Journal of Engineering Research, Volume 29, Number 1, March 2024

Assessment of Groundwater Suitability for Industrial Purpose in Oredo LGA of Benin City, Nigeria Using Langelier Saturation Index

A. Rawlings[1*], J.A. Ofili[1], and S. Seghosime[2]

[1]Department of Civil Engineering, Faculty of Engineering, University of Benin, Benin City, Nigeria.
[2]Department of Civil Engineering, School of Engineering, Auchi Polytechnic, Auchi, Nigeria.
Corresponding Author's Email:*animetu.seghosime@uniben.edu

Abstract

Most industries make use of groundwater resources not only where surface water is limited in quantity but also where quality is paramount. However, corrosion is an inherent problem associated with some groundwater, and it is a pernicious process that impairs the efficiency of industries. Hydro-chemical parameters (such as pH, electrical conductivity, hardness, etc.) provide valuable information, but they do not cover all aspects of industrial suitability. The presence of certain ions (e.g., Na^+, Ca^{2+}, and Mg^{2+}) can lead to corrosion behavior in groundwater, and the ionic exchange between these ions can affect the stability of pipes, machinery, and infrastructure used in industrial operations. Hence, different techniques (besides hydrochemical) are now being used to evaluate the suitability of groundwater for industrial uses. In this study, groundwater samples were randomly collected from fifteen different boreholes in the Oredo Local Government Area and investigated for their suitability for industrial purposes. These samples were collected within the period of May to June 2023. In order to assess the groundwater quality, these samples were analyzed for some selected parameters, namely: pH, Temperature, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Dissolved Oxygen (DO), Bicarbonate (HCO_3^-), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^+), Sodium (Na^+), Chloride (Cl^-), Nitrite (NO_2^-), Nitrate (NO_3^-), Sulfate (SO_4^{2-}), Iron (Fe), Zinc (Zn), Copper (Cu), Manganese (Mn), Ammonium Nitrogen (NH4N), and Coliforms. Based on this, the Langelier Saturation Index (LSI) was used to determine the suitability of groundwater for industrial purposes. The results of the groundwater quality analysis revealed that the groundwater is warm and acidic in nature. The LSI results indicated that the groundwater has a high corrosion tendency; thus, there is a possibility for corrosion to take place in industrial equipment when used, which may hinder the efficiency of the industry. Therefore, regular monitoring and treatment of the groundwater before industrial use are essential.

Keywords: Groundwater Quality, Langelier Saturation Index, Corrosion, Physiochemical Analysis, Oredo LGA.

1.0 INTRODUCTION

Groundwater is the water found underground in the cracks and spaces in soil, sand, and rock. It is held in aquifers and can be extracted through wells or bubbles up naturally through a spring or is discharged into lakes or streams (Hermann and Prunes, 2022). Even though it is underground, when it does bubble up or flow into streams, groundwater helps to replenish and maintain levels of surface water, thus helping to keep our rivers flowing. Groundwater supplies are replenished, or recharged, by rain and snow melt that seep down into the cracks and crevices beneath the land's surface (Mukherji, 2006; Rawlings and Ikediashi, 2020). About 22% of the freshwater on earth exists as groundwater, and about 97% is available for human consumption (Foster, 1998; Panaskar et al., 2016). It is a vital resource used for drinking, irrigation, and industry, especially in areas where tap water reticulation infrastructure is undeveloped and surface water is scarce or unreliable (Agossou and Yang, 2021; Hermann and Prunes, 2022), and Benin City, Nigeria, happens to be one of such areas.

One of the main challenges to protecting groundwater is that it is, of course, underground, and as such, groundwater levels are not easily monitored with the naked eye. So, supplies can be unknowingly polluted or overexploited without proportionate recharge by both natural as well as anthropogenic factors (Peterson and Kennedy, 1997; Hsan et al., 2017; Hermann and Prunes, 2022). Benin City comprises different local government areas (LGAs), including Oredo LGA (Balogun and Orimoogunje, 2015), which is experiencing a tremendous increase in population, urbanization, and industrialization. These factors have led to increased anthropogenic activities in Oredo LGA. It has been shown that anthropogenic activities in all sectors impact and alter the natural water cycle and subsequent groundwater quality (Nicole et al., 2019). Hence, groundwater can be polluted by landfills, septic tanks, leaky underground gas tanks, and overuse of fertilizers and pesticides (Panaskar et al., 2016; Hermann and Prunes, 2022). Contaminated water impacts human health and is not safe for industrial uses (WHO, 2017). It has a great potential for transmitting a wide variety of diseases (Ogbeifun et al., 2019). About 80% of the diseases that affect the global population today and more than one-third of the deaths in developing countries are all attributed to contaminated water (Adegbite et al., 2018). Thus, there is a need for constant monitoring of groundwater quality in Benin City, considering that it is the major source of portable water supply (Agatemor and Okolo 2007).

Most industrial processes that use water (such as those used in most industries in Oredo LGA) often experience corrosion or scaling. Process efficiency is affected by scaling due to lower pipe capacity, and process reliability is affected by corrosion due to pipe failure. Corrosion or scaling is an inherent problem associated with some groundwater and is related to the type of rocks or sediments in contact with the groundwater. Corrosion is a physicochemical reaction that may happen between a surface and other materials surrounding it and cause changes in material properties (Abbasniaa et al., 2018). It is a chemical process (oxidation or reduction) that brings refined or processed metals to their more stable ore state. These chemical processes gradually dissolve metal, leading to the deterioration and failure of plumbing pipes, fixtures, and water-using equipment (McFarland et al., 2020). Corrosion can result in water losses and introduce toxic heavy metals (like lead, iron, copper, zinc, arsenic, and cadmium) into water, posing health risks (Abbasniaa et al., 2018). Scaling occurs due to the reaction between divalent cations and water-soluble substances (Abbasniaa et al., 2018). It forms thin layers in pipes and facilities, especially when water contains high levels of minerals like calcium carbonate (UGA Extension, 2020). Increased scaling levels can harm water distribution networks and equipment (Mirzabeygi et al., 2016; Mirzabeygi et al., 2017; Mohammadiet et al., 2018). The Langelier Saturation Index (LSI) is commonly used to predict the degree of corrosiveness or scaling. It indicates water's saturation with respect to calcium carbonate (Energy Pulse, 2023). Today, it is generally accepted that corrosion and pollution are interconnected processes, with pollutants accelerating corrosion and contributing to water body contamination. Hence, groundwater suitability for industrial use should be evaluated using techniques beyond hydrochemicals. Therefore, this study aimed at assessing groundwater suitability for industrial purposes in Oredo LGA of Benin City, Nigeria, using the Langelier Saturation Index. Information obtained from this study will help indicate the condition of groundwater used in food industries in Oredo LGA of Benin City as well as promote the reduction or elimination of corrosion or scale during groundwater treatment. The main types of industries in Oredo LGA include food (including bakery), laundry, and packaged water industries, which are among the major heavy water-using industries, as reported by Islam and Mostafa (2023). Hence, these industries were considered for this study.

2.0 MATERIALS AND METHODS

2.1 Study Area

Oredo Local Government Area (see Figure 1) has its headquarters in Benin City and a land area of about 319 square kilometers (Ojiako et al., 2018). It lies between latitudes 6°00' and 6° 30' north of the equator and longitudes 5° 25' and 5° 35' east of the Greenwich meridian (Ojiako et al., 2018). It is located within the rainforest zone of Nigeria, with mean annual rainfall in the range of 1500 mm to 2500 mm and the mean monthly temperature varying from 25°C to 28°C (Rawlings and Ikediashi, 2020). The LGA is made up of several districts, such as Ekehuan, Orogo, Abiala, Gelegele, Ibaro, Igbobi, Ikpako, and Oduna (Manpower, 2023). Oredo is home to many; thus, it has a population of about 374,515 people (NPC, 2006). The LGA witnesses two distinct seasons, which are the dry and the rainy seasons, with an average humidity level of about 61% (Manpower, 2023). Apart from having a vibrant trade sector, the LGA hosts several banks, government establishments, hotels, restaurants, relaxation spots, privately owned firms, and industries (mostly food industries), all of which contribute to the economy of the LGA.

Figure 1: Map Sowing the Location of Oredo LGA, Benin City (Source: Google Earth, 2023)

2.2 Sample Collection and Analysis

Groundwater samples were collected (through tap) using a simple random sampling technique from fifteen different boreholes located in Oredo LGA within the period of May to June 2023. The locations of the borehole water samples are indicated in Table 1 and Figure 2. Pretreated plastic cans (of 75 liters each) were used for the collection of the groundwater samples. The plastic cans were sealed, labeled, and transported to the Martlet Environmental

Research Laboratory in Benin City for analysis. The samples were analyzed for twenty physiochemical parameters, namely: pH, Temperature, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Dissolved Oxygen (DO), Bicarbonate (HCO_3^-), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^+), Sodium (Na^+), Chloride (Cl^-), Nitrite (NO_2^-), Nitrate (NO_3^-), Sulfate (SO_4^{2-}), Iron (Fe), Zinc (Zn), Copper (Cu), Manganese (Mn), Ammonium Nitrogen (NH_4N), and a biological parameter (Coliforms-Col.). All laboratory analyses were conducted in accordance with the techniques described by American Public Health (APHA, 1985 and 2005), and the methods adopted for analyzing the groundwater quality parameters are shown in Table 2. Water quality data were analyzed statistically using the Statistical Package for the Social Sciences (SPSS, version 26.0, 2018).

Table 1: Location and GPS Coordinates of Groundwater Samples

Sample ID	Industry	GPS Coordinates	
		Longitude (E)	Latitude (N)
BH1	Food Processing	5°37'20.77"	6°19'35.80"
BH2	Food Processing	5°37'47.91"	6°17'53.20"
BH3	Food Processing	5°37'21.66"	6°18'41.74"
BH4	Laundry	5°36'22.14"	6°17'7.95"
BH5	Food Processing	5°37'3.31"	6°18'23.47"
BH6	Food Processing	5°36'58.69"	6°18'34.00"
BH7	Food Processing	5°37'8.28"	6°18'10.18"
BH8	Food Processing	5°37'42.70"	6°18'52.94"
BH9	Food Processing	5°36'35.07"	6°17'9.33"
BH10	Pure and Bottle Water	5°36'13.66"	6°20'5.94"
BH11	Food Processing	5°36'34.26"	6°18'17.73"
BH12	Pure and Bottle Water	5°37'15.08"	6°16'24.33"
BH13	Laundry	5°36'46.91"	6°19'15.45"
BH14	Pure and Bottle Water	5°36'46.90"	6°19'32.71"
BH15	Laundry	5°36'22.30"	6°15'44.79"

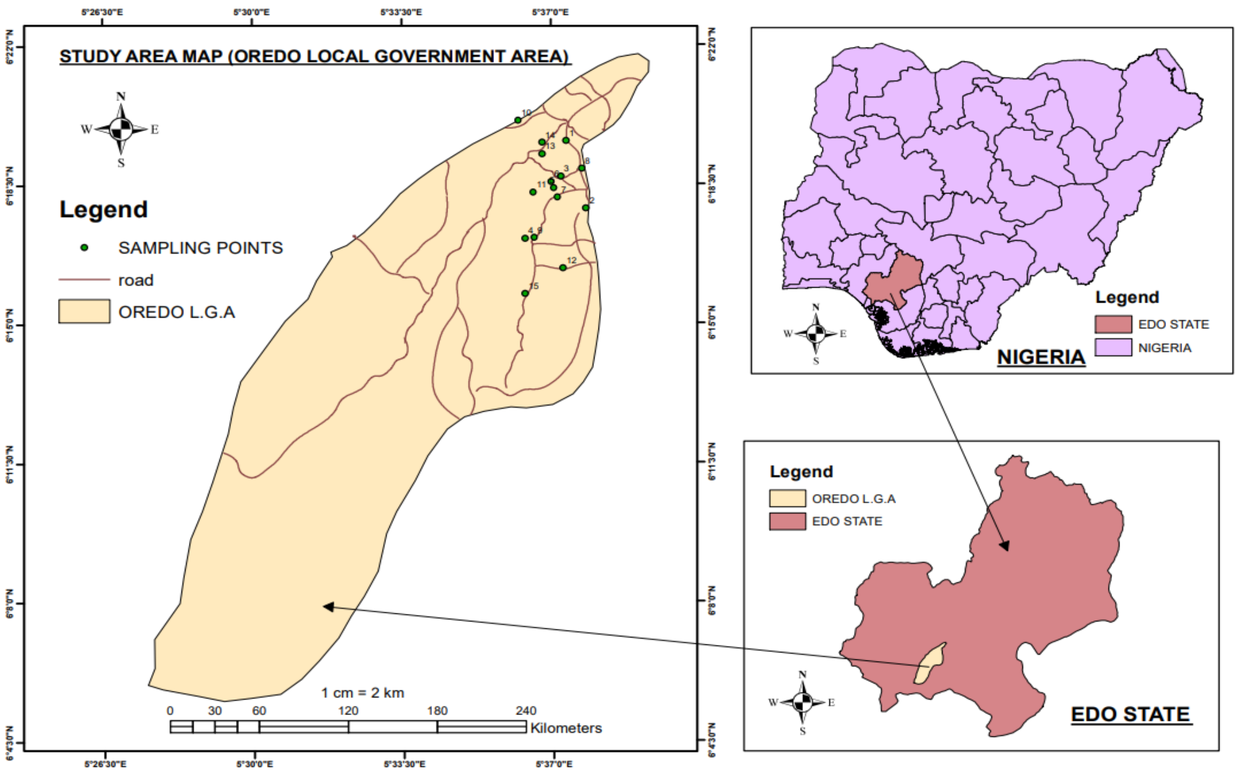

Figure 2: Map of Study Area Showing Groundwater Sampling Points

Table 2: Analytical Methods for Water Quality Parameters

Parameters	Analytical Methods
pH	Flame Photometric Method
Temperature	Thermometer Method
Electrical Conductivity	Flame Photometric Method
Total Dissolved Solids	Flame Photometric Method
Dissolved Oxygen	Titrimetric Method
Bicarbonate	Titrimetric Method
Calcium	Titrimetric Method
Magnesium	Titrimetric Method
Potassium	Flame Photometric Method
Sodium	Flame Photometric Method
Chloride	Titrimetric Method
Nitrite	Spectrophotometry Method (Atomic Absorption Spectrophotometer)
Nitrate	Spectrophotometry Method (Atomic Absorption Spectrophotometer)
Sulfate	Spectrophotometry Method (Atomic Absorption Spectrophotometer)
Iron	Spectrophotometry Method (Atomic Absorption Spectrophotometer)
Zinc	Spectrophotometry Method (Atomic Absorption Spectrophotometer)
Copper	Spectrophotometry Method (Atomic Absorption Spectrophotometer)
Manganese	Spectrophotometry Method (Atomic Absorption Spectrophotometer)
Ammonium Nitrogen	Titrimetric Method
Coliforms	Membrane Filtration Method

2.3 Langelier Saturation Index (LSI)

Langelier Saturation Index (LSI) is used to determine the need for calcium carbonate precipitation scale control in water sources containing a total dissolved solid (TDS) of less than 10,000 mg/l (Arthur, 2020). It is often used as an indicator of the corrosivity of water. The scaling in pipe or heat exchanger tubes can cause insulation for heat transfer or metal loss in the case of the corrosion tendency of water. LSI is an equilibrium model derived from the theoretical concepts of saturation and helps in indicating the degree of saturation of water with respect to calcium carbonate (Lenntech, 2021). Most industries use groundwater for cooling, product treatment and cleaning, processing, boiler make-up, etc. (Islam and Mostafa, 2023). Many pollutants accelerate corrosion and corrosion products (such as rust) and also pollute water bodies, including groundwater. Both corrosion and pollutants are inherent properties of some groundwater, and they are pernicious processes that impair the quality of the environment, the durability of infrastructure assets, and the efficiency of the industry. LSI gives guidance for stabilizing measures to mitigate scale formation and internal corrosion. Hence, assessing groundwater suitability using LSI has become a key factor for the operational management of an industry. The LSI used in this study was calculated according to the formula by Arthur (2020) and Lenntech (2021):

$$\mathrm{LSI} = \mathrm{pH} - \mathrm{pH_S} \quad (1)$$

where,

pH =Measured water pH

pH_s = pH at saturation in calcite or calcium carbonate and is given as:

$$pH = (9.3 + A + B) - (C + D) \quad (2)$$

where;

$$A = {}^{log_{10}[TDS] - 1}/_{10}$$

$$B = -13.12 \times log_{10}(℃ + 273) + 34.55$$

$$C = log_{10[Ca^{2+}\ as\ CaCO_3]-0.4}$$

$$log_{10[Alkalinity\ as\ CaCO_3]}$$

Where,

TDS = Total Dissolved Solids

°C = Temperature in degree Celsius

$CaCO_3$ = Calcium Carbonate

Ca^{2+}= Calcium

In this study, bicarbonate alkalinity was used. The LSI values gotten from the study were interpreted based on Table 3.

Table 3: Interpretation of LSI (Arthur,2020)

LSI	Interpretation
If LSI is negative (LSI< 0)	No potentials to scale, water will dissolve $CaCO_3$
If LSI is positive (LSI > 0)	Scale will be formed and $CaCO_3$ precipitation occurs
If LSI is zero (LSI = 0)	Water is considered as stable water

3.0 RESULTS AND DISCUSSION

The results obtained from the study are presented in Tables 4 to 6. Table 4 shows the physiochemical quality of borehole water samples in the study area; Table 5 indicates the statistical description of physiochemical parameters in the borehole water samples and their comparison with standards; and Table 6 presents the LSI of the borehole water samples.

Table 4: Physiochemical Quality of Borehole Water Samples in the Study Area

	Sampling Points														
Parameters	**BH1**	**BH2**	**BH3**	**BH4**	**BH5**	**BH6**	**BH7**	**BH8**	**BH9**	**BH10**	**BH11**	**BH12**	**BH13**	**BH14**	**BH15**
pH	5.5	5.3	5.1	5.1	5.1	5.2	4.9	6.1	5.3	6.4	5.8	5.1	5.1	5.2	4.5
Temp. (^oC)	28.0	28.9	28.5	28.9	28.9	28.8	28.9	28.9	28.0	28.9	28.9	28.0	28.1	28.0	28.0
EC (µS/cm)	261	36	34	100	243	239	158	289	64	154	146	160	184	112	659
TDS (mg/l)	130	19	42	50	121	119	79	141	32	77	73	80	92	56	328
DO (mg/l)	3.4	5.0	5.1	4.6	3.6	3.5	4.5	3.3	5.0	4.0	4.2	3.7	3.9	4.6	2.7
HCO_3^- (mg/l)	103.7	61.0	48.8	67.1	97.6	91.5	85.4	110.3	61.0	73.2	67.1	85.4	91.5	67.1	152.5
Ca^{2+} (mg/l)	1.85	0.70	0.63	0.88	1.76	1.63	1.32	2.01	0.74	1.23	1.17	1.44	1.51	0.87	5.17
Mg^{2+} (mg/l)	1.12	0.44	0.41	0.51	1.02	0.99	0.73	1.74	0.48	0.70	0.66	0.85	0.87	0.56	3.33
K (mg/l)	0.77	0.15	0.10	0.22	0.73	0.71	0.43	0.80	0.18	0.41	0.33	0.56	0.61	0.27	0.88
Na (mg/l)	0.89	0.21	0.18	0.31	0.87	0.77	0.54	1.22	0.27	0.51	0.43	0.61	0.73	0.40	1.85
Cl^- (mg/l)	88.6	35.5	35.5	53.2	88.6	88.6	70.9	106.4	53.2	53.2	53.2	70.9	70.9	53.2	159.5
NO_2^- (mg/l)	0.087	0.011	0.011	0.022	0.061	0.055	0.044	0.121	0.018	0.031	0.028	0.048	0.053	0.025	0.881
NO_3^- (mg/l)	1.084	0.177	0.140	0.394	1.041	0.993	0.721	1.084	0.199	0.604	0.465	0.823	0.971	0.455	2.921
SO_4^{2-} (mg/l)	0.084	0.017	0.014	0.024	0.071	0.067	0.037	0.094	0.022	0.033	0.028	0.063	0.063	0.024	0.155
Fe (mg/l)	0.284	0.053	0.031	0.084	0.231	0.230	0.154	0.301	0.084	0.133	0.132	0.155	0.180	0.130	1.881
Zn (mg/l)	0.114	0.040	0.020	0.053	0.105	0.098	0.061	0.124	0.051	0.073	0.071	0.077	0.087	0.066	1.220
Cu (mg/l)	0.028	0.005	0.005	0.007	0.020	0.017	0.009	0.035	0.005	0.008	0.008	0.010	0.011	0.010	0.662
Mn (mg/l)	0.088	0.028	0.015	0.036	0.080	0.073	0.052	0.087	0.033	0.050	0.043	0.056	0.061	0.047	0.877
NH_4N (mg/l)	0.491	0.312	0.281	0.341	0.488	0.472	0.422	0.514	0.320	0.392	0.389	0.451	0.460	0.372	0.851
Col. (Pt. Co)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 5: Statistical Description of Physiochemical Parameters in the Borehole Water Samples and their Comparison with Standards

						Standards		
Parameters	**Min.**	**Max.**	**Mean**	**Std. Deviation**	**Variance**	**WHO (GDWQ, 2011 and 2017)**	**NIS (NSDWQ, 2015)**	**FIS (Islam and Mostafa, 2023)**
pH	4.5	6.4	5.313	0.474893	0.226	6.5-8.5	6.5-8.5	6.5-7.5
Temp. (°C)	28.0	28.9	28.513	0.432380	0.186952	Ambient	Ambient	-
EC (µS/cm)	34	659	189.267	151.96544	23093.5	1500	1500	-
TDS (mg/l)	19.0	328.0	95.933	73.808117	5447.64	1000	500	500
DO (mg/l)	2.7	5.1	4.073	0.716606	0.513524	N/A	5	-
HCO_3^- (mg/l)	48.8	152.5	84.213	25.833585	667.374	500	500	200
Ca^{2+} (mg/l)	0.63	1.85	1.527	1.098652	1.207035	200	N/A	20
Mg^{2+} (mg/l)	0.41	3.33	0.961	0.739299	0.546564	50	20	10
K^+ (mg/l)	0.1	0.88	0.477	0.263212	0.069281	N/A	20	-
Na^+ (mg/l)	0.18	1.85	0.653	0.439991	0.193592	200	200	-
Cl^- (mg/l)	35.5	159.5	72.093	31.73719	1007.249	250	250	200
NO_2^- (mg/l)	0.011	0.881	0.0997	0.218172	0.0475	3	0.2	-
NO_3^- (mg/l)	0.14	2.921	0.8048	0.676671	0.457884	50	50	5
SO_4^{2-} (mg/l)	0.014	0.155	0.0531	0.038272	0.00146	N/A	N/A	50
Fe (mg/l)	0.031	1.881	0.271	0.452389	0.204656	0.3	0.3	-
Zn (mg/l)	0.02	1.22	0.1507	0.297159	0.0883	N/A	3	-
Cu (mg/l)	0.005	0.662	0.056	0.167876	0.0281	2	1	-
Mn (mg/l)	0.015	0.877	0.108	0.213713	0.04567	N/A	0.2	-
NH_4N (mg/l)	0.281	0.851	0.437	0.13534	0.018317	0.5	0.5	-
Col. (Pt.Co)	ND	ND	ND	ND	ND	0	0	0

ND=Not Detected; N/A= Not Applicable

Results from Tables 4 and 5 revealed that all parameters examined were below/within World Health Organization (WHO) and Nigerian Industrial Standard (NIS) acceptable limits for drinking water quality standards except for pH and temperature. Also, all parameters examined were below or within the food industry standard (FIS) except for pH. The mean pH value of 5.313 was below the acceptable 6.5–8.5 limits of WHO (2011 and 2017), NIS (2015), and food industry standards (adapted from Islam and Mostafa, 2023) and indicates that the groundwater (borehole) samples are strongly acidic in nature. This may be attributed to an increase in waste generation owing to population growth and industries in the study area. These factors might lead to the indiscriminate disposal of acidic waste materials, which, through surface runoff and consequent infiltration into the aquifer, may have given rise to the strongly acidic nature of the water (Egbueri et al., 2021). The acidic nature of groundwater quality in Benin City has been noted by several researchers (Omoigberale et al., 2009; Orjiekwe et al., 2013; Achadu et al., 2018; Ogbeifun et al., 2019). Though pH has no direct effect on humans (WHO, 2011 and 2017), low pH increases the dissolution of heavy metals and minerals in water (Rawlings and Ikediashi, 2020; Egbueri et al., 2021), which results in contamination of drinking water and thus affects human health. Generally, at low pH, acidic waters have lots of H^+ ions to react with the electron at the cathode and, as such, increase corrosion (Hem, 1985; Islam and Mostafa, 2023). Subsequently, this may lead to different problems, such as the deterioration of the water distribution network as well as water-using equipment (Mirzabeygi et al., 2016; Mirzabeygi et al., 2017; Abbasnia et al., 2018; Mohammadiet al., 2018). The recorded temperature of all borehole water samples was high, and the mean value is 28.513 ^oC, which is well above the recommended limits (ambient) of WHO (2011 and 2017) and NIS (2015) for drinking water quality, and it indicates that the groundwater is warm. This high temperature value may be attributed to the geochemical processes (rock-water interactions) taking place in the aquifer basement (which is generating a thermal reaction in the subsurface) as the study area is underlain by sedimentary rock (Ikhile, 2016) and thus implies that the ground-water flow path is through a deep aquifer system in which geothermal heating has taken place (Betageri and Patil, 2020). High water temperatures enhance the growth of microorganisms and may increase problems related to taste, odor, color, and corrosion (WHO 2011 and 2017).

High mean values of EC (189.267µS/cm), TDS (95.933 mg/l), DO (4.073 mg/l), HCO_3^- (84.213 mg/l), and Cl^- (72.093 mg/l) were observed; however, these values were below the acceptable limits of WHO, NIS, and FIS. The high values of these parameters (EC, TDS, HCO_3^-, and Cl^-) might be attributed to the warm and acidic nature of the groundwater, which increases the aquifer minerals (from both natural and anthropogenic sources) solubility in the groundwater, while the high levels of DO might be owing to the indiscriminate disposal of organic waste (e.g., food waste) in the study area. The organic waste produced through surface runoff and consequent infiltration into the aquifer may have given rise to the high levels of DO in the borehole water samples. The high concentrations of these parameters (EC, TDS, DO, HCO_3^- and Cl^-) are known to influence the rate of corrosion (Hamzah et al., 2008; Kumar et al., 2015; Omeka et al., 2022; Islam and Mostafa, 2023). Additionally, high concentrations of these parameters in water decrease its palatability and may possibly cause gastro-intestinal irritation in humans, laxative effects, and high blood pressure (WHO, 2017; Srigirisetty et al., 2017; Lewin, 2023).

Table 6: LSI of the Borehole Water Samples

Borehole Water Samples	LSI
BH1	-4.05
BH2	-4.8
BH3	-5.29
BH4	-4.91
BH5	-4.47
BH6	-4.46
BH7	-4.85
BH8	-3.38
BH9	-4.82
BH10	-3.45
BH11	-4.1
BH12	-4.63
BH13	-4.59
BH14	-4.83
BH15	-4.49
Mean	-4.4

Results from Table 6 show that the LSI values of the borehole water samples varied from -5.29 to -3.38 with a mean value of -4.4, implying that there is no scaling potential in the waters and, as such, they will dissolve $CaCO_3$. Hence, this suggests that the groundwater has a higher corroding potential. This may be attributed to the acidic nature of the groundwater; the low pH of the groundwater may have increased the levels of EC and TDS (including HCO_3^- and Cl^-) as observed in the groundwater (see Tables 4 and 5) and thus resulted in the corrosive tendency of the groundwater. Studies (Hamzah et al., 2008; Abbasniaa et al., 2018; Islam and Mostafa, 2023) have shown the influence of these parameters on corrosion. Corrosive water can cause system failures in equipment and public health issues because of some harmful dissolved components (Rawlings and Ikediashi, 2020; Islam and Mostafa, 2023). Hence, the quality of the groundwater is unfit for industrial purposes and, as such, requires treatment before use.

4.0 CONCLUSION

In this study, the suitability of the groundwater in Oredo LGA, Benin City, was investigated for industrial use. The results of the physiochemical analysis revealed that all parameters examined were below or within the WHO and NIS acceptable limits for drinking water quality standards, except for pH and temperature. Also, all parameters examined were below or within the food industry standard (FIS) except for pH. These results implied that the groundwater is acidic in nature. Higher levels of EC, TDS, DO, HCO_3^- , and Cl^- were observed; however, these values were below the acceptable limits of WHO, NIS, and FIS. The results of the LSI indicated that the groundwater has a high corrosion tendency, which may have resulted from the acidic nature of the groundwater. This suggests that there is a strong tendency for corrosion to take place in industrial equipment. The durability of industrial equipment and the quality of finished products depend on the quality of the water supplied. Thus, corrosion is a major threat to plant operations, and as such, this has rendered the groundwater unsuitable for industrial purposes. Therefore, in order to sustain and improve the quality of groundwater, regular monitoring and treatment of the groundwater before industrial use is essential.

REFERENCES

Abbasnia, A., Yousefi, N., Mahvi, A. H., Nabizadeh, R., Radfard, M., Yousefi, M. and Alimohammadi, M. (2018): Evaluation of Groundwater Quality Using Water Quality Index and Its Suitability for Assessing Water for Drinking and Irrigation Purposes: Case Study of Sistan and Baluchistan Province (Iran). *Human and Ecological Risk Assessment: An International Journal,* 1-19.

Abbasniaa, A., Yousefia, N., Mahvia, A. H., Nabizadeha, R., Radfardc, M., Yousefia, M. and Alimohammadia, M. (2018). Evaluation of Groundwater Quality using Water Quality Index and Its Suitability for Assessing Water for Drinking and Irrigation Purposes: Case Study of Sistan and Baluchistan province (Iran). *Human and Ecological Risk Assessment: An International Journal,* 1-19.

Achadu, M. A., Uyigue, L. and Obahiagbon, K.O. (2018). Analysis of the Interactions of Dumpsite with Leachate and Groundwater in Benin City and Port Harcourt. *International Journal of Engineering and Modern Technology,* 4 (3): 40-51.

Adegbite, J.T., Aigbogun, C. O. and Kuforijimi, O. (2018). Physiochemical Analysis of the Quality of Groundwater in Egbeta, Ovia North East Local Government Area of Edo State, Nigeria. *Journal of Applied Geology and Geophysics,* 6(3): 9-32

Agatemor, C. and Okolo, P. O. (2007). University of Benin Water Supply System: Microbiological and Physico-Chemical Assessments. *Environmentalist,* 27:227–239.

Agossou, A. and Yang, Y. (2021). Comparative Study of Groundwater Vulnerability to Contamination Assessment Methods Applied to the Southern Coastal Sedimentary Basin of Benin. *Journal of Hydrology: Regional Studies,* 35: 1-20

Alley, E. R. and DAAEE, P.E. (2007). Water Quality Control Handbook, 2nd Edition, New York, Chicago, San Francisco, Lisbon, London, Madrid, Mexico City, Mikan, New Delhi, San Juan, Seoul, Singapore, Sydney, Toronto, Water Environment Federation (WEF) Press Alexandria, Viginia.

American Public Health, APHA (1985). Standard Methods for the Examination of Water and Waste water, 16th edition. *American Public Health Association (APHA),* Washington DC, USA.

American Public Health, APHA (1998). Standard Methods for the Examination of Water and Wastewater, 19th edition. *American Public Health Association (APHA),* Washington DC, USA.

American Public Health, APHA (2005). Standard Methods for the Examination of Water and Wastewater, 21th edition. *American Public Health Association (APHA),* Washington DC, USA.

Arthur, D. (Daniel), (2020). Langelier Saturation Index Calculation. Available online from: https://www.watertreatmentbasics.com/langelier-saturation--index/, Accessed 07/10/2023

Balogun, V. S. and Orimoogunje, O. O. I. (2015). An Assessment of Seasonal Variation of Air Pollution in Benin City, Southern Nigeria. *Atmospheric and Climate Sciences,* 5: 209-218

Chan, C. L., Zalifah, M. K. and Norrakiah, A. S. (2007). Microbiological and Physiochemical Quality of Drinking Water. *The Malaysian Journal of Analytical Sciences,* 11 (2): 414 – 420

Egbuer, J. C. (2020): Heavy Metals Pollution Source Identification and Probabilistic Health Risk Assessment of Shallow Groundwater in Onitsha, Nigeria. *Analytical Letters,* 1-20

Egbueri, J.C., Unigwe, C. O., Omeka, M. E. and Ayejoto, D. A. (2021): Urban Groundwater Quality Assessment Using Pollution Indicators and Multivariate Statistical Tools: A Case Study in Southeast Nigeria. *International Journal of Environmental Analytical Chemistry,* 1-28.

Energy Pulse, (2023). Langelier Saturation Index (LSI) and Its Importance in Water Chemistry. Available Online from: https://www.energypurse.com/langelier-saturation-index-lsi-its-importance-in-water-chemistry/, Accessed 02/03/2023

Foster, S. (1998) Groundwater: Assessing Vulnerability and Promoting Protection of a Threatened Resource. Stockholm Water Symposium

Google Earth, (2023). Explore Google Earth. Available online from: https://earth.google.com, Accessed 09/03/2023

Hamzah, Z., Abdul Ghani, H. and Alias, M. (2008). Water Quality Analysis and Its Relation to the Scaling and Corrosion Tendency in an Open Water-Cooling System. *Malaysian Journal of Analytical Sciences, 12 (2):* 380 – 383

Hasan, M., Shang, Y., Akhter, G. and Jin, W. (2017). Evaluation of Groundwater Suitability for Drinking and Irrigation Purposes in Toba Tek Singh District, Pakistan. *Irrigation and Drainage Systems Engineering,* 6 (1): 1-16**.**

Hem, J. D. (1985). Study and Interpretation of the Chemical Characteristics of Natural Water, 3rd Edition, *U.S. Geological Survey,* 604 South Pickett St. Alexandria, VA 22304.

Hermann, E. and Prunes, E. (2022). What is Groundwater and Why it is so Important. Available online from: https://www.worldwildlife.org/stories/what-is-groundwater-and-why-it-is-so-important, Accessed 21/04/2023

Ikhile, C. I. (2016). Geomorphology and Hydrology of the Benin Region, Edo State, Nigeria. *International Journal of Geosciences,* 7: 144-157

Islam, Md. S. and Mostafa, M. G. (2023). Suitability Assessment of Shallow Groundwater for Industrial Uses in Terms of Storability and Corrosivity. *Journal of Pollution and Effects on Community Health*, 1(1): 1-20

Kumar, S. K., Logeshkumaran A., Magesh N. S., Godson, P. S. and Chandrasekar, N. (2015). Hydro-geochemistry and application of water quality index (WQI) for groundwater quality assessment, Anna Nagar, part of Chennai City, Tamil Nadu, India. *Applied Water Science,* 5:335–343.

Lenntech, (2021). Langelier Saturation Index Calculator. Available online from: https://www.lenntech.com/calculators/langelier, Accesses 07/10/2021

Lewin, P. (2023). Chloride in Drinking Water: Health Effects and 3 Ways to Remove it. Home Water Research. Available online from: http://homewaterresearch.com/chloride-in-drinking-water/, Accessed 10/06/2023

Manpower, (2023). Oredo Local Government Area. Available online from: https://www.manpower.com.ng/places/lga/273/oredo, Accessed 04/03/2023

McFarland, M. L., Provin, T. L. and Boellstorff, D. E. (2020). Drinking Water Problems: Corrosion. Available online: https:// agrilifebookstore.org, Accessed 27/03/2020

Mirzabeygi, M., Naji, M., Yousefi, N., Shams, M., Biglari, H., & Mahvi, A. H. (2016). Evaluation of Corrosion and Scaling Tendency Indices in Water Distribution System: A Case Study of Torbat Heydariye, Iran. *Desalination and Water Treatment,* 57(54): 25918–25926.

Mirzabeygi, M., Yousefi, N., Abbasnia, A., Youzi, H., Alikhani, M., & Mahvi, A. H. (2017). Evaluation of Groundwater Quality and Assessment of Scaling Potential and Corrosiveness of Water Supply Networks, Iran. *Journal of Water Supply: Research and Technology - Aqua,* 66(6),: 416–425.

Mohammadi, A. A., NajafiSaleh, H., Mahvi, A. H., Alimohammadi, M., Nabizadeh, R. and Yousefi, M. (2018). Data on Corrosion and Scaling Potential of Drinking Water Resources Using Stability Indices in Jolfa, East Azerbaijan, Iran. *Data in Brief,* 16: 724– 731.

Nicole, M. B., Robin, W., Christian, M. and Mario, S. (2019). A Review of Treat to Groundwater Quality in the Anthropocene. *Science of the Total Environment,* 684: 36-154

NIS, Nigerian Industrial Standard (2015). Nigerian Standard for Drinking Water Quality (NSDWQ), NIS 554: 17–21

NPC (National Population Commission), (2006). Nigeria National Census

Ogbeifun, D. E., Archibong, U. D., Chiedu, I. E. and Ikpe, E. E. (2019). Assessment of the Water Quality of Boreholes in Selected Areas in Benin City, Edo State, Nigeria. *Chemical Science International Journal,* 28(2): 1-13

Ojiako, J. C., Igbokwe, E. C. and Oliha, A. (2018). Creation of Geospatial Database for Educational Facilities in Oredo Local Government Area of Edo State, Nigeria. *Journal of Research & Method in Education,* 8(2) Ver. IV (Mar. – Apr.):72-84

Omeka, M. E, Egbueri, J. C., Unigwe, C. O. (2022) Investigating the Hydrogeochemistry, Corrosivity and Scaling Tendencies of Groundwater in an Agrarian Area (Nigeria) Using Graphical, Indexical and Statistical Modelling. *Arabian Journal of Geosciences*, 15:1233-1256.

Omoigberale, M. O., Ogbeibu, A. E. and Olotu, N. O. (2009). Assessment of Groundwater Quality of Benin City, Edo State, Nigeria. *Tropical Freshwater Biology,* 18(2): 11-20.

Orjiekwe, C. L., Dumo, D. T. and Chinedu, N. B. (2013). Assessment of Water Quality of Ogbese River in Ovia North-East Local Government Area of Edo State, Nigeria. *International Journal of Biological and Chemical Sciences,* 7(6): 2581-2590.

Panaskar, D. B., Wagh, V. M., Muley, A. A., Mukate, S. V., Pawar, R. S. and Aamalawa, M. L. (2016). Evaluating Groundwater Suitability for the Domestic, Irrigation, and Industrial Purposes in Nanded Tehsil, Maharashtra, India, Using GIS and Statistics. *Arabian Journal of Geosciences,* 9 (615)

Peterson N., Kennedy, M. (1997). Water Quality Trends and Geological Mass Balance. *John Whiley and Sons,* pp: 139-179

Rawlings, A. and Ikediashi, A. I. (2020). Impact of Urbanizing Ovia-North East on the Quality of Groundwater using Water Quality Index. *Nigerian Journal of Environmental Sciences and Technology (NIJEST),* 4 (1): 87 – 96.

Sajil-Kumar, P. J. (2019). Assessment of Corrosion and Scaling Potential of the Groundwater in the Thanjavur District Using Hydrogeochemical Analysis and Spatial Modeling Techniques. *SN Applied Sciences,* 1:395

Srigirisetty, S., Jayasri, T. and Netaji, C. (2017). Open Dumping of Municipal Solid Waste-Impact on Groundwater and Soil. *International Journal of Current Engineering and Scientific Research,* 4(6):26-33.

UGA (University of Georgia) Extension, (2020). Corrosive or Scaling Water. Available Online from: extension.uga.edu/publications/detail.html?number=C858-9, Accessed 02/03/2023

Valdez, B., Schorr, M., Zlatev, R., Carrillo, M., Stoytcheva, M., Alvarez, L., Eliezer, A. and Rosas, N. (2012). Corrosion Control in Industry. Environmental and Industrial Corrosion: Practical and Theoretical Aspect, Benjamin Valdez and Michael Schorr Edition, *IntechOpen,* London.

WHO, (2017). Guidelines for Drinking Water Quality, 4th Edition, Incorporating the First Addendum, 307-442

WHO, World Health Organisation (2011). Guidelines for Drinking Water Quality, 4th Edition, 7853-7859