before use for any intended purpose. However, the traditional way of ascertaining the fitness of a given water sample by just comparing its examined parameters with existing guidelines or limits have been reported to have some setbacks [1]. This is because water quality parameters are numerous with varying health impacts hence, the general public prefer knowing the overall health status of the water sample instead of individual parameters. For instance, researchers have earlier described the groundwater quality of Port Harcourt by comparing the examined parameters with their respective permissible limits, which did not really state the overall health status of the water whether it is very good, moderate or poor [2], [3], [4]. Such limitation led to the development of water quality indices (WQI) by different countries and regulatory bodies, which mathematically combine all the examined parameters to provide a readily understood description of the water. The common water quality indices include Oregon Water Quality Index (OWQI), Canadian Water Quality Index (CWQI), National Sanitation Foundation Water Quality Index (NSFWQI) and Weighted Arithmetic Water Quality Index (WAWQI). However, the Global Environmental Monitoring System (GEMS) adopted the CWQI, developed by the Canadian Council of Ministers of Environment in the global evaluation of water quality due to it numerous advantages over others [5]. Actually, the water quality index of Port

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Harcourt has been examined by some researchers [6], [7], [8]. However, none of these authors used the globally adopted index which is Canadian Water Quality Index, as they all used the Weighted Arithmetic Water Quality Index. Hence, it becomes necessary to develop the water quality index of Port Harcourt using the most suitable index.

Potable groundwater in Port Harcourt can only be sampled in wells (boreholes and hand-dug wells) however, the number of wells in the city are numerous hence there is need to consider selected wells evenly distributed within the city. This will however create the problem of not knowing the water quality in the wells that were not sampled. Interpolation being a means of estimating an unknown value that lies between known values will successfully address this problem. Nevertheless, there are many ways of interpolating geospatial data including Inverse Distance Weighted Interpolation (IDW), Spline, and Kriging method. Notwithstanding, past literatures have reported that IDW has an advantage over Spline and Kriging methods as it gives explicit control over the influence of distance between sampling points [9], [10]. 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 in Geography which states that "everything is related to everything else, but near things are more related than distant things". In other words, it will be more appropriate to use the Inverse Distance Weighted Interpolation (IDW) method to estimate the Canadian Water Quality Index of the non-sampled wells within the city (Port Harcourt).

2. Materials and Method

2.1 Description of Study Area

The study area (Port Harcourt) is located in Sothern Nigeria and it is a well known city due to the presence of numerous oil servicing and exploration companies in the city. It is the capital of River state as well as the largest and most populated city in the state; lying in between Latitude 4^0 42' 00" to 4^0 57' 03" North and Longitude 6^0 53' 11" to 7^0 8' 49" East, thus occupying an approximate area of 369km2 [11]. The entire Rivers state of Nigeria has 23 Local Government Areas (LGAs) however, Port Harcourt itself which is the state capital has two LGAs known as Obio-Akpor and Port Harcourt LGAs, respectively located at the northern and southern parts of the city as could be seen in Figure 1.

Despite the numerous surface waterbodies surrounding the study area (Figure 1), the major source of water supply to residents in Port Harcourt is groundwater from boreholes drilled and maintain by house owners. In fact, even water treatment industries that provide bottled and sachet waters for commercial purpose within Port Harcourt get their raw water from drilled boreholes. This might be due to the fact that most of the surface waters (streams, creeks) surroundings the study area especially at the southern part are saline due to the close proximity to numerous seas thus, increasing treatment cost if raw water is abstracted. Another reason might be due to the shallowness of the water table which made the cost of drilling boreholes to be less expensive. The chemistry of Port Harcourt groundwater is influenced by precipitation and rock weathering in terms of ion formations while Na-Cl and Ca-Cl are mostly the hydrochemical facies of the groundwater [12].

2.2 Water Sampling and Analysis

The map of the study area was obtained through global online portal and thereafter, 30 points (evenly distributed) were selected randomly within the study area map, and presumed to represent the locations of sampled boreholes. A preliminary visit (feasibility studies) to the selected locations was made with the guide of the presumed study area map. However, it was noticed that the geographical coordinates of the presumed sampling locations did not correspond the exact locations of boreholes within the areas visited. Hence, the nearest boreholes to the presumed sampling locations were considered as the real sampling locations after negotiating with owners of boreholes in order to grant accessibility during sampling days. The position of the sampled boreholes were recorded using a hand-held Etrex 20x Global Position System (GPS) as could be seen in Table 1.

The sampling was done at a frequency of three months from thirty (30) boreholes, evenly distributed within the study area for a period of one years (Aril, 2017 to January, 2018) thus, the months considered for sampling were April, July, October and January. However, the considered parameters were turbidity, total dissolved solids (TDS), pH, electrical conductivity (EC), and Chloride (Cl). Others include sulphate (SO_4), nitrate (NO_3), phosphate (PO_4), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total coliform, iron (Fe), lead (Pb) and manganese (Mn).

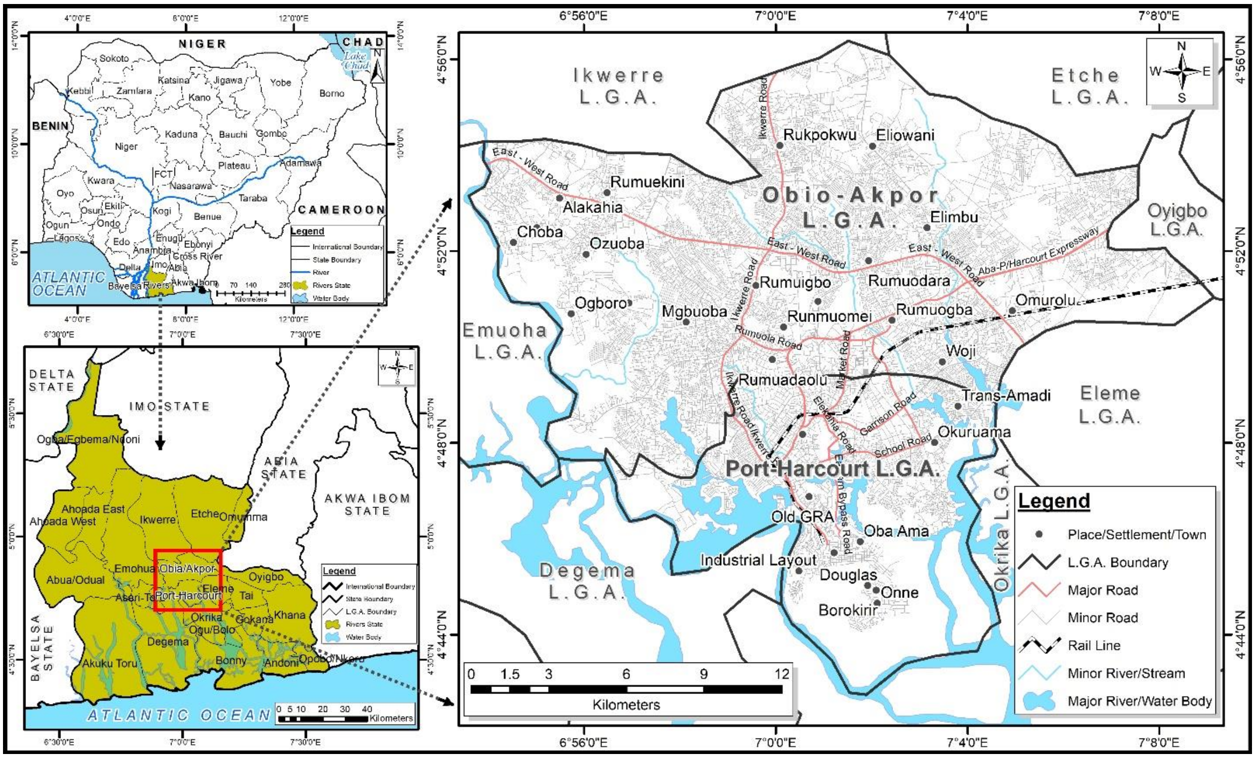

Figure 1: Map of Port Harcourt Metropolis

Prior to sampling, the borehole taps were flamed and water were allowed to flow out for five seconds thereafter, well labeled sample bottles (earlier washed with HNO_3) were thoroughly rinsed with the sample water. For the sake of preserving the quality of the samples before analysis, the filled sample bottles were refrigerated in a mobile cooler with ice packs maintained at a temperature less than 4 ^oC. Thereafter, the samples were transported on the same day to the laboratory where they were refrigerated until analysis. This was to eliminate the need for storage treatment or acidification procedure for sample preservation. Parameters such as pH, electrical conductivity (EC) and total dissolved solids (TDS) were determined in-situ (on site) using pocket-sizes pH meter (pHep®, made by Hanna Ltd, England) as well as dissolved solids and conductivity meter (TDS & EC hold, ±2% made by Griffin Company, USA). Nevertheless, other parameters were analyzed in the laboratory using standard methods recommended by the American Public Health Association (APHA), after allowing them to attain room temperature. The average value for each analyzed parameter in each of the sampled location was recorded, to represent the quality of the concerned parameter with respect to the sampled location.

Table 1: Description of sampled locations

Location Code	Location Name	Geographical Coordinate	Description
B1	Rukpoku	N 04º 55' 42.9", E 007º 00' 39.8"	Residential area at Egbelu new road, Rukpoku
B2	UPTH	N 04º 54' 05.8", E 006º 55' 37.7"	Uniport Teaching Hospital water scheme.
B3	Rumuagholu	N 04º 53' 21.5", E 006º 58' 52.7"	Residential/school area, off SARS road, Rumuagholo
B4	Rumuodomaya	N 04º 53' 33.4", E 006º 59' 56.6"	Residential area at Akwaka phase 3, Rumuodomaya.
B5	Eneka	N 04º 53' 40.1", E 007º 02' 28.5"	Model Health Centre, Eneka.
B6	Rumuokwachi	N 04º 52' 00.6", E 006º 55' 31.4"	Residential area at 14, Ogbogoro road, Rumuokwachi.

B7	Uzoba	N 04º 52' 04.5", E 006º 56' 53.3"	Residential area opposite Provil School, Uzoba
B8	Loretha School	N 04º 52' 26.0", E 006º 58' 54.0"	Staff quarters at Loretha School, Rumuogholu
B9	Eligolo Road	N 04º 51' 58.8", E 007º 00' 48.0"	Residential/school area at Eligolo road.
B10	Oroigwe	N 04º 52' 21.8", E 007º 02' 40.1"	Residential area at Oroigwe, Elimgbu.
B11	Rumuokwurushi	N 04º 52' 05.2", E 007º 04' 24.8"	Residential area before Nzor hotel, Rumuokwurushi.
B12	Iriebe	N 04º 52' 08.7", E 007º 06' 32.6"	Residential area at Iriebe, off Confidence School Junction.
B13	Elioparanwo	N 04º 50' 07.8", E 006º 57' 16.6"	Residential area at 27, Royal Avenue, Elioparanwo Town.
B14	Rumuepirikom	N 04º 50' 08.5", E 006º 58' 36.2"	Commercial area at Rumuepirikom by Ada George Road.
B15	Rumuigbo	N 04º 50' 25.4", E 007º 00' 16.5"	Residential area behind PHWC, Psychiatric Rd, Rumuigbo
B16	Woji	N 04º 53' 17.2", E 007º 02' 30.3"	Residential area at Temple Ejekwe Street, Woji Road.
B17	Elelenwo	N 04º 50' 07.3", E 007º 04' 16.0"	Church premises/residential area at Elelewon.
B18	Rumuolumini	N 04º 48' 40.4", E 006º 57' 20.4"	Church Premises (St Mark’s Ang. Church, Rumuolumini).
B19	Rumuokokwa	N 04º 48' 22.9", E 006º 59' 02.4"	Commercial area at 4, Nnokam Street (close to RSU gate).
B20	Diobu	N 04º 47' 28.3", E 007º 00' 03.6"	Church Premises (CKC church, mile 1, Diobu).
B21	T/Amadi	N 04º 48' 10.5", E 007º 02' 52.3"	School premises (Tago Int’l Sch., off Odili Rd, T/Amadi).
B22	Gbalajam	N 04º 48' 39.5", E 007º 04' 11.3"	Residential area at Gbalajam, Woji (close to a creek).
B23	Eagle Island	N 04º 47' 00.9", E 006º 58' 34.5"	Residential area at 38D, Collin Owonda Str., Eagle Island.
B24	Town	N 04º 45' 52.6", E 007º 01' 09.6"	Residential area at 6, Hospital Road, PH Township.
B25	Abuloma	N 04º 46' 50.9", E 007º 02' 59.3"	Hotel/residential area at Abuloma.
B26	Borokiri	N 04º 45' 01.6", E 007º 02' 23.4"	Commercial area at UPE, Borokiri.
B27	Timber	N 04º 56' 06.0", E 007º 01' 25.4"	Timber market/SPDC flow station, PH/Owerri Rd, Rukpoku.
B28	New Layout	N 04º 53' 11.9", E 007º 05' 46.6"	New layout (farming activities) along Interlocked Rd, Iriebe
B29	Sand fill	N 04º 44' 07.7", E 007º 01' 42.1"	Comercial area (petroleum products) close to Borokiri Sand Fill.
B30	Iwofe	N 04º 48' 47.7", E 006º 56' 18.1"	Newly residential area at Erico Street, Iwofe Road.

2.3 Calculation of Water Quality Index

The Canadian water quality index for each sample was calculated based on a combination of three factors which were determined using equations (1) to (7), [13].

Scope, F_1 – the number of variables whose objectives were not met.

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

Frequency, F_2 – the frequency with which the objectives were not met.

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

Amplitude, F_3 – the amount by which the objectives were 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, termed as “excursion” and expressed as follows. When the test value must not exceed the objective:

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

For cases in which the test value must not fall below the objective:

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

(b). 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:

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

(c). 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.

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

The Canadian Council of Ministers of Environment Water Quality Index (CCME WQI) was then determined by substituting the values of F_1, F_2 and F_3 into equation (6). That is;

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

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 [13]. These five categories for the assessment 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.

2.4 Mapping of Water Quality

Inverse Distance Weighted Interpolation (IDW) method of the spatial analyst extension in the ArcGIS 10.5 was used in mapping the water quality parameters within the catchment area. Like other methods, IDW uses linear combination of weights at known points to estimate unknown location values. 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), [14].

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

However, the weights $\lambda_i(S_0)$ were estimated through inverse distance from all points to the new points by applying equation (9), [14].

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

Where: $\boldsymbol{\lambda_i}$ is the weight for neighbor *i* (the sum of weights must be unity to ensure an unbiased interpolator), $\boldsymbol{d(S_0, S_1)}$ is the distance from the new point to a known sample point, $\boldsymbol{\beta}$ is the coefficient used to adjust the weights, $\boldsymbol{n}$ is the total number of points in the neighbourhood analysis.

All the measured points (water quality data) were used in the calculation of each interpolation cell (water quality grid). A feature dataset (groundwater network) was used for the mask. Only cells that falls within the specified shape of the feature data (groundwater network) received the values of the first input raster (water quality grid) on the output raster (water quality result). The output raster is the extraction of the cells of the water quality grid (input raster) that correspond to the routes defined by the mask.

3. Results and Discussion

For the sake of simplicity in computing the Water Quality Index (WQI), only the laboratory results of the first sampled location (B1, Rukpoku) is presented in Table 2. Hence, the procedure for determining the Canadian Water Quality Index (WQI) was only demonstrated for sampled location B1 (Rukpoku) which is applicable to the remaining sampled locations.

From Table 2, the number of variables (parameters) not meeting the objectives is 5 (i.e. pH, PO_4, BOD, Fe and Pb) while the total number of variables is 14. Therefore,

$$\text{Scope, } F_1 = \left[\frac{5.0}{14}\right] \times 100 = 35.71$$

The number of tests not meeting the objectives is 7 while the total number of tests is 56. Hence, Frequency, $F_2 = \left[\frac{7}{56}\right] \times 100 = 12.5$

$excusion_1 = \frac{6.5}{5} - 1 = 0.3$, (*This is a special case hence Equation 4 was used*)

$excusion_2 = \frac{0.9}{0.1} - 1 = 8,$

$excusion_3 = \left[\frac{0.64}{0.1}\right] - 1 = 5.4,$

$excusion_4 = \left[\frac{1.22}{0.1}\right] - 1 = 11.2,$

$excusion_5 = \left[\frac{8.56}{2.0}\right] - 1 = 3.28,$

$excusion_6 = \left[\frac{1.82}{0.3}\right] - 1 = 5.07,$

$excusion_7 = \left[\frac{0.012}{0.01}\right] - 1 = 0.2,$

Normalized sum of excursions,

$$nse = \frac{\sum_{i=1}^{n} excursion_i}{number\ of\ tests} = \frac{33.45}{56} = 0.60$$

Table 2: Water quality index computation table for sampled location B1 (Rukpoku)

Month	Turb	TDS	pH	EC	Cl	SO_4	NO_3	PO_4	BOD	COD	TC	Fe	Pb	Mn
April, 2017	0.001	19	**5.0**	35.4	14.7	2	0.8	**0.9**	0	0.1	0	0.02	0.001	0.02
July, 2017	0.001	13.41	6.5	26.3	7.39	1.41	0.56	**0.64**	0.1	2.99	0	**1.82**	0.001	0
October, 2017	0.001	14.01	6.6	30.94	10.31	2.7	1.08	**1.22**	0.1	2.43	0	0.03	0.001	0
January, 2018	0.01	14.2	8.08	28.3	6	0.01	0.11	0.01	**8.56**	10.7	0	0.0046	**0.012**	0.14
Objective	≤ 5.0	≤ 500	6.5 - 8.5	≤ 750	≤ 250	≤ 200	≤ 50	≤ 0.1	≤ 2.0	≤ 20	0	≤ 0.3	≤ 0.01	≤ 0.2

1) Turb = turbidity (NTU), TDS = total dissolved solids (mg/L), pH = potential of hydrogen, EC = electrical conductivity (μS/cm), Cl^- = chloride (mg/L), SO_4 = sulphate (mg/L), NO_3 = nitrate (mg/L), PO_4 = phosphate (mg/L), BOD_5 = 5-days biochemical oxygen demand (mg/L), COD = chemical oxygen demand (mg/L), TC = total coliform (CFU/100ml), Fe = Iron (mg/L), Pb = Lead (mg/L), Mn = Manganese (mg/L), ≤ = less than or equal to, ≥ = greater than or equal to.
2) **Bold values** do not meet the objective or WHO guideline.

Amplitude, $F_3 = \frac{nse}{0.01nse + 0.01}$

$$= \left[\frac{0.60}{0.01(0.60) + 0.01}\right] = \frac{0.60}{0.017371} = 37.5$$

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

$$= 100 - \frac{\sqrt{(35.71^2 + 12.5^2 + 37.5^2)}}{1.732} = 100 - 30.76$$

$\Rightarrow WQI = 69.24$

As earlier stated, the WQI for the remaining sampled locations were calculated in a similar way and their values are given in Table 3.

Table 3: Summary of Canadian Water Quality Index for sampled locations

Location Code	Location Name	WQI	Interpretation
B1	Rukpoku	69.24	Fair; occasionally impaired (65 – 79)
B2	UPTH	70.97	Fair; occasionally impaired (65 – 79)
B3	Rumuagholu	69.93	Fair; occasionally impaired (65 – 79)
B4	Rumuodomaya	73.16	Fair; occasionally impaired (65 – 79)
B5	Eneka	58.10	Marginal; frequently impaired (45 – 64)
B6	Rumuokwachi	63.40	Marginal; frequently impaired (45 – 64)
B7	Uzoba	73.49	Fair; occasionally impaired (65 – 79)
B8	Loretha School	56.50	Marginal; frequently impaired (45 – 64)
B9	Eligolo Road	72.25	Fair; occasionally impaired (65 – 79)
B10	Oroigwe	74.02	Fair; occasionally impaired (65 – 79)

B11	Rumuokwurushi	71.50	Fair; occasionally impaired (65 – 79)
B12	Iriebe	74.40	Fair; occasionally impaired (65 – 79)
B13	Elioparanwo	71.56	Fair; occasionally impaired (65 – 79)
B14	Rumuepirikom	56.25	Marginal; frequently impaired (45 – 64)
B15	Rumuigbo	67.94	Fair; occasionally impaired (65 – 79)
B16	Woji	62.52	Marginal; frequently impaired (45 – 64)
B17	Elelenwo	71.76	Fair; occasionally impaired (65 – 79)
B18	Rumuolumini	62.83	Marginal; frequently impaired (45 – 64)
B19	Rumuokokwa	54.18	Marginal; frequently impaired (45 – 64)
B20	Diobu	76.73	Fair; occasionally impaired (65 – 79)
B21	T/Amadi	62.13	Marginal; frequently impaired (45 – 64)
B22	Gbalajam	60.98	Marginal; frequently impaired (45 – 64)
B23	Eagle Island	65.86	Fair; occasionally impaired (65 – 79)
B24	Town	47.08	Marginal; frequently impaired (45 – 64)
B25	Abuloma	72.37	Fair; occasionally impaired (65 – 79)
B26	Borokiri	35.60	Poor; always impaired or threatened (0-45)
B27	Timber	59.45	Marginal; frequently impaired (45 – 64)
B28	New Layout	75.65	Fair; occasionally impaired (65 – 79)
B29	Sand fill	47.37	Marginal; frequently impaired (45 – 64)
B30	Iwofe	68.37	Fair; occasionally impaired (65 – 79)

The calculated Canadian WQI values shown in Table 3 were used to develop the map of the groundwater quality of the entire study area by means of Inverse Distance Weighted (IDW) interpolation method as shown in Figure 2.

It could be inferred from Table 3 that the groundwater quality of Port Harcourt lies between fair and poor on the Canadian scale, with 56.67% of the total boreholes sampled being fair (occasionally impaired) and 40% marginal (frequently impaired) while 3.33% is poor (always impaired). This negate the assertions of some researchers who reported that Port Harcourt groundwater quality are majorly excellent [6], [8]. Similarly, Figure 2 revealed that the groundwater quality of Port Harcourt deteriorate towards the southern part of the city with the worst condition at Borokiri town. In other words, the groundwater quality in Obio-Akpor LGA is better than that of Port Harcourt LGA. This is in line with a previous similar research that recorded poor water quality in boreholes within Borokiri town mostly in terms of chloride ions and TDS, and was attributed to the close proximity to the sea which might have led to seawater intrusion (geogenic factor) during pumping [12]. Moreover, Borokiri town and its environs has a lot commercial activities dealing with petroleum products. This suggest that the petroleum products might have leached into the shallow aquifers to contaminate the groundwater in addition to other anthropogenic activities such as leachates from failed septic tanks thus, rendering the water poor quality on the scale of Canadian WQI.

4. Conclusion and Recommendations

Based on the analyzed results from this research, it could be concluded that the groundwater quality in Port Harcourt is occasionally, frequently and always threatened by anthropogenic and (or) geogenic factors. This is because the water quality in all the sampled boreholes recorded either fair, marginal or poor on the Canadian index. Also, the groundwater quality in Port Harcourt deteriorate towards the southern part of the city with the worst condition at Borokiri town. In other words, the groundwater quality in Obio-Akpor LGA is better than that of Port Harcourt LGA. Hence, it is recommended that borehole owners within the entire Port Harcourt (Obio-Akpor LGA and Port Harcourt LGA) should ensure to treat the pumped water before consumption. It is also recommended that the relevant regulatory bodies such the Rivers State Waste Management Agency (RIWAMA) should investigate the anthropogenic activities that are likely to contaminate groundwater within the entire Port Harcourt with more emphasis at Borokiri town.

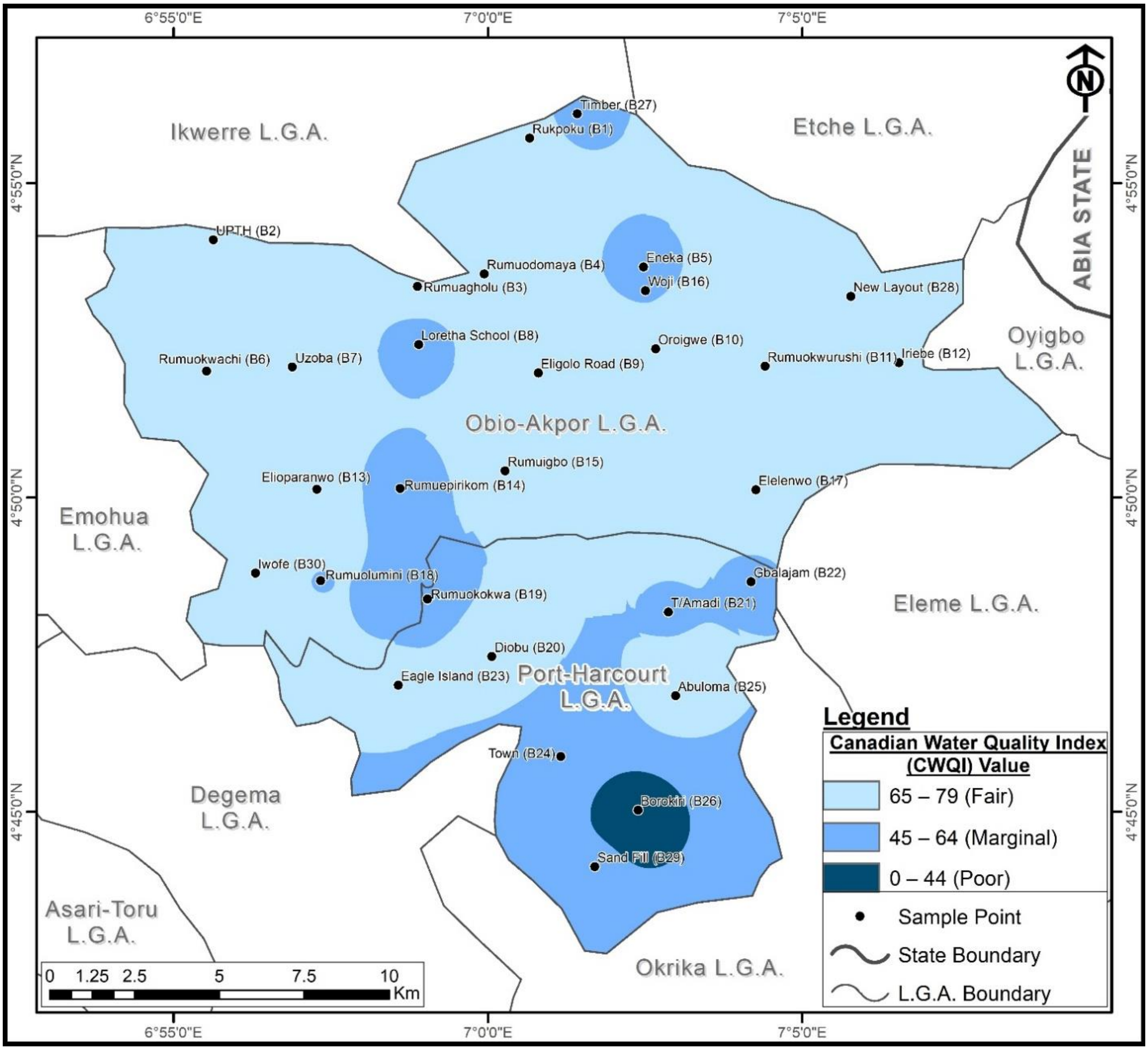

Figure 2: Canadian water quality index map of Port Harcourt

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