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Simulation of the Spatio-Temporal Fluctuation of Groundwater Standard in Different Geological Formations in Imo State Using Suitable Modelling.

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Abstract: *The study centers on the simulation of the spatio-temporal differences of groundwater standard in different geological formations in Imo state, using suitable iterative modeling. For a period of twelve (12) months, seventy two groundwater samples were collected from six hydrological formations of Imo State. The obtained values were analyzed for twenty-two different physiochemical parameters. The considered zones were the Benin Formation (BF), Ogwashi Asaba Formation (OAF), Nsukka Formation (NF), Alluvium Formation (AF), Imo Clay Shale Formation (ICSF), and False Bedded Sandstones Formation (FBSF). 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 (WQI) was evaluated in accordance with WHO permissible standards for safe drinking water on a scale of 0 to 100. The WQI for dry season were 50.10, 24.98, 20.18, 35.79, 79.77 and 55.94 for BF, OAF, NF, AF, ICSF, and FBSF respectively while for rainy season, the WQI gotten were 35.04, 73.30, 27.54, 30.37, 86.98 and 108.95 for BF, OAF, NF, AF, ICSF and FBSF respectively. The results reveal that during dry season, groundwater samples from OAF and NF have excellent water quality, samples from BF, NF, and AF have good quality water and samples from ICSF have very poor water quality. The WQI 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 standard from ICSF shows very poor quality and the water quality from FBSF is unsuitable for drinking purpose. This suggests 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.*
The modeling was done for several iterations using XG boost model and after several iterations the dataset and a value decreased.

Keywords: *Simulation, Boost Model, Mean Monitored Value, Quality Rating, Spatiotemporal variability, Water Quality Index.*

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I. Introduction:

Groundwater is a valuable resource all around us. In places where surface water--such as rivers, streams, and lakes—is either few or absent, groundwater satisfies many of the hydrological needs of humans globally. In rural as well as urban environments, it is the main source of drinking water. Common surface pollution of shallow aquifers comes from urban and suburban settings, where contaminated shallow groundwater can be found in many probable sources. Among the sources of pollution include landfills, sewage treatment plants, industrial effluences, septic fields, gasoline storage tanks, air deposition, and runoff. Additional contaminants include mercury, chloride (Cl^-), sulfate (SO_4^{-2}), nitrogen (nitrate, ammonium), dangerous metals such as cadmium, lead, and chromium and various organic groups such as petroleum compounds, solvents, and pesticides (Walton et al., 2008.). Reports by Nwankwo and Ogagarue (2011), Ocheri et al. (2014), and Agori et al. (2021) claim that assessments of urban groundwater quality correlate With land use.

Many theoretical models exist for groundwater quality change both geographically and temporally. Fryar et al. (2000) looked at the spatial and temporal fluctuations in seepage between a contaminated aquifer and Ohio River tributaries. Hayashi and Rosenberry (2002) investigated how surface water hydrology and ecology responded to groundwater exchange.

Fryar et al. (2000) studied the temporal and spatial fluctuations in seepage between a contaminated aquifer and Ohio River tributaries. Hayashi and Rosenberry (2002) investigated how surface water hydrology and ecology might be affected by groundwater exchange. Allison (2005) investigated throughout time and space how groundwater discharge to streams changed. Mini et. al., 2014 investigated the temporal and geographical behavior of groundwater level in the coastal aquifers of Minjur in Tamilnadu, India using the GS+ and geostatistical modules of Arc GIS 9.3 software. They found that groundwater level exhibits notable spatial dependency. Dhar et al. (2008) examined the temporal variability of groundwater chemistry in shallow and deep aquifers in Araihazar Bangladesh and identified a link between aquifer age and mobility of Ions like As, Fe and so forth independent of the redox impact. Essien and Abasifreke (2004) investigated groundwater quality in boreholes located in the urbanized state capital of Uyo as well as four adjacent local government areas (LGAs) of Ibiono Ibom, Ikot Ekpene, Itu, and Nsit Ubium, all under the formation of coastal plain sands (CPS), in order to ascertain the spatial and temporal variability of groundwater quality and its fit with Nigerian Standards for Drinking Water Quality (NSDWQ). Their results suggested that the spread of urbanization could lead to pollution diffusion. Three types of boreholes: government-owned public boreholes, privately owned boreholes used for personal use, and individual-owned boreholes utilized for business usage were investigated by Agunwamba et al. (2000). Maintenance, a serious issue, could affect the quality of the groundwater released.

Problem Statement: Groundwater pollution can have effects on poor drinking water quality, water supply interruption, degraded surface water systems, costly remedial action, the necessity for additional water sources, and/or possible health problems. Groundwater contaminated or degraded surface water could have negative impacts. Sundara et al. (2010) claim that groundwater has a spectrum of elements at different concentrations: gases, microbes, inorganic and organic compounds, etc. These concentrations create a concern and are regarded as undesirable contaminants when they exceed WHO drinking water recommendations (Amangabara & Ejenma 2012). Oladipo et al. (2014) claim that water pollution with trace metals can result from contaminated water seeping into the groundwater through rock and soil, as well as from prolonged exposure to intense sunlight, high temperatures, fragmentation, biological activity, etc., tend to bring bacteria or viruses into the water and water dissolves the minerals that are soluble in sedimentary rocks and soils. Thus, maintaining consumer safety and lowering the frequency of infectious diseases depend on constant observation of groundwater quality.

Objectives of Study: The main objective of this research simulation of the spatio-temporal fluctuation of groundwater standard in different geological formations in imo state using suitable modeling and the other goals to

i) To evaluate groundwater quality by means of laboratory technique examination of a few chosen water quality criteria.

ii) To evaluate the findings against World Health Organisation (WHO 2017), FMEnv (2012) and BIS (2015) allowable limits.

iii.)Collecting samples during both wet (April to October) and dry season (November to March) can help one ascertain the effect of time on the chosen physio-chemical parameters.

iv)To ascertain and calculate the Water Quality Index (WQI) of some particular criteria.

v) Using XGBoost Model, to replicate the Spatio-temporal fluctuation of the water quality in several geological formations of Imo State.

Materials: The materials employed for this research work are: Microsoft office package software, Google chrome and Mozilla firefox browser. In the list of hardware include, Intel Pentium Dell inspiron 5000, 4 GB RAM, HID Optical Mouse, HP Deskjet Ink Advantage 1515 printer, Tecno Pova Neo., Stop watch, Thermometer and pH meter, Atomic absorption spectrophotometer (AAS), 300 ml and 250 ml Amber DO and BOD bottles, 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.

Methods: Grab sampling and random sample methodologies were employed. Seventy-two (72) borehole water samples were obtained from six distinct hydrological formations during a duration of 12 months. The various locations were in proximity to waste disposal stations within the distinct hydrological formations. This aimed to guarantee that sample collection encompassed both dry and rainy seasons for sufficient data and thorough comparative analysis. Twice, the containers were sufficiently cleaned at the collecting sites with relevant materials; they were then filled with samples and tightly corked. Before examination, the gathered samples were stored in a water cooler. Measuring pH, conductivity, and dissolved oxygen in situ with a digital meter. The analysis of several physiochemical parameters, including pH, total alkalinity, chlorides, sulfate, nitrate, total hardness, calcium, magnesium, electrical conductivity, dissolved oxygen, biochemical oxygen demand, total dissolved solids, and total suspended particles were carried out in the Laboratory.

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 weighted arithmetic water index method water quality uses:

i. 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.

ii. Water quality rating scale, (q_i)

iii. Relative weight and (w_i)

iv. 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:

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

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

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

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

The relative weight (W_i) is calculated by

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad . \qquad \text{iii}$$

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

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

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

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

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

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

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.

Determinant of Water Quality: Accurate representation of all indicators of water quality depends on the use of basic water quality measurements. Commonly used water quality metrics by researchers are dissolved oxygen, total phosphates, temperature, pH, turbidity, chemical oxygen demand, fecal colium, total solids, biochemical oxygen demand, and nitrates. The applicable criteria define the weight given to every parameter; so, the weight indicates the importance and effect of the parameter on the index. The weighting considerations for different water quality criteria are as follows.

II. Results

Calculate the water Quality Index (WQI).

For the period of dry season were 50.10, the Water Quality Index (WQI) values were, 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 3 and 4. 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 0water quality, as shown in Tables 4.8, 4.9, and 4.10, 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 4.11, 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 potability.

Table 1 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

Source: Ketata – Rokban et al. 2011.

Table 2: 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

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

Table 3: 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

WQI = $\sum$(Qi.Wi)/$\sum$Wi = 96, 5465/3.8649 = 24.9801

Table 4: 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

WQI = $\sum$ (Qi. Wi)/$\sum$Wi = 78.0119/3.8649 = 20.1847

Table 5: 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

WQI = $\sum$ (Qi .Wi)/$\sum$Wi = 138.3206/3.8649 = 35.7889

Table 6: 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	210.20	750	0.00133	28.0267	0.0373

	(EC)					
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 = ∑ (Q_i. Wi)/∑W_i = 308.3202/3.8649 = 79.7744

Table 7: 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 = ∑ (Q_i.Wi)/∑W_i = 216.1987/3.8649 = 55.9390

Table 8: 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

WQI = ∑ (Q_i .Wi)/∑W_i = 135.4384/3.8649 = 35.0432

Table 9: 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 = ∑(Q_i. Wi)/∑W_i = 383.331/3.8649 = 73.3077

Table 4.10: 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 = ∑ (Q_i. Wi)/∑W_i = 106.4519/3.8649 = 27.5433

Table 4.11: 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 = ∑ (Q_i .Wi)/∑W_i = 117.3617/3.8649 = 30.3660

Table 4.12: 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 = ∑ (Q_i. Wi)/∑W_i = 336.1891/3.8649 = 86.9852

Table 4.13: 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 = ∑ (Q_i. Wi)/∑W_i = 421.0902/3.8649 = 108.9524

III. Discussion:

Based on these results generated in the course of this work, one can firstly, conduct periodic monitoring and remediation of acidic and nitrate-rich water, so as to prevent future contamination and ensure the sustainable utilization of groundwater resources.

secondly, additional research may be conducted regarding other significant climatic variables, including soil and air temperature, as well as solar radiation, which could affect aquifer conditions and dictate the depletion and degradation of groundwater. Further collaborative efforts among the state environmental protection agency, the water resources ministry, the sanitation agency, and waste management organizations can be of positive contribution for developing and implementing a framework that protects water resources, enhances community access to potable water, and guarantees sustainable waste management.

IV. Conclusions:

The quality of groundwater is a crucial determinant of human health, especially in countries reliant on natural resources, such as Nigeria. Groundwater is a vital and precious natural resource, anticipated to be devoid of contaminants. This water supply is frequently polluted by numerous contaminants originating from agricultural, industrial, and domestic sources. The fast increase in population and industry necessitates an examination of groundwater quality due to its susceptibility to municipal and industrial waste disposal.This study examined the spatiotemporal variability of groundwater quality across six geological zones in Imo State. It assessed the physiochemical characteristics of groundwater samples from the Benin Formation (BF), Ogwashi Asaba Formation (OAF), Nsukka Formation (NF), Alluvium Formation (AF), Imo Clay Shale Formation (ICSF), and False Bedded Sandstone Formation (FBSF).The mean concentrations of total dissolved solids, chloride, nitrate, sulfate, total hardness, and electrical conductivity were heightened throughout the dry season relative to the rainy season, although the mean concentrations of potassium and bicarbonate were higher in the wet season. The findings indicate that during the dry season, groundwater samples from Ogwashi Asaba and Nsukka formations exhibit excellent water quality, while samples from the Benin and Alluvium formations demonstrate good water quality. Conversely, samples 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, CODexceeded 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 XGBOOST 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.

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