International Journal of
Science, Architecture, Technology and Environment

Determination of the Varying Spatio-Temporal Conditions of Groundwater Quality, Considering Various Geological Formations in Imo State

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DOI: https://doi.org/10.63680/ijsate1025084.075

Abstract

The determination of the Spatio-Temporal conditions of groundwater quality was carried out with two different models, this is to be sure of the values derived at the end work. This paper in particular, deals with the application of Aquifer model in carrying out the project. It began with several iterative processes using the. On a monthly basis for a period of 12 months, good samples of groundwater were collected from different hydrological formations. This was done in Imo Sate. The collected samples were analyzed for several physiochemical parameters: pH, electrical conductivity, total dissolved solid, total suspended solid, total solid, dissolved Oxygen, Biochemical Oxygen Demand, Chemical Oxygen Demand, Nitrate, Bicarbonate, Potassium, Phosphate, Iron, total alkalinity, total Chloride, Calcium hardness, total hardness, Magnesium hardness, Calcium Magnesium Sodium and Sulphate. Several formations in these zones were studied. The average concentrations of total dissolved solids, chloride, nitrate, sulphate, total hardness and electric conductivity were higher in the dry season compared to the rainy season, while average concentrations potassium and bicarbonate were higher in wet season. The water quality index was evaluated in accordance with World Health Organization permissible standards for safe drinking water, ranging from the scale of 0 to 100. The Water Quality Index for both dry season and Rainy season were derived and recorded. From the results, the Water Quality Index for the zone of BF, OAF, NF, AF, ICSF and FBSF were gotten as 35.04, 73.30, 27.54, 30.37, 86.98 and 108.95 respectively, showing that during dry season, groundwater samples from OAF and NF have excellent water quality, also samples from BF, NF, and AF have good quality water where as samples from ICSF have very poor water quality. The Water Quality Index obtained during the rainy season indicate that water samples from BF, NF and AF have good water quality for drinking and agricultural applications based on national and international indices and standards while the water samples from OAF were of poor water quality. The water quality from ICSF is safe for consumption while that from FBSF remains unsuitable for drinking purpose. The outcome shows that there is need for continuous monitoring and treatment for acidic and high nitrate water to mitigate future pollution and ensure sustainable use of the groundwater resource. Aquifer Model was used to model the dataset and a value of 142.829234 was obtained as the RMSE which subsequently decreased to 130.309532 at the final iteration.

Keywords: First keyword; Second keyword; Write at least four keywords Biochemical Oxygen Demand, Aquifer Model, Physiochemical parameters, Water Quality, Spatio-Temporal Variability, Hydrological Formations

1.2 Background Information

Water is one of the major resources of the world and it is vital for man's existence, that is, it is the basis of life on earth as all living organisms on earth need water for their survival and growth (Mahalingam, Ramu, and Jayashree, 2014; Subramani and Kumaresan 2012). The earth is made up of about 70% of water occurring naturally as surface or groundwater. 97% of this water is saltwater (Balakrishnan, Saleem, and Mallikarjun, (2011) which is not useful for domestic use. The remaining 3% which is fresh water exists in lakes, rivers, groundwater and the atmosphere with only 1% of it being available for consumption (El-Hoz, Mohsen, and Laaly, 2013). Groundwater makes about 20% of the world's freshwater supply for various uses (Balakrishnan et.al, 2011; El-hoz et.al 2013, Lathamani et al. 2015). 40% of Nigerians are known to derive their agricultural, domestic and industrial water from groundwater.

Groundwater quality refers to the state of water that is located beneath Earth's surface. Groundwater can gather in cracks in subsurface rocks and in between soil particles. Since many compounds can dissolve in water and others can be suspended in water, there is a potential for contamination with toxic compounds.

Groundwater refers to all the water occupying the voids, pores and fissures within geological formations, which originated from atmospheric precipitation either directly by rainfall infiltration or indirectly from rivers, lakes or canals. Sands, gravel, sandstones, and limestone formations are the usual sources of groundwater supply though some may be drawn from impervious rocks such as granite when they have an over burden of sand or gravel. Groundwater is a valued fresh water resource and constitutes about two-third of the fresh water reserves of the world (Wang, Liu, Liao & Lee 2014). Ruždjak, and Ruždjak, (2015) also estimated the groundwater reservoir of the world at about 5.0×10^{24} L, this volume is more than 2,000 times the volume of waters in all the world's rivers and more than 30 times the volume contained in all the world's fresh water lakes. Groundwater is used for agricultural, industrial and domestic purposes. It accounts for about 50% of livestock and irrigation usage and just under 40% of water supplies, whilst in rural areas, 98% of domestic water use is from groundwater (Zheng,Yu, & Wang. 2016). Utilization of groundwater as a source for domestic, municipal, agricultural and industrial activities continue to increase principally because of the heavy capital outlay and maintenance of surface water development through Dams especially in developing countries (Ishaku, Ahmed, & Abubaka, 2012). Another factor which is responsible for the attention being diverted to this source is improved technology manifested by deep boring in form of borehole which satisfies WHO drinking water quality standard (Osot, 2000). Groundwater is abstracted through hand-dug wells; hand-pump operated shallow-wells and submersible pump operated deep well or boreholes (Ojo, 2002). Groundwater is often high in mineral content such as magnesium and calcium salts, iron and manganese depending on the chemical composition of the stratum through which the rock flows (Rajkumar, Subramani&Elangol, 2010).

1.3 Objectives of Study

The main aim of this work is to determination of the varying Spatio-Temporal conditions of groundwater quality, considering various geological formations of Imo state. The objectives include

i) To evaluate groundwater quality by means of laboratory technique examination of a few chosen water quality criteria and also investigate the World Health Organization's allowable limits.

ii) To determine the Water Quality Index of some particular criteria.

v) To replicate the Spatio-Temporal fluctuation of the water quality in several discussed geological formations, using Aquifer Model.

1.4 Materials

These include Thermometer and pH meter, Atomic absorption spectrophotometer Conductivity/TDS Meter, Spectrophotometer, Whatman Filter Paper, Pipettes and burettes, MnSO4 solution, Alkali-Iodide-Azide solution, K_2CrO_7 solution, Ag_2SO_4 – H_2SO_4 solution and Fe $(NH_2)_2$ $(SO_4)_2$ $.6H_2O$ solution, Phenolphthalein indicator, P-nitrophenol, Ascorbic Acid and Sodium Acetate,Alkaline Phenol, Sodium Potassium Titrate, Sodium Hypochlorite and Brucine, Weighing scale, mercury in glass thermometer, Durham tubes, incubator, oven, and turbidity meter., Water bath, electrode colony counter etc.

1.5 Methodology

Aquifer Model: The model was developed to predict the Spatio-temporal variability of groundwater quality in the various geological zones of Imo State.. The model application is an implementation of the gradient boosting algorithm, which builds models sequentially, with each new model focusing on correcting the errors of the previous ones.

Decision Trees as Base Learners:

The uses decision trees as its base learners, which are then combined to create a strong predictive model.

Regularization:

Aquifer Model uses incorporates regularization techniques to prevent overfitting and improve the generalization ability of the model.

Parallel Processing:

Aquifer Model is designed for efficient processing, utilizing parallel processing to speed up training, especially on large datasets.

Handling Missing Values:

Also Aquifer Model can handle missing data effectively, making it robust for real-world datasets. In summary, Aquifer is a powerful and versatile machine learning algorithm that is well-suited for a wide range of predictive modeling tasks, especially when speed, accuracy, and scalability are important. In machine learning, different algorithms are often combined to get better and optimized results. The main goal is to **minimize loss function** for which, one of the famous algorithm is Aquifer (Extreme boosting) technique **which works by building an ensemble of decision trees sequentially where each new tree corrects the errors made by the previous one. It uses advanced optimization techniques and regularization methods that reduce overfitting and improve model performance.**

The Aquifer model was trained using a 70:30 ratio to predict the variable Parameter value based on two features: Season and Region. The model underwent 100 boosting iterations, adding sequential trees to refine predictions. Despite its simplicity, the model effectively captures interactions between the two features, as evidenced by the stabilized root mean square error (RMSE) of 130.3095 at the final iteration, indicating convergence and limited potential for improvement with further iterations.

Aquifer offers several advantages, including regularization techniques that prevent overfitting and its ability to model complex feature interactions, thus providing insights into how Season and Region influence the target variable. The decreasing RMSE from 142.8292 to 130.3095 suggests enhanced prediction accuracy throughout training. Hence, Aquifer is well-suited for regression tasks, combining speed and efficiency while laying a strong foundation for actionable data insights.

Hence, the Aquifer model based on the outcome can be expressed as:

$$\hat{y} = \sum_{k=1}^{100} f_k\,(x)$$

Where: $f_k(x)$is a decision tree defined by the parameters set within the training process of the explanatory variables, optimizing for squared error as the loss function and controlling complexity through the regularization term.$\hat{y}$ is the predicted response variable.

Evaluation of Water Quality Index: Considered as the most accurate approach of assessing water quality is the Water Quality Index (WQI). A mathematical equation rates water quality by including several water quality criteria, therefore guiding the acceptability of water for consuming. Horton first created the index in 1965 using 10 (ten) most often utilized water characteristics to gauge water quality. Different specialists then changed the approach. These indices made use of water quality criteria varying in number and nature. Every parameter's weight is determined by its relevant standards; the allocated weight denotes the parameter's relevance for the index.

It is concluded that the general norm for reporting water quality parameters by means of comparison between the several examined parameters with their respective permissible limits and standards established by local, regional, national, or international regulating authorities is inadequate in environmental monitoring program by both managers and the whole public.

Using some of the often used water metrics (BOD, temperature, turbidity, conductivity etc), the index shows the degree of quality of a water body such lake, river or stream. Based on the measurement of several water quality criteria, the WQI offers a means to display a cumulatively obtained numerical expression characterizing water quality. In line with a selected method or model of computation, the water quality index lowers water quality data to common scale and aggregates them into a single number. Calculated from the perspective of the suitability of surface and groundwater for intended use, WQI displays the composite influence of several water quality indices.

Three steps comprise a typical WQI approach: i. parameter selection; ii. calculation of quality function for every parameter; and iii. mathematical equation aggregation.
Based on some water criteria, the index offers a single value that shows general water quality at a given place and time. The index helps one to compare several sampling locations.

WQI turns a difficult dataset into clearly comprehensible and useful knowledge. The WQI's water quality classification system helps to indicate how fit water is for consumption. Derived from many criteria, the single-value output of this index offers clear understanding, even for non-technical readers significant information regarding water quality.

Using weighted arithmetic WQI approach, they provided water quality information to WASH practitioners in a resource- poor nation like Bangladesh where assuring availability and sustainable management of excellent quality water is one of the hardest sectors towards progress. This approach has one advantage in that less parameters are needed to evaluate water quality for particular usage. To rank the general water quality, the Canadian Council of Ministers of Environment CCME developed the use of an index that statistically combines all water quality measurements and offers a broad and easily understandable description of the quality of water. Many nations have embraced the CCME system throughout the years as a means of monitoring and evaluating surface and subterranean water in terms of their chemical, biological, and nutritional elements and general esthetic state, therefore reflecting the water quality index. The simplicity of the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) makes it ideal for the work since it allows complicated water quality data to be combined without sacrificing its technical integrity. Considered the most reliable approach of assessing water quality to ascertain its fit for a given intended purpose is the CCME Water quality index.

The US National Foundation bases water quality definitions in the United States on a weighted linear system of the WQI. Using the same ideas, many other nations including China, Spain, Bangladesh, and Malaysia have defined their water quality status. The water quality index offers a single value and lowers the bulk of water parameters used in an evaluation. Based on analytical values of physiochemical parameters, this value a logical and simplified form expresents the average quality of water at a given moment. Instead of evaluating every parameter and allowing simple public access and knowledge of the water quality data, this process helps to interpret the data in a simpler and easier manner.

Though many water quality criteria are utilized for water assessment, some of the parameters seem to have common similarities as they have their base of comparing water quality parameters with their respective regulating standards with interpretation of the results as good or bad.

The weighted arithmetic water index method water quality uses:

Degree of purity which is obtained from the most commonly measured water quality variables: temperature, biochemical oxygen demand, fecal coliform, pH, dissolved oxygen, total phosphates, turbidity, nitrates and total solids.

Water quality rating scale, (q_i)

Relative weight and (w_i)

Overall WQI (Q_i)

The WQI is computed by averaging the individual index values of some or all of the parameters inside five water quality parameter groups, therefore reflecting the degree of pollution in the water.

The water quality data provides the numerical value of the quality rating (qi), which is then multiplied by a weighting factor commensurate with the significance of the test to water quality.

The formula below is used to obtain q_i:

$$q_i = \frac{ci}{si} x\ 100 \qquad \text{a}$$

where,

q_i, = quality rating scale.

c_i, = concentration of *i* parameter.

s_i = WHO standard value of *i* parameter.

Relative weight (w_i) is calculated by

$$W_i = \frac{1}{si} \qquad \text{b}$$

The standard value of the *i* parameter is inversely proportional to the relative weight.

The relative weight (W_i) is calculated by

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad c$$

Finally, overall WQI was calculated according to the following expression:

$$WQI = \frac{\sum Q_i W_i}{\sum W_i} \qquad .\text{d}$$

The sub-index SI_i and WQI are computed using the relationship in Eqns. (e) and (f), respectively

$$SI_i = W_i x\ q_i \qquad \text{e}$$

$$WQI = \sum SI_i \qquad \text{f}$$

where SI_i is the sub-index of the ith parameter and q_i is the rating based on the concentration of the ith parameter.

3.2.5 Water quality Standards:

Three components define water quality standards: statements and numerical values that define water quality, arranged in three groups:

i. Designed uses for the water body related to agricultural development, aquatic ecosystems, water supply or leisure activities.

ii. Together with specific numerical concentrations for numerous parameters, water quality criteria and broad descriptions of optimal water quality.
iii. An anti-degradation program developed to protect the present water consumption for every water body.

The expected use of a certain water source defines its requirement for particular quality. The table below shows numerous acceptable criteria for several water quality standards. While the standards for the Aquatic Water Quality Index are used to protect aquatic life, the defined standard for drinking water is just used in the assessment of the Drinking Water Quality Index. Three separate uses for the index are possible:
i. Drinking Water Quality Index including agricultural, recreational, drinkable, and livestock watering uses.

ii. Aquatic Water Quality Index covering the preservation and application of aquatic life.

iii. Comprehensive Water Quality Index covering animal, aquatic, and human health protection.

Table: 1 Parameters and methods employed in the physiochemical examination of water samples

S/N	Parameter	Method Employed
1.	pH	Potentiometric
2.	Electrical Conductivity (μS/cm)	Potentiometric
3.	Total Dissolved Solid (mg/L)	Gravimetric
4.	Total Suspended Solid (mg/L)	Gravimetric
5.	Total Solid (mg/L)	Gravimetric
6.	Dissolved Oxygen (mg/L)	Electro-membrane
7.	Biochemical Oxygen Demand, BOD (mg/L)	Incubation & Electro-membrane
8.	Chemical Oxygen Demand (mg/L)	Titrimetric
9.	Nitrate (mg/L)	UV Spectrometric
10.	Bicarbonate, HCO_3, (mg/L)	Diazotization
11.	Potassium, K, (mg/L)	Tetraphenylborate
12.	Phosphate, PO_4^{-3} (mg/L)	Ascorbic Acid
13.	Iron, Fe, (mg/L)	UV Spectrometric
14.	Total Alkalinity, $CaCO_3$, (mg/L)	Titrimetric
15.	Total Chloride, Cl, (mg/L)	Argentometric
16.	Calcium Hardness (mg/L)	EDTA Titrimetric
17.	Total Hardness (mg/l)	EDTA Titrimetric
18.	Magnesium Hardness, mg, (mg/L)	EDTA Titrimetric
19.	Calcium, Ca,(mg/L)	EDTA Titrimetric
20.	Magnesium, Mg, (mg/L)	Titrimetric
21.	Sodium, Na, (mg/L)	Spectrophotometric
22.	Sulphate, SO_4^{-2}, (mg/L)	AAS

1.6 Results

Water Quality Index (WQI)

The Water Quality Index (WQI) measures water quality via an index value that indicates its overall appropriateness for diverse applications. The Water Quality Index (WQI) is an evaluative tool that measures the aggregate effect of specific water quality metrics on overall water quality. The average concentrations of ten physiochemical parameters—pH, electrical conductivity, total dissolved solids, dissolved oxygen, biochemical oxygen demand, iron, total alkalinity, total chloride, total hardness, and sulfate were employed to

Calculate the water Quality Index (WQI).

The Water Quality Index (WQI) values during the dry season were 50.10 for the Benin Formation (BF), 24.98 for the Ogwashi Asaba Formation (OAF), 20.18 for the Nsukka Formation (NF), 35.79 for the Alluvium Formation (AF), 79.77 for the Imo Clay Shale Formation (ICSF), and 55.94 for the False Bedded Sandstones Formation (FBSF), as presented in Tables 4.5 to 4.10. During the wet season, the WQI values recorded for the same formations were 35.04, 73.31, 27.54, 30.37, 86.99, and 108.95, as detailed in Tables 4.11 to 4.16.

Water samples collected during the dry season from the Ogwashi-Asaba and Nsukka Formations demonstrate enhanced water quality, as shown in Tables 4.6 and 4.7. In contrast, water samples from the Benin Formation and Alluvium Formation exhibit acceptable water quality, as seen in Tables 4.5 and 4.8, respectively. Table 4.10 demonstrates that samples from False Bedded Sandstone Formations display inferior water quality. The water sample from the Imo Clay shale formation has exceedingly low water quality during the dry season, as seen in Table 4.9. In contrast, during the rainy season, water samples from the Benin formation, Nsukka formation, and Alluvium formation exhibit high water quality, as shown in Tables 4.11, 4.13, and 4.14, whereas samples from the Ogwashi-Asaba formation reveal low water quality. The Water Quality Index obtained from groundwater samples in the Imo Clay Shale Formation, as shown in Table 4.15, reveals that the water quality in that area is extremely poor, and the water samples from the False Bedded Sandstones formation are considered unsuitable for consumption. This sector necessitates an innovative institutional economic strategy to tackle its current and future problems. The problems can be attributed to main pollutants and other deleterious elements that undermine water portability.

Table 2: Classification of water quality index (WQI) of drinking water

Water quality index level	Water quality status	Grading
0-25	Excellent water quality	A
26-50	good water quality	B
51-75	poor water quality	C
76-100	Very poor water quality	D
> 100	Unsuitable for drinking	E

.

Table 3: Calculation of WQI values for groundwater samples in Benin Formation during dry season

S/N	Parameter	Mean Monitored Value (V_i)	WHO Maximum Standard (S_i)	Unit weight ($W_i=1/S_i$)	Quality Rating ($Q_i= 100V_i/S_i$)	Q_i x W_i

1.	*pH*	*5.63*	*8.5*	*0.1176*	*66.2353*	*7.7893*
2.	*Electrical Conductivity (EC)*	*215.00*	*750*	*0.00133*	*28.6667*	*0.03813*
3.	*Total Dissolved Solid (TDS)*	*139.75*	*1000*	*0.001*	*13.9750*	*0.01398*
4.	*Dissolved Oxygen (DO)*	*11.75*	*5*	*0.2*	*235*	*47*
5.	*Biochemical Oxygen Demand, (BOD)*	*6.95*	*5*	*0.2*	*139*	*27.8*
6.	*Iron(Fe) (mg/L)*	*0.10*	*0.3*	*3.33*	*33.3*	*111.10*
7.	*Total Alkalinity, ($CaCO_3$,)*	*5.00*	*200*	*0.005*	*2.5*	*0.0125*
8.	*Total Chloride, (Cl)*	*49.98*	*250*	*0.004*	*19.992*	*0.0799*
9.	*Total Hardness (TH)*	*77.70*	*500*	*0.002*	*15.54*	*0.0311*
10.	*Sulphate, (SO_4^{-2})*	*11.58*	*250*	*0.004*	*4.632*	*0.0185*
	∑ Wi = 3.8649			*∑(Qi x Wi) = 193.8694*		*∑(Qi x Wi) = 193.8694*

$$\mathbf{WQI = \sum (Q_i .Wi)/\sum W_i =} 205.059/3.8649 = 50.103$$

Table 4: Calculation of WQI values for groundwater samples in Ogwashi Asaba Formation during dry season

S/N	Parameter	Mean Monitored Value (V_i)	WHO Maximum Standard (S_i)	Unit weight (W_i=1/S_i)	Quality Rating (Q_i= 100V_i/S_i)	Q_i x W_i
1.	pH	5.70	8.5	0.1176	67.0588	7.8861
2.	Electrical Conductivity (EC)	91.00	750	0.0013	12.1333	0.0161
3.	Total Dissolved Solid (TDS)	66.50	1000	0.001	6.65	0.0067
4.	Dissolved Oxygen (DO)	7.58	5	0.2	151.6	30.32
5.	Biochemical Oxygen Demand, (BOD)	3.45	5	0.2	69	13.8
6.	Iron (Fe)	0.04	0.3	3.33	13.33	44.3889
7.	Total Alkalinity, ($CaCO_3$,)	19.65	200	0.005	9.825	0.0491
8.	Total Chloride, (Cl)	17.45	250	0.004	6.98	0.0279
9.	Total Hardness (TH)	109.25	500	0.002	21.85	0.0437
10.	Sulphate(SO_4^{-2})	5.00	250	0.004	2.00	0.008
				∑ Wi = 3.8649		∑(Qi x Wi) = 96.5465

$$\mathbf{WQI = \sum(Q_i.W_i)/\sum W_i} = 96,5465/3.8649 = 24.9801$$

Table 5: Calculation of WQI values for groundwater samples in Nsukka Formation during dry season

S/N	Parameter	Mean Monitored Value (V_i)	WHO Maximum Standard (S_i)	Unit weight (W_i=1/S_i)	Quality Rating (Q_i= 100V_i/S_i)	Q_i x W_i
1.	Ph	6.51	8.5	0.1176	76.5882	9.0068
2.	Electrical Conductivity (EC)	300.00	750	0.00133	40	0.0532
3.	Total Dissolved Solid (TDS)	400.00	1000	0.001	40	0.04

4.	Dissolved Oxygen (DO)	8.40	5	0.2	168	33.6
5.	Biochemical Oxygen Demand, (BOD)	6.00	5	0.2	120	24
6.	Iron, (Fe)	0.01	0.3	3.33	3.33	11.11
7.	Total Alkalinity, ($CaCO_3$,)	32.00	200	0.005	16	0.08
8.	Total Chloride, (Cl)	27.61	250	0.004	11.044	0.0442
9.	Total Hardness (TH)	160.18	500	0.002	32.036	0.0641
10.	Sulphate, (SO_4^{-2},)	8.50	250	0.004	3.40	0.0136
				∑ Wi = 3.8649		∑(Qi x Wi) = 78.0119

$$\textbf{WQI} = \sum (Q_i.\ W_i)/\sum W_i = 78.0119/3.8649 = 20.1847$$

Table 6: Calculation of WQI values for groundwater samples in Alluvium Formation during dry season

S/N	Parameter	Mean Monitored Value (V_i)	WHO Maximum Standard (S_i)	Unit weight (W_i=1/S_i)	Quality Rating (Q_i= 100V_i/S_i)	Q_i x W_i
1.	pH	5.78	8.5	0.1176	68	7.9968
2.	Electrical Conductivity (EC)	166.00	750	0.00133	22.133	0.0294
3.	Total Dissolved Solid (TDS)	107.90	1000	0.001	10.79	0.0108
4.	Dissolved Oxygen (DO)	7.20	5	0.2	144	28.8
5.	Biochemical Oxygen Demand, (BOD)	5.20	5	0.2	104	20.8
6.	Iron, (Fe)	0.072	0.3	3.33	24	79.920
7.	Total Alkalinity, ($CaCO_3$,)	35.00	200	0.005	17.5	0.0875
8.	Total Chloride, (Cl)	33.99	250	0.004	13.596	0.0544
9.	Total Hardness (TH)	152.81	500	0.002	30.562	0.0611
10.	Sulphate, (SO_4^{-2},)	6.71	250	0.004	2.684	0.0107
				∑ Wi = 3.8649		∑(Qi x Wi) = 138.3206

$$\textbf{WQI} = \sum (Q_i.W_i)/\sum W_i = 138.3206/3.8649 = 35.7889$$

Table 7: Calculation of WQI values for groundwater samples in Imo Clay Shale Formation during dry season.

S/N	Parameter	Mean Monitored Value (V_i)	WHO Maximum Standard (S_i)	Unit weight (W_i=1/S_i)	Quality Rating (Q_i= 100V_i/S_i)	Q_i x W_i
1.	pH	5.31	8.5	0.1176	62.4705	7.3465
2.	Electrical Conductivity (EC)	210.20	750	0.00133	28.0267	0.0373
3.	Total Dissolved Solid (TDS)	234.13	1000	0.001	2.413	0.0024
4.	Dissolved Oxygen (DO)	10.60	5	0.2	212	42.40
5.	Biochemical Oxygen Demand, (BOD)	6.30	5	0.2	126	25.20
6.	Iron, (Fe)	0.21	0.3	3.33	70	233.10
7.	Total Alkalinity, ($CaCO_3$,)	45.80	200	0.005	22.90	0.1145
8.	Total Chloride, (Cl)	38.41	250	0.004	15.364	0.0615
9.	Total Hardness (TH)	130.30	500	0.002	26.06	0.0521
10.	Sulphate, (SO_4^{-2},)	3.68	250	0.004	1.472	0.0059
				∑ Wi = 3.8649		∑(Qi x Wi) = 308.3202

$$WQI = \sum (Q_i . Wi)/\sum W_i = 308.3202/3.8649 = 79.7744$$

Table 8: Calculation of WQI values for groundwater samples in False Bedded Sandstones Formation during dry season

S/N	Parameter	Mean Monitored Value (V_i)	WHO Maximum Standard (S_i)	Unit weight (W_i=1/S_i)	Quality Rating (Q_i= 100V_i/S_i)	Q_i x W_i
1.	pH	6.01	8.5	0.1176	70.706	8.3150
2.	Electrical Conductivity (EC)	156.70	750	0.00133	20.893	0.0278
3.	Total Dissolved Solid (TDS)	286.00	1000	0.001	28.60	0.0286
4.	Dissolved Oxygen (DO)	8.25	5	0.2	165	33.00
5.	Biochemical Oxygen Demand, (BOD)	4.82	5	0.2	96.4	19.28
6.	Iron (Fe)	0.14	0.3	3.33	15.00	155.411
7.	Total Alkalinity, ($CaCO_3$,)	18.36	200	0.005	9.18	0.0459
8.	Total Chloride, (Cl)	46.27	250	0.004	18.508	0.0740
9.	Total Hardness (TH)	180.93	500	0.002	36.186	0.0724
10.	Sulphate, (SO_4^{-2},)	10.25	250	0.004	4.1	0.0164
				∑ Wi = 3.8649		∑(Qi x Wi) = 216.1987

$$WQI = \sum (Q_i.W_i)/\sum W_i = 216.1987/3.8649 = 55.9390$$

Table 9: Calculation of WQI values for groundwater samples in Benin Formation during rainy season.

S/N	Parameter	Mean Monitored Value (V_i)	WHO Maximum Standard (S_i)	Unit weight (W_i=1/S_i)	Quality Rating (Q_i= 100V_i/S_i)	Q_i x W_i
1.	pH	4.21	8.5	0.1176	66.2353	7.7893
2.	Electrical Conductivity (EC)	134.30	750	0.00133	49.5294	0.0659
3.	Total Dissolved Solid (TDS)	128.30	1000	0.001	12.80	0.0128
4.	Dissolved Oxygen (DO)	10.93	5	0.2	218.60	43.72
5.	Biochemical Oxygen Demand, (BOD)	4.28	5	0.2	85.60	17.12
6.	Iron(Fe) (mg/L)	0.06	0.3	3.33	20	66.60
7.	Total Alkalinity, ($CaCO_3$,)	4.10	200	0.005	2.05	0.0125
8.	Total Chloride, (Cl)	45.24	250	0.004	18.096	0.0724
9.	Total Hardness (TH)	72.50	500	0.002	14.50	0.0290
10.	Sulphate, (SO_4^{-2},)	10.28	250	0.004	4.112	0.0165
				∑ Wi = 3.8649		∑(Qi x Wi) = 135.4384

$$\mathbf{WQI = \sum (Q_i .Wi)/\sum W_i =} 135.4384/3.8649 = 35.0432$$

Table 10: Calculation of WQI values for groundwater samples in Ogwashi Asaba Formation during rainy season

S/N	Parameter	Mean Monitored Value (V_i)	WHO Maximum Standard (S_i)	Unit weight (W_i=1/S_i)	Quality Rating (Q_i= 100V_i/S_i)	Q_i x W_i
1.	pH	5.34	8.5	0.1176	62.8235	7.3881
2.	Electrical Conductivity (EC)	60.10	750	0.00133	8.013	0.1068
3.	Total Dissolved Solid (TDS)	61.40	1000	0.001	6.14	0.0061
4.	Dissolved Oxygen (DO)	7.30	5	0.2	146.00	29.20
5.	Biochemical Oxygen Demand, (BOD)	3.35	5	0.2	67.00	13.40
6.	Iron,(Fe)	0.21	0.3	3.33	70.00	233.10
7.	Total Alkalinity, ($CaCO_3$,)	19.65	200	0.005	9.825	0.0491
8.	Total Chloride, (Cl)	17.82	250	0.004	7.128	0.0285
9.	Total Hardness (TH)	102.25	500	0.002	20.45	0.0409
10.	Sulphate(SO_4^{-2})	4.80	250	0.004	1.92	0.0077
				∑ Wi = 3.8649		∑(Qi x Wi) = 283.331

WQI = $\sum(Q_i. Wi)/\sum W_i$ = 383.331/3.8649 = 73.3077

Table 11: Calculation of WQI values for groundwater samples in Nsukka Formation during rainy season

S/N	Parameter	Mean Monitored Value (V_i)	WHO Maximum Standard (S_i)	Unit weight (W_i=1/S_i)	Quality Rating (Q_i= 100V_i/S_i)	Q_i x W_i
1.	Ph	5.12	8.5	0.1176	60.24	7.0837
2.	Electrical Conductivity (EC)	260.00	750	0.00133	34.67	0.0462
3.	Total Dissolved Solid (TDS)	356.00	1000	0.001	35.6	0.0356
4.	Dissolved Oxygen (DO)	7.80	5	0.2	156	31.2000
5.	Biochemical Oxygen Demand, (BOD)	5.60	5	0.2	112	22.4000
6.	Iron, (Fe)	0.041	0.3	3.33	13.67	45.5100
7.	Total Alkalinity, ($CaCO_3$,)	31.00	200	0.005	15.5	0.0775
8.	Total Chloride, (Cl)	21.42	250	0.004	8.568	0.0343
9.	Total Hardness (TH)	130.18	500	0.002	26.036	0.0521
10.	Sulphate, (SO_4^{-2},)	7.78	250	0.004	3.112	0.0125
				∑ Wi = 3.8649		∑(Qi x Wi) = 106.4519

WQI = $\sum (Q_i. Wi)/\sum W_i$ = 106.4519/3.8649 = 27.5433

Table 12: Calculation of WQI values for groundwater samples in Alluvium Formation during rainy season

S/N	Parameter	Mean Monitored Value (V_i)	WHO Maximum Standard (S_i)	Unit weight (W_i=1/S_i)	Quality Rating (Q_i= 100V_i/S_i)	Q_i x W_i
1.	pH	5.20	8.5	0.1176	61.1765	7.1944
2.	Electrical Conductivity (EC)	130.00	750	0.00133	17.333	0.0231
3.	Total Dissolved Solid (TDS)	101.20	1000	0.001	10.12	0.0101
4.	Dissolved Oxygen (DO)	6.41	5	0.2	128.2	25.6400
5.	Biochemical Oxygen Demand, (BOD)	4.34	5	0.2	86.8	17.3600
6.	Iron, (Fe)	0.67	0.3	3.33	20.1	66.933

7.	Total Alkalinity, ($CaCO_3$,)	33.50	200	0.005	16.75	0.0838
8.	Total Chloride, (Cl)	33.99	250	0.004	13.596	0.0544
9.	Total Hardness (TH)	132.07	500	0.002	26.414	0.0528
10.	Sulphate, (SO_4^{-2},)	6.34	250	0.004	2.536	0.0101
				∑ Wi = 3.8649		∑(Qi x Wi) = 117.3617

$$WQI = \sum (Q_i.W_i)/\sum W_i = 117.3617/3.8649 = 30.3660$$

Table 13: Calculation of WQI values for groundwater samples in Imo Clay Shale Formation during rainy season.

S/N	Parameter	Mean Monitored Value (V_i)	WHO Maximum Standard (S_i)	Unit weight (W_i=1/S_i)	Quality Rating (Q_i= 100V_i/S_i)	Q_i x W_i
1.	pH	4.75	8.5	0.1176	55.8824	6.5718
2.	Electrical Conductivity (EC)	185.80	750	0.0013	24.773	0.0322
3.	Total Dissolved Solid (TDS)	230.45	1000	0.001	23.045	0.0231
4.	Dissolved Oxygen (DO)	10.45	5	0.2	522.5	104.5000
5.	Biochemical Oxygen Demand, (BOD)	5.15	5	0.2	103	20.6000
6.	Iron, (Fe)	0.18	0.3	3.33	60	199.800
7.	Total Alkalinity, ($CaCO_3$,)	42.60	200	0.005	21.3	0.1065
8.	Total Chloride, (Cl)	35.20	250	0.004	14.08	0.0563
9.	Total Hardness (TH)	124.60	500	0.002	24.92	0.0498
10.	Sulphate, (SO_4^{-2})	3.56	250	0.004	1.424	0.0057
				∑ Wi = 3.8649		∑(Qi x Wi) = 336.1891

$$WQI = \sum (Q_i. W_i)/\sum W_i = 336.1891/3.8649 = 86.9852$$

Table 14: Calculation of WQI values for groundwater samples in False Bedded Sandstones Formation during rainy season

S/N	Parameter	Mean Monitored Value (V_i)	WHO Maximum Standard (S_i)	Unit weight (W_i=1/S_i)	Quality Rating (Q_i= 100V_i/S_i)	Q_i x W_i
1.	pH	5.62	8.5	0.1176	66.118	7.7754
2.	Electrical Conductivity (EC)	130.40	750	0.00133	17.387	0.0226
3.	Total Dissolved Solid (TDS)	246.00	1000	0.001	24.60	0.0246
4.	Dissolved Oxygen (DO)	8.02	5	0.2	160.4	32.0800
5.	Biochemical Oxygen Demand, (BOD)	3.75	5	0.2	75.0	15.0000
6.	Iron, (Fe)	0.33	0.3	3.33	110.0	366.300
7.	Total Alkalinity, ($CaCO_3$,)	16.32	200	0.005	9.18	0.0459
8.	Total Chloride, (Cl)	32.55	250	0.004	13.02	0.0521
9.	Total Hardness (TH)	175.68	500	0.002	35.136	0.0727
10.	Sulphate, (SO_4^{-2})	10.12	250	0.004	4.048	0.0169
				∑ Wi = 3.649		∑(Qi x Wi) = 421.0902

$$WQI = \sum (Q_i . Wi)/\sum W_i = 421.0902/3.8649 = 108.9524$$

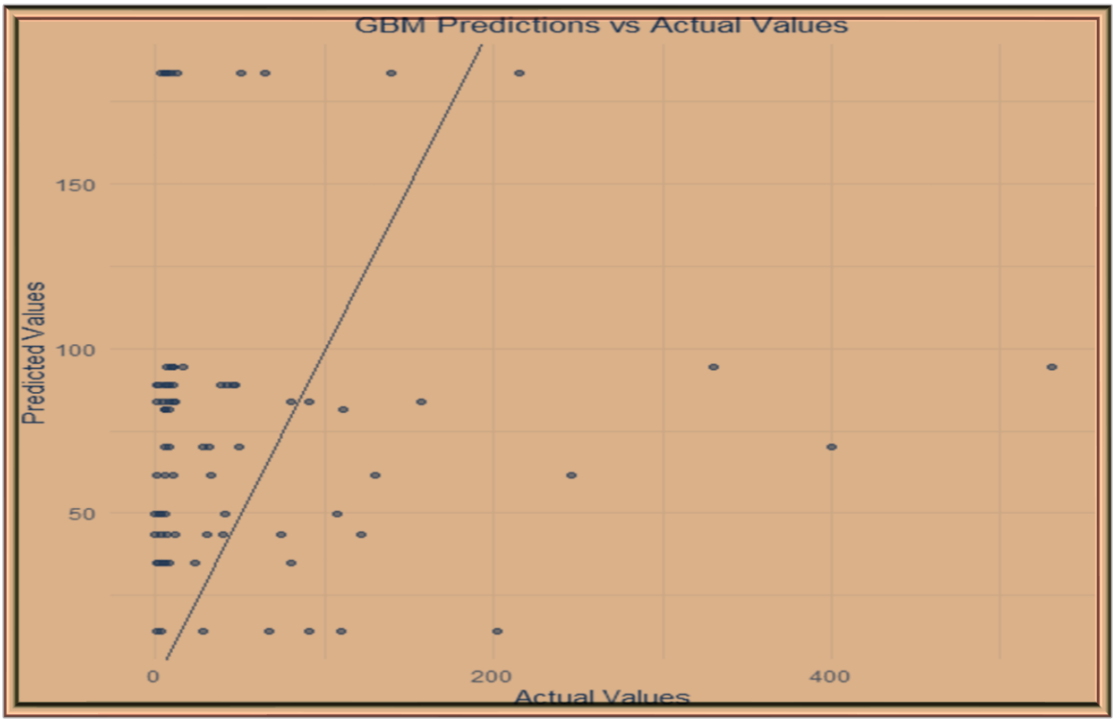

Figure 3. Graph of Actual and Predicted using the XG-Boost Model.

1.7 Conclusions

In conclusion, during the dry season, it was recorded that the groundwater samples from Ogwashi Asaba and Nsukka formations exhibit excellent water quality, while samples from the Benin and Alluvium formations demonstrate good water quality. In another record, the results from the False Bedded Sandstones and Imo Clay Shale formations are characterized by poor water quality according to national and international indices and standards. This indicates that water from these two places necessitates treatment beforehand. The results from the rainy season showed that water samples from the Benin formation, Nsukka formation, and Alluvium formation exhibited high water quality, whereas samples from the Ogwashi Asaba and Imo Clay Shale formations demonstrated poor and extremely bad water quality, respectively. The sample from the false Bedded Sandstone formation is unfit for drinking purposes. This pertains to identifiable, indiscriminate releases of industrial wastewater and sewage. Conclusively, the groundwater quality across the six geological zones of Imo State was evaluated by analyzing various water quality parameters using laboratory techniques. Secondly, the results obtained were juxtaposed with the permitted limits established by WHO, BIS, and FMEnv.During the dry season, it was found that dissolved oxygen levels above the permissible limit of 7.5 in all formations, except for the Alluvium formation, which recorded exactly 7.5. Chemical Oxygen Demand exceeded the WHO allowed limit in all formations; Phosphate levels beyond the allowable limit in the Benin Formation, Nsukka Formation and Alluvium Formation. During the rainy season, Dissolved Oxygen was higher in all except Alluvium formation, COD exceeded the allowable limit in all the formations except Ogwashi Asaba formation; potassium was higher than the limit in Alluvium formation and phosphate was higher than the allowable limit except in Ogwashi Asaba Formation and False Bedded Sandstone Formations. Thirdly, the data collected demonstrated that TDS, Chlorides, Nitrates, Sulphate, Total Hardness and Electrical Conductivity increased in dry season whereas Potassium and Bicarbonate were higher in wet season. Fourthly, the Water Quality Index (WQI) of the tested water samples was calculated, and they yielded the following values: The Water Quality Index (WQI) for the dry season was 50.10, 24.98, 20.18, 35.79, 79.77, and 55.94 for BF, OAF, NF, AF, ICSF, and FBSF, respectively. In contrast, the WQI for the wet season was 35.04, 73.30, 27.54, 30.37, 86.98, and 108.95 for BF. OAF, NF, AF, ICSF, and FBSF respectively. Finally, the Aquifer model was employed to analyze the variances. This was trained using a 70-30 ratio where 70% was for calibration (training) and 30% for validation (testing), this resulted in a Root Mean Square Error (RMSE) value of 142.8292 that later decreased to 130.3095 at the final iteration after having undergone hundred (100) iterations. The decreased value of RMSE from 142.8292 to 130.3095 indicates convergence and limited potential for improvement with further iterations. Invariably, at this point of final iteration that was optimized, the system can be predicted.

1.8 Contributions

This study which was aimed at the determination of the varying spatio-temporal conditions of groundwater quality, considering various geological formations, has added to knowledge in this area of Water Engineering by improving the understanding of the hydrogeology of geological zones. The produced spatial variability will aid water resource managers and policymakers in formulating guidelines to combat future pollution and in the wise control of groundwater resources for both agricultural and consumable applications in the research areas.

iii. Forecasts of groundwater quality and quantity will assist in pinpointing suitable agricultural regions and preventing over-extraction of water, when salt levels relative to Calcium and magnesium concentrations could significantly rise.

Declaration of Conflicting Interests

The authors declare no potential conflicts of interest with respect to the research, authorship and publication of this article.

Funding

The author received no financial support for the research, authorship and publication of this article.

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