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RESEARCH ARTICLE

Assessment of Water Quality Index and Irrigation Indices in Ese Odo Area of Ondo State, Southwestern Nigerian

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ABSTRACT

An assessment of the ground water quality was carried out in Ese Odo local government area of Ondo State, southwestern Nigeria. The study was aimed at examining the various samples of ground water and the quality of the ground water as it relates to drinking and irrigation purposes. Forty-Five ground water samples were taken from boreholes and open wells and analyzed for physical, chemical and biological properties. The results were compared with World Health Organization standards. The usefulness of these parameters in predicting ground water quality characteristics were studied and water quality index was determined from these parameters. In assessing the water for irrigation uses, indices such as percent (%Na), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), permeability index (PI), Kelly's ratio (KR), magnesium ratio (MR), equivalent salinity concentration (ESC) and Wilcox plot were used. The result obtained shows that the water studied has a mean value of 2.8 NTU for turbidity, 7.3 for pH, 294 µS/cm for electrical conductivity, 52mg/L for total dissolved solids, temperature 28.3°C, total hardness 41 mg/L, chloride 38.3 mg/L, calcium 15.8 mg/L, 5.64 mg/L for magnesium, nitrate 1.47mg/L, sulphate 51.7 mg/L, bicarbonate 15mg/L. Zinc, iron, manganese have mean values less than 1mg/L. The results indicated all the physicochemical parameters are within the recommended levels set by World Health Organization (WHO). Although traces of heavy metal and mineral oil contaminations are observed some of the samples. All the samples are plotted on the "Excellent irrigation class" of Wilcox plot with good/excellent irrigation indices. Consequently, the groundwater in the study area is good and suitable for drinking and irrigation purposes.

Keywords: Wilcox plot, Ese Odo, physicochemical parameter, irrigation indices, water quality index

1 Introduction

Groundwater is one the major sources of fresh water and it accounts for about 98% of the world's fresh water [1, 2]. Groundwater is exploited through shallow wells, hand pumped wells, and boreholes. The variability of groundwater quality parameters is linked to various processes such as weathering, organic matter degradation, aerobic respiration, iron reduction, mineral dissolution and precipitation, cation exchange and mixing of salt water with fresh water [3]. Shallow aquifers worldwide are highly susceptible to contamination in areas with intensive agriculture and the discharge from shallow aquifers can add significant amounts of contamination to surface water [4, 5]. Shallow groundwater is used by many rural families, and is therefore a valuable resource that requires protection. However, the quality required of ground water supply depends on its purpose or intended use [6 - 9]. Groundwater contamination is a major problem especially in the developing countries due to incessant anthropogenic pollution. Disposal of sewage effluent is a major threat to water resources in many urban centres

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[10, 11]. The rapid development and expansion of urban areas, concentrating people and their wastes and the development of industries is reported to have led to the deterioration of water quality and the degradation of urban environments in Africa [11 -13]. Groundwater has generally been regarded as the safest water source especially in rural communities. Ese Odo and environs have witnessed an upsurge in infrastructural development and increase in human population especially in Akotogbo, Igbotu, Igbekebo, and Shabomi. Hence, the demand for quality potable water for human consumption and agriculture is increasing daily. However, with the increase in socio-economic activities which include agriculture, mining among other activities, it is not evident that groundwater is the safest option for drinking and irrigation [14-16]. The natural filtration and purification processes which take place underground help to purify groundwater [17-19]. However, these processes can become ineffective owing to sewage, fertilizers, and toxic chemicals, which may seep into the groundwater supply [20-24]. Consequently, groundwater testing and monitoring in both protected and unprotected water sources has become an important component in water and sanitation programmes [25, 26]. Such investigation/testing should involve physical, chemical and biological analysis. One of the key elements in water resource management is the management of groundwater which deals with the operation and maintenance of water supply systems and the quality of water supply in a sustainable manner. Sustainable management is important because once aquifers become contaminated, remediation is extremely difficult and expensive, and therefore prevention is key in maintaining good ground water quality [28, 29]. Therefore, groundwater exploitation should be viewed as part of water resources management [6, 27].

Coliform bacteria are commonly found in soil, on vegetation, and in surface water. Coliform bacteria will not likely cause illness but since coliform bacteria are most commonly associated with sewage or surface waters, their presence in drinking water indicates that other disease-causing organisms (pathogens) may be present in the water system [13]. Water containing faecal material may seep into the groundwater from the land surface or from underground sources of contamination. Major surface sources in rural communities include seepage from contaminated lakes and other surface-water bodies and faeces from cattle and other livestock operations [30]. Faecal contamination can also reach the groundwater from underground sources and on-site sanitation systems such as pit latrines. Overflow and leakages from a pit latrine can percolate (seep) down to the water table and maybe into a homeowner's own well [31]. Coliform bacteria can persist within slime formed by naturally occurring ground water microorganisms [1]. The slime (or biofilm) clings to the well screen, casing, drop pipe, and pump and can also harbour bacteria in a protected well. Disturbances during pumping or well maintenance can cause the slime to dislodge, releasing the coliform bacteria [1]. This study therefore seeks to assess variations in groundwater quality in Ese Odo local government area of Ondo State, southwestern Nigeria for domestic and irrigation uses. Irrigation water evaluation is placed on the chemical and physical characteristics [32-36]. In agriculture, if there's good quality water, it will give sustainable yield. Therefore, the analysis of the parameters of the water sample is important, since its quality would determine the usability for the growing crops or other reasonable uses. In this study, the groundwater quality index (GWQI) map of Ese Odo area was developed, with samples derived from open well, stream water and borehole using drinking and irrigation water quality standard of World Health Organization. By mapping, the areas of high and low water quality index were established, which can easily be distinguished by researchers as well as policymakers or the general public. Also, areas of potential good/poor irrigation water were also delineated. Many researchers have demonstrated the usefulness of water quality index and irrigation indices in groundwater assessment for drinking and irrigation uses [22-24], [33-36]. The information these methods have provided have yielded sufficient results that benefited and helped the governments (as well as borehole developers) in groundwater planning programme, exploitation and development.

2 Research Methodology

2.1 Study Area

Ese Odo local government area is located in the southwestern part of Nigeria and falls within the Dahomey Basin (Figure 1) between 705000 and 735000mE and 695000 and 735000mN. The Dahomey Basin is a combination of inland/coastal/offshore basin that stretches from southeastern Ghana through Togo and the Republic of Benin to southwestern Nigeria. The study is made of two stratigraphic units; the Benin formation in the north and coastal alluvium sand in the south. The Benin Formation is the youngest stratigraphic sequence in the eastern Dahomey basin. It is also known as the coastal plain sands [30] and consists of poorly sorted sands with lenses of clays. The sands are in parts cross bedded and show transitional to continental characteristics. The age is from Oligocene to recent. The Dahomey Basin is separated from the Niger Delta by a subsurface basement high referred to as Okitipupa Ridge. Its offshore extent is poorly defined. Sediment deposition follows an east-west trend. The sediments of the coastal plain, deposited during the Late Tertiary-Early Quaternary period [37], consist of unconsolidated, coarse to medium fine-grained sands and clayey shale in places [38]. The sands are generally moderately sorted and poorly cemented. The Benin Formation is overlain by lateritic overburden or recent alluvial deposits and underlain by Paleocene Akinbo Formation. This formation is predominantly shally. The Akinbo shale is underlain by the continental Cretaceous sediments of the Abeokuta Group [30]. The coastal plain sands constitute the major shallow hydrogeologic units in the area. Aquifers are characteristically continental sands, gravels, or marine sands. The lateritic earth overlying the sands as well as the underlying impervious clay/shale member of the Akinbo Formation, constitute protective configuration for the aquifer units. The northern part of the study area is devoted to agricultural activities (crop production) while southern part engages in fish farming. The people of the area depend on government boreholes due to deep aquifer system associated with the area.

The area is within the tropical rain forest region of Nigeria characterized by wet and dry seasonal variations, with a mean annual rainfall of 180 cm, mean temperature of 24°C, and mean humidity of 80% [39]. The study area is generally characterized by flat and gently undulating topography. Topographic elevations vary from about 2 to 42 m above sea level. The area is drained by many perennial streams and rivers such as Ominla, Akeun, Ufara, Okomu, Ofara and others, which form a network of dendritic drainage pattern and empty their waters into the Atlantic Ocean to the south. These rivers and streams are being fed by several lagoons, ponds, canals, creeks and small streams scattered across the study area. The area is characterized by heavy annual rainfall averaging about 2,500 mm. Rainfall is distributed virtually over all the months of the year with the minima occurring between November and March [39]. Plant type is generally mangrove in the costal part of the study area, typical of swamp forest, while the mainland area is characterized by oil palm, rubber plantation and other broadleaved species, typical of rainforest vegetation.

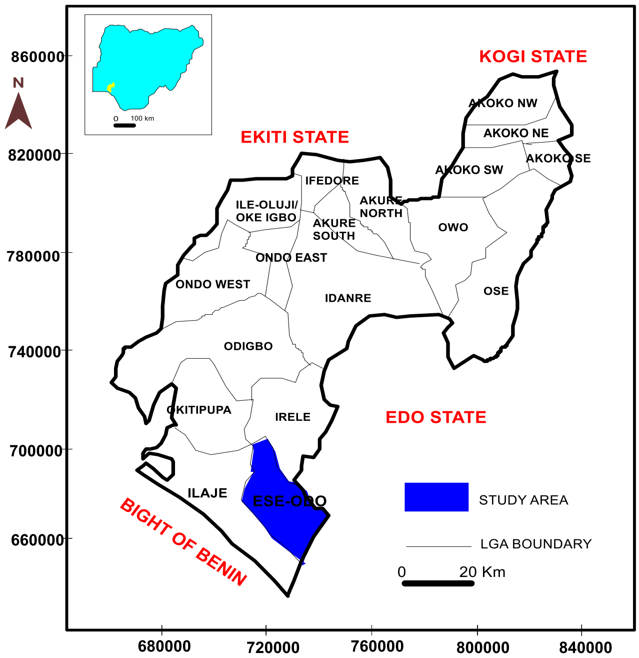

Figure 1: *Location map of the study area*

2.2 Sampling and Laboratory Analysis

To evaluate the suitability of groundwater for domestic and irrigation agriculture, a total of forty-five water samples were collected from various sites. Samples were collected from boreholes (BH), open well (OW) and streams (ST) (Figure 2).

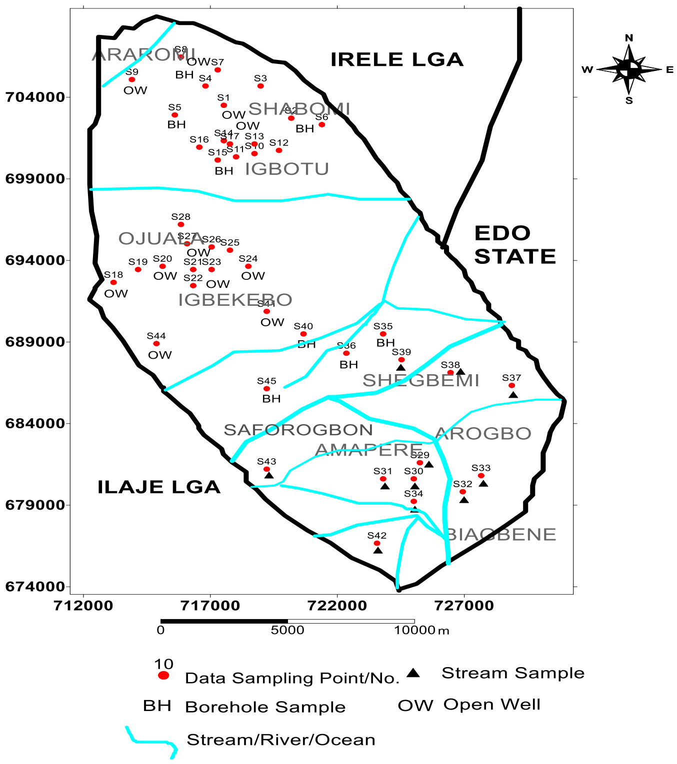

Figure 2: *Data Acquisition map for the study*

Each sample was a composite of two sub-samples to minimize error and heterogeneity. Before sampling a high density, PVC bottles were used and thoroughly cleaned by rinsing with HNO_3. Before we started for sampling from a well sufficient amount of water should be pumped out. For the identification the bottles were kept air tight and labelled properly. The samples were analyzed for physical, chemical and bacteriological parameters. The instruments used were operated as per the instruments' manual. The water samples were analyzed for other heavy ions using standard methods [40-42]. The samples were stored in a sterilized 250ml bottle and transferred to the laboratory for analyses. The conductivity, total suspended solids and total dissolved solids were determined using a conductivity/TDS meter. The pH was determined using a pH meter. The turbidity was determined using a spectrophotometer. The determination of Na^+ and K^+ were done by flame photometry; Ca^{2+}, Mg^{2+}, Fe by visible spectrophotometry; $C1^-$ and HCO_3 by titration method. By using the values obtained for, Ca^{2+}, Mg^{2+} in meq/l the sodium adsorption ratio (SAR) was estimated; by the equation using the values obtained for Na^+, K^+, Ca^{2+}, Mg^{2+}, CO_3^{2-}, HCO_3, in meq/l the soluble sodium percentage, sodium adsorption ratio (SAR), residual sodium carbonate, magnesium ration, Kelly's ratio were determined in accordance to [43-44]. The calculation of water quality was determined using the approaches of [26]-[45-46].

3 Results and Discussion

The results of the physicochemical, heavy metals/toxic contaminant bacteriological parameters are presented in Tables 1-4. In their physical states, the water samples are colourless, odourless, tasteless, and clear, with temperature ranging from 25.7 to 30.8°C and average of 28.3°C. The mean value obtained marginally deviate from the recommended value of 27°C [47]. Turbidity is the amount of cloudiness in the water. This can vary from a river full of mud and silt where it would be impossible to see through the water (high turbidity), to a spring water which appears to be completely clear (low turbidity). Turbidity can be caused by silt, sand and mud, bacteria and other germs, and chemical precipitates. It is very important to measure the turbidity of domestic water supplies, as these supplies often undergo some type of water treatment which can be affected by turbidity [47]. Turbidity in the study area varies from 0.1 – 7.1 with a mean of 2.8, which is generally less than 5NTU [48-50]. The pH of the water samples ranges from 6.5 and 8.3. The pH values are not within the acceptable WHO range for portable water of 6.5 - 8.5 [51] and is generally uniform in the study area (Figure 3). The concentration of Chloride varies from 7.2 – 87mg/l with a mean of 38.3mg/l. This range of values is within the recommended standard of 250mg/l. However, relatively high concentration characterized southern part of Igbekebo, and Shabomi (Figure 3).

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Table 1: *Results of the Physical Parameters*

Location	Easting	Northing	Well No.	Temp (°C)	EC (μS/cm)	Turbidity NTU	Colour	Odour	Taste	Appearance
SHABOMI	716964	705876	1 OW.	30.8	113	3.9	Colourless	Odourless	Tasteless	Clear
	720318	704925	2 OW.	28.4	225	4.3	Colourless	Odourless	Tasteless	Clear
	718794	707303	3 OW.	30.4	228	3.2	Colourless	Odourless	Tasteless	Clear
	716049	707303	4 BH.	27.6	158	2.5	Colourless	Odourless	Tasteless	Clear
	714524	705163	5 BH.	28.1	189	2.9	Colourless	Odourless	Tasteless	Clear
	721843	704449	6 BH.	29.3	326	3.4	Colourless	Odourless	Tasteless	Clear
	716659	708492	7 OW.	29.4	221	1.5	Colourless	Odourless	Tasteless	Clear
ARAROMI	714829	709444	8 OW.	28.5	153	0.9	Colourless	Odourless	Tasteless	Clear
	712390	707779	9 OW.	29.6	145	1.2	Colourless	Odourless	Tasteless	Clear
IGBOTU	718489	702309	10 OW.	29.2	286	3.2	Colourless	Odourless	Tasteless	Clear
	717574	702071	11 OW.	29.2	358	1.2	Colourless	Odourless	Tasteless	Clear
	719708	702546	12 OW.	30.5	236	3.3	Colourless	Odourless	Tasteless	Clear
	718489	703022	13 OW.	29.6	225	4.6	Colourless	Odourless	Tasteless	Clear
	716964	703260	14 OW.	30.1	202	3.2	Colourless	Odourless	Tasteless	Clear
	716659	701833	15 BH.	29.6	136	1.1	Colourless	Odourless	Tasteless	Clear
	715744	702784	16 OW.	29.8	125	0.8	Colourless	Odourless	Tasteless	Clear
	717269	703022	17 OW.	27.4	150	0.3	Colourless	Odourless	Tasteless	Clear
	711475	692795	18 OW.	28.2	258	1.4	Colourless	Odourless	Tasteless	Clear
IGBEKEBO	712695	693746	19 OW.	27.0	492	4.4	Colourless	Odourless	Tasteless	Clear
	713914	693984	20 OW.	28.2	190	2.2	Colourless	Odourless	Tasteless	Clear
	715439	693746	21 OW.	27.4	320	2.5	Colourless	Odourless	Tasteless	Clear
	715439	692557	22 OW.	29.5	258	3.2	Colourless	Odourless	Tasteless	Clear
OJUALA	716354	693746	23 OW.	27.5	390	3.3	Colourless	Odourless	Tasteless	Clear
	718184	693984	24 OW.	28.2	149	1.9	Colourless	Odourless	Tasteless	Clear
	717269	695173	25 OW.	26.8	335	4.8	Colourless	Odourless	Tasteless	Clear
	716354	695411	26 OW.	27.5	174	2.2	Colourless	Odourless	Tasteless	Clear
	715134	695649	27 OW.	26.4	205	0.5	Colourless	Odourless	Tasteless	Clear
	714829	697076	28 ST.	28.5	160	0.1	Colourless	Odourless	Tasteless	Clear
AKOTOGBO	726722	679476	29 ST.	27.8	185	0.5	Colourless	Odourless	Tasteless	Clear
	726417	678287	30 ST.	28.4	160	0.9	Colourless	Odourless	Tasteless	Clear
	724892	678287	31 ST.	25.7	152	1.7	Colourless	Odourless	Tasteless	Clear
	728857	677336	32 ST.	27.5	221	1.9	Colourless	Odourless	Tasteless	Clear
	729771	678525	33 ST.	27.6	520	3.2	Colourless	Odourless	Tasteless	Clear
	726417	676622	34 BH.	28.1	255	5.1	Colourless	Odourless	Tasteless	Clear
AMAPERE	724892	688990	35 BH.	26.8	449	1.1	Colourless	Odourless	Tasteless	Clear
	723063	687563	36 BH.	26.5	412	4.1	Colourless	Odourless	Tasteless	Clear
	731296	685184	37 ST.	27.7	325	3.3	Colourless	Odourless	Tasteless	Clear
BIAGBENE	728247	686136	38 ST.	28.3	501	3.9	Colourless	Odourless	Tasteless	Clear
GBELEJU	725807	687087	39 ST.	27.9	625	5.8	Colourless	Odourless	Tasteless	Clear
SHAGBEMI	720928	688990	40 BH.	29.8	523	7.1	Colourless	Odourless	Tasteless	Clear
	719098	690655	41 ST.	27.2	650	4.2	Colourless	Odourless	Tasteless	Clear
	724587	673530	42 ST.	27.6	320	6.2	Colourless	Odourless	Tasteless	Clear
	719098	679000	43 ST.	27.5	520	1.2	Colourless	Odourless	Tasteless	Clear
	713610	688276	44 ST.	27.3	487	3.6	Colourless	Odourless	Tasteless	Clear
	719098	684946	45 ST.	27.1	520	4.4	Colourless	Odourless	Tasteless	Clear
Min				25.7	113	0.1				
Max				30.8	650	7.1				
Average				28.3	294	2.8				

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Table 2: *Result of the Chemical Parameters*

Well No.	pH	Cl^-	Hardness	SO_4^{2-}	NO_3^-	Mn	TDS	HCO_3^-	Mg^{2+}	Ca^{2+}	Zn^{2+}	Fe^{2+}	Na^+	K^+
1	7.2	43.5	69	65.5	1.8	0.010	130.2	15	1.98	43.4	0.07	0.23	7.25	0.4
2	7.5	55.7	40	62.2	0.85	0.013	145.2	15	1.87	42.2	0.09	0.27	9.32	9.6
3	7.3	48.2	12	69.3	0.23	0.008	120.3	12	1.90	15.1	0.07	0.25	11.8	7.4
4	7.4	56.4	38	33.4	0.75	0.015	134.1	9	1.25	29.9	0.01	0.22	13.3	3.5
5	6.9	39.1	28	42.1	0.98	0.022	42.2	7	1.56	22.6	ND	0.22	16.9	1.9
6	6.8	58.2	44	48.3	1.52	ND	65.3	12	1.04	5.5	0.01	0.29	9.4	4.5
7	7.2	55.2	56	18.2	1.45	ND	45.1	25	6.99	8.6	0.01	0.21	1.2	2.2
8	7.4	9.5	37	19.5	1.24	0.01	10.1	22	6.52	6.8	0.04	0.22	4.5	13.1
9	6.8	12.1	84	44.3	1.86	0.015	8.5	11	4.20	12.4	0.01	0.18	6.3	9.4
10	6.9	24.3	62	42.3	1.12	0.03	23.3	10	4.35	19.2	0.01	0.19	7.7	3.5
11	7.3	9.9	44	51.3	0.36	0.021	5.5	11	5.69	44.5	0.02	0.21	3.2	6.9
12	7.7	85.1	12	55.3	0.58	0.024	5.6	8	1.12	48.6	0.07	0.20	13.5	8.1
13	7.7	44.5	35	69.2	0.69	0.018	7.4	12	1.25	7.2	ND	0.27	6.4	19.3
14	7.5	9.8	19	70.4	0.21	0.015	6.9	7	22.2	6.5	0.09	0.24	9.9	10.5
15	7.7	15.2	28	44.5	0.22	0.007	6.8	16	13.4	22.1	0.09	0.29	9.7	0.3
16	7.2	48	22	22.3	0.45	0.002	6.8	22	1.23	25.5	0.01	0.22	7.4	9.4
17	7.4	14.8	26	29.2	0.87	0.012	44.2	29	1.52	6.6	0.05	0.23	5.1	4.4
18	7.9	10.2	19	39.3	0.98	0.018	19.5	20	2.36	4.2	0.05	0.15	7.8	12.8
19	7.5	87	43	87.2	0.15	0.012	22.2	20	4.69	4.1	0.08	0.21	12.1	0.9
20	7.7	8.8	98	44.5	0.62	0.003	11.2	14	4.25	5.3	ND	0.17	7.2	0.8
21	7.1	12.9	94	88.1	0.36	0.002	8.5	14	1.58	4.2	ND	0.11	5.3	0.3
22	6.8	10.4	44	76.4	5.36	0.003	6.9	22	1.18	5.3	ND	0.21	5.1	0.5
23	6.6	7.2	52	55.2	4.12	0.003	7.6	28	6.32	8.4	ND	0.29	4.5	1.2
24	7.2	26.5	58	62.1	4.14	0.002	30.5	15	2.33	8.8	0.01	0.25	9.9	1.3
25	7.8	25.5	56	60.5	5.36	0.001	35.2	13	2.54	20.2	0.01	0.19	3.8	6.2
26	7	9.9	54	72.2	0.25	0.001	40.9	19	9.25	41.6	0.02	0.14	4.2	2.3
27	7.2	11.5	40	75.8	0.14	0.014	23.5	22	1.98	5.6	0.09	0.22	8.8	13.7
28	7.5	11.3	12	65.8	1.82	0.011	33.3	26	1.12	6.5	0.07	0.28	6.3	15.9
29	7.8	44.8	19	65.2	1.58	0.024	125.5	28	9.28	4.8	0.09	0.22	3.5	1.1
30	7.1	44.9	25	66.6	0.69	0.021	122.2	6	8.87	8.8	0.01	0.19	14.1	12.4
31	7.9	16.8	32	60.8	4.55	0.002	112.5	8	7.25	6.3	0.05	0.20	18.9	9.9
32	8.1	15.4	15	56.5	3.32	0.002	119.5	10	5.23	12.5	0.05	0.14	15.5	10.7
33	8.3	19.5	47	54.2	1.9	0.001	132.6	15	5.24	13.5	0.02	0.11	19.5	11.4
34	7.8	44.4	52	66.3	1.62	ND	98.9	19	1.25	17.4	0.01	0.22	11.2	6.3
35	7.4	65.2	65	24.5	1.87	ND	52.3	22	22.3	11.1	0.03	0.29	14.3	3.2
36	6.9	60.2	88	28.3	2.25	0.002	6.5	19	44.5	5.1	0.09	0.30	10.9	3.4
37	7.1	51.2	45	25.8	2.24	0.003	25.5	28	2.25	6.6	0.09	0.35	15.1	2.5
38	7.5	50.1	20	39.2	1.39	0.002	10.5	11	1.25	8.9	ND	0.11	7.8	5.3
39	7.8	85	21	18.9	1.2	ND	12.8	14	3.28	9.1	0.07	0.21	9.4	6.5
40	6.6	65	11	18.5	0.25	0.001	23.6	6	8.25	12.5	ND	0.29	4.2	9.4
41	6.5	87	12	44.2	0.98	0.015	145.5	8	8.14	13.3	0.01	0.27	2.5	4.5
42	7.3	48	33	40.3	0.82	0.022	126.6	14	4.48	17.5	0.01	0.24	3.1	5.6
43	7.8	65.2	40	69.5	0.33	0.021	12.3	9	2.36	7.2	ND	0.23	36.2	2.5
44	6.7	32.1	35	69.9	1.2	ND	25.8	6	3.22	36.6	ND	0.23	18.1	9.8
45	6.6	80.4	69	65.2	1.54	0.009	148.8	25	1.12	36.8	0.02	0.28	17.8	5.8
Min.	6.5	7.2	11	18.2	0.14	0.001	5.5	6	1.04	4.1	0.01	0.11	6.5	7.2
Max.	8.3	87	98	88.1	5.36	0.03	148.8	29	44.5	48.6	0.09	0.35	8.3	87
Mean	7.3	38.3	41	51.7	1.47	0.011	52.1	15	5.64	15.8	0.04	0.22	7.3	38.3

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Table 3: *Concentrations of the analyzed toxic chemicals and contaminants in the water samples*

	Toxic Chemicals							Contaminants				
Well No.	Lead	Cyanide	Cadmium	Arsenic	Barium	Mercury	Pesticide	Mineral oil	Ammonia	Phenol	Detergent	Radionuclides (Bq/L)
1	0.0000	0.0000	0.0000	0.0011	0.0000	0.0000	0.0000	0.0000	0.0011	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0011	0.0000	0.0000	0.0000	0.0000	0.0015	0.0000	0.0000	0.0000
3	0.0000	0.0000	0.0000	0.0011	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	0.0041	0.0011	0.0000	0.0012	0.0000	0.0000	0.0000	0.0002	0.0001	0.0000	0.0000	0.0000
5	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
6	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
7	0.0022	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000
8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
10	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	0.0011	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0014	0.0000	0.0000	0.0000
13	0.0021	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0014	0.0000	0.0000	0.0000
14	0.0001	0.0000	0.0000	0.0011	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000
15	0.0002	0.0000	0.0000	0.0011	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000
16	0.0002	0.0001	0.0000	0.0011	0.0000	0.0000	0.0000	0.0000	0.0013	0.0000	0.0000	0.0000
17	0.0030	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	0.0004	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	0.0014	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
20	0.0014	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
21	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
22	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
23	0.0004	0.0020	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
24	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
26	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
27	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
28	0.0004	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
29	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
30	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
31	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
32	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
33	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
34	0.0000	0.0000	0.0000	0.0015	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
35	0.0001	0.0000	0.0000	0.0011	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
36	0.0000	0.0000	0.0000	0.0013	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
37	0.0000	0.0000	0.0000	0.0009	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
38	0.0000	0.0000	0.0000	0.0008	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
39	0.0000	0.0000	0.0000	0.0015	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
40	0.0012	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
41	0.0000	0.0000	0.0000	0.0011	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
42	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
43	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
44	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
45	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

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Table 4: *Summary of the Microbiological analysis*

Well No.	*Clostridium perfringenes*	*Chromobacterium violaceum*	E. *Coli*	*Faecal streptococci*	*Klebsiella acrogenes*	S. *aeurus*	Yeast/Mould
1	NIL	NIL	NIL	NIL	NIL	NIL	NIL
2	NIL	NIL	NIL	NIL	NIL	NIL	NIL
3	NIL	NIL	NIL	NIL	NIL	NIL	NIL
4	NIL	NIL	NIL	NIL	NIL	NIL	NIL
5	NIL	NIL	NIL	NIL	NIL	NIL	NIL
6	NIL	NIL	NIL	NIL	NIL	NIL	NIL
7	NIL	NIL	NIL	NIL	NIL	NIL	NIL
8	NIL	NIL	NIL	NIL	NIL	NIL	NIL
9	NIL	NIL	NIL	NIL	NIL	NIL	NIL
10	NIL	NIL	NIL	NIL	NIL	NIL	NIL
11	NIL	NIL	NIL	NIL	NIL	NIL	NIL
12	NIL	NIL	NIL	NIL	NIL	NIL	NIL
13	NIL	NIL	NIL	NIL	NIL	NIL	NIL
14	NIL	NIL	NIL	NIL	NIL	NIL	NIL
15	NIL	NIL	NIL	NIL	NIL	NIL	NIL
16	NIL	NIL	NIL	NIL	NIL	NIL	NIL
17	NIL	NIL	NIL	NIL	NIL	NIL	NIL
18	NIL	NIL	NIL	NIL	NIL	NIL	NIL
19	NIL	NIL	NIL	NIL	NIL	NIL	NIL
20	NIL	NIL	NIL	NIL	NIL	NIL	NIL
21	NIL	NIL	NIL	NIL	NIL	NIL	NIL
22	NIL	NIL	NIL	NIL	NIL	NIL	NIL
23	NIL	NIL	NIL	NIL	NIL	NIL	NIL
24	NIL	NIL	NIL	NIL	NIL	NIL	NIL
25	NIL	NIL	NIL	NIL	NIL	NIL	NIL
26	NIL	NIL	NIL	NIL	NIL	NIL	NIL
27	NIL	NIL	NIL	NIL	NIL	NIL	NIL
28	NIL	NIL	NIL	NIL	NIL	NIL	NIL
29	NIL	NIL	NIL	NIL	NIL	NIL	NIL
30	NIL	NIL	NIL	NIL	NIL	NIL	NIL
31	NIL	NIL	NIL	NIL	NIL	NIL	NIL
32	NIL	NIL	NIL	NIL	NIL	NIL	NIL
33	NIL	NIL	NIL	NIL	NIL	NIL	NIL
34	NIL	NIL	NIL	NIL	NIL	NIL	NIL
35	NIL	NIL	NIL	NIL	NIL	NIL	NIL
36	NIL	NIL	NIL	NIL	NIL	NIL	NIL
37	NIL	NIL	NIL	NIL	NIL	NIL	NIL
38	NIL	NIL	NIL	NIL	NIL	NIL	NIL
39	NIL	NIL	NIL	NIL	NIL	NIL	NIL
40	NIL	NIL	NIL	NIL	NIL	NIL	NIL
41	NIL	NIL	NIL	NIL	NIL	NIL	NIL
42	NIL	NIL	NIL	NIL	NIL	NIL	NIL
43	NIL	NIL	NIL	NIL	NIL	NIL	NIL
44	NIL	NIL	NIL	NIL	NIL	NIL	NIL
45	NIL	NIL	NIL	NIL	NIL	NIL	NIL

The total dissolved solids (TDS) provides a rough indication of the overall suitability of water for whatever purpose. The WHO standard for TDS in drinking water is 250mg/l. The total dissolved solids of groundwater ranges from 5.5 and 148.8mg/l and average (av.) of 52.1mg/l. Low values accounts for 80% of the study area (Figure 4).

Although relatively high values are observed in Igbekebo, Saforogbon and south of Arogbo. Total hardness is between 11 and 98mg/l (av. 41mg/l) and relatively higher in the eastern part (Figure 5). The map of the spatial variation of electrical conductivity is shown in Figure 5. Electrical conductivity of water is used as an indicator of how salt-free, ion-free, or impurity-free the sample is; the purer the water the lower the conductivity (the higher the resistivity). The World Health Organization standard for acceptable electrical conductivity is 100µs/cm. Pure water has an electrical conductivity of 5.5µs/cm, which is a measure of the total dissolved solid (TDS), while rain water and ocean water have 5000 to 30000µs/cm and 45,000 to 60,000µs/cm respectively [50]. Normal groundwater has a range of 100 to 2000µs/cm [48]. The values electrical conductivity in all areas (113 - 650 µs/cm) within the study area fall within the WHO standard for electrical conductivity (1000 µs/cm).

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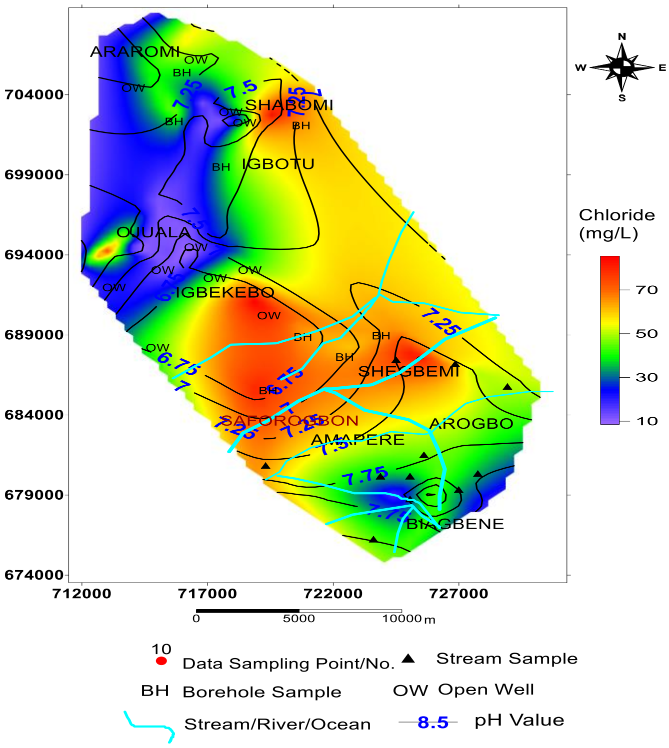

Figure 3: *Spatial Distribution of Chloride and pH*

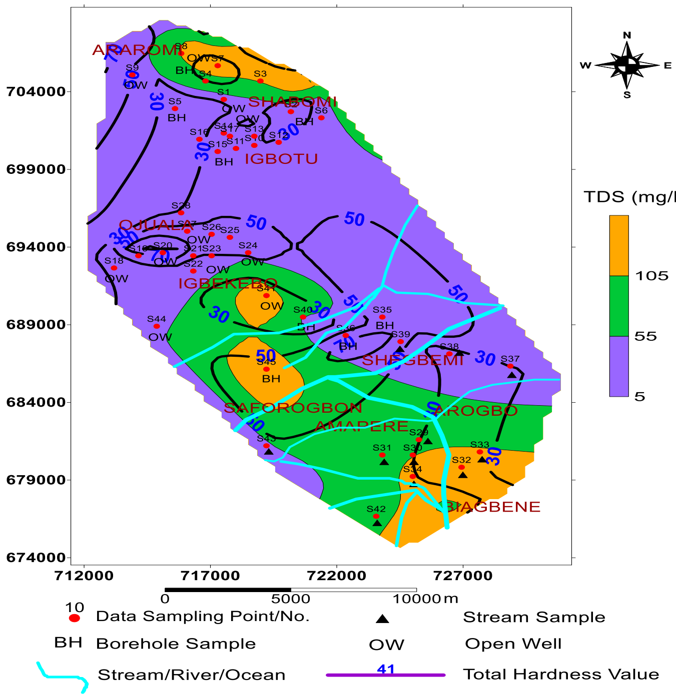

Figure 4: *Spatial Distribution of TDS and Total Hardness*

The recorded bicarbonate concentration ranges from 6 – 29mg/l (av. 15mg/l), with the south and north having relatively low and high concentrations respectively. The measured nitrate concentration varies from 0.14 to 5.36mg/l (av. 1.47mg/l) and satisfies the WHO standard of highest desirable limit of 10mg/l. In parts of Ojuala and Igbekebo (Figure 6), nitrate is relatively higher (greater than 4.5mg/l). This could be as a result of anthropogenic activities in the area. Nitrate is an essential ingredient of plant nutrition. It is, however regarded as an indicator of pollution in public water supply [42]. Figure 6 shows the map of the spatial variation of sulphate concentration in the study area. Sulphate occurs mostly as Calcium Sulphate (Gypsum). Sodium and Magnesium Sulphate are readily soluble in water than Calcium Sulphate.

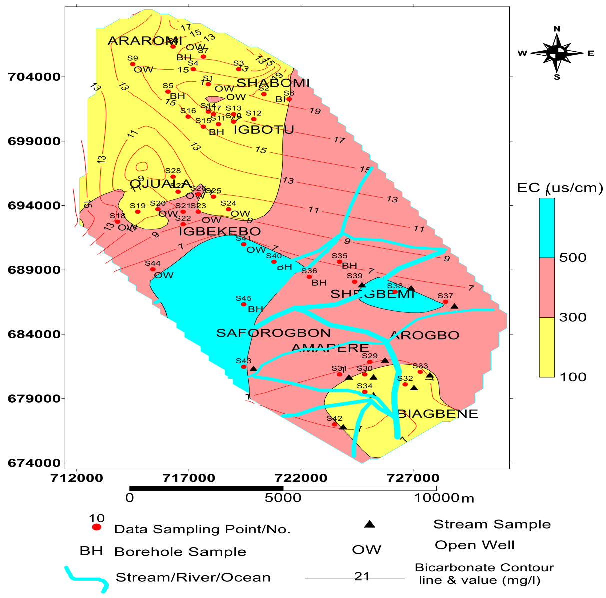

Figure 5: *Spatial Distribution of Electrical Conductivity and Bicarbonate*

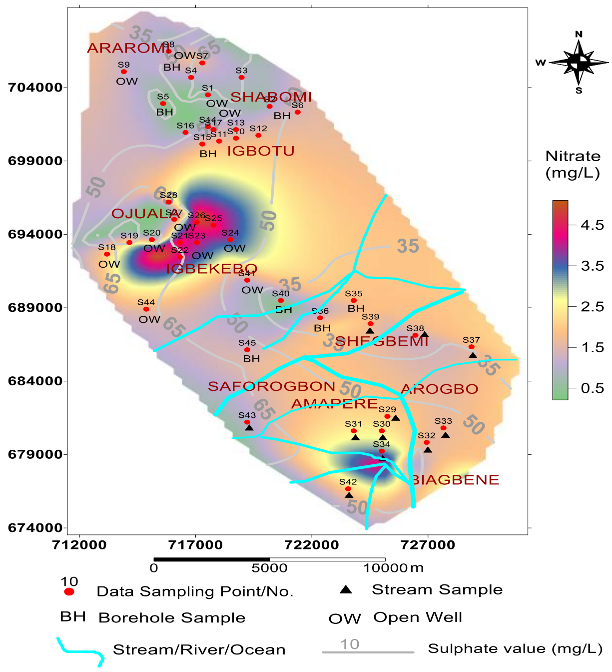

Figure 6: *Spatial Distribution of Nitrate and Sulphate*

Sulphur is useful to plants. High levels of sulphate in drinking water can cause diarrhea [27]. The WHO [48] standard for Sulphate in drinking water is 250mg/l.

From the study, the concentration of sulphate is in between 18.2 and 88.1mg/l and a mean of 51.7mg/l. The mean value obtained is within the WHO recommendation. The concentrations of manganese, magnesium, calcium, zinc, iron, sodium, potassium range from 0.001 – 0.03mg/l (av. 0.011), 1.04 – 44.5 mg/l (av. 5.64mg/l), 4.1 – 48.6 mg/l (av. 15.8mg/l), 0.01 – 0.35mg/l (av. 0.22mg/l), 1.2 – 36.2mg/l (av. 9.78mg/l) and 0.3 – 19.3mg/l (av. 6.24mg/l) respectively. This range of values are within the recorded limits of 0.1 mg/l, 20mg/l, 75mg/l, 0.1mg/l, 0.1mg/l, 200mg/l, and 75mg/l respectively. However, there are evidences of trace concentrations of lead (0.0000-0.0041mg/l), cyanide (0.0000-0.0020mg/l), arsenic (0.0001-0.0015mg/l), mineral oil (0.0001-0.0002mg/l), and ammonia (0.0000-0.0015mg/l). Subsequently, this may be as a result of petroleum exploration in Ilaje which is just a border town to the study area. In addition no traces of *clostridium perfringenes*, *chromobacterium violaceum*, E.*Coli*, *faecal streptococci*, *klebsiella acrogens*, S. *aeurus*, and *yeast*. The values of water quality index varies from 34 to 182% with a mean of 59% (Figure 7). Excellent water types (WQI of 0-50) account for 15% of the study area including Araromi, Ojuala, and Shabomi.

Good water (WQI of 50 - 100) accounts for 80% of the study area which included Igbotu and Igbekebo; poor water (WQI of 100 - 200) common in account for 5% of the area. There is no occurrence of very poor or unsuitable water in the area.

Sodium absorption ratio helps is determining the utility of water for irrigation purpose. There are different processed by which salinity can be enhanced in water viz., Climate, weathering, manmade activities and leaching of salts. To maximize the crop productivity of the region, proper quality irrigation water is required [44]. The calculated values of SAR (Table 5) from the study area range from 0.07 to 2.99meq/l (av. 0.62meq/l). All Samples entirely fall in Good irrigation water category (Table 6). The structure of the soil is considerably affected by the presence of Sodium. Na concentration is important in classifying water for irrigation purposes. The Na% range from 0.70 of 68.47% with a mean of 22.41. From Table 6, 60%, 22%, 9%, and 9% of the samples fall within Excellent, Good, Permissible and Doubtful categories. Electrical conductivity of the samples varies from 113 - 650µs/cm (av. 294µs/cm. Table 6 shows that 51% fall within the low salinity hazard range while 49% belongs to medium salinity hazard category.

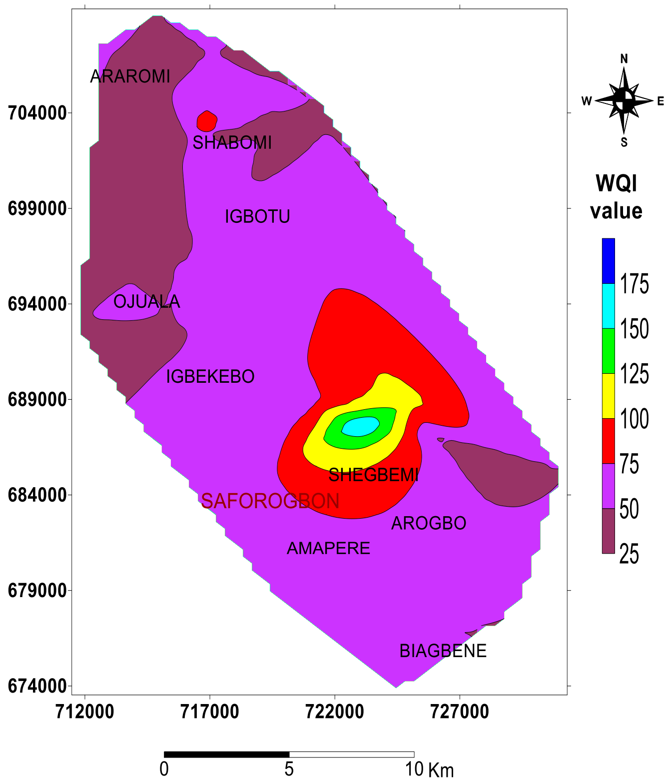

Figure 7: *Spatial variation of Water Quality Index*

Permeability index is a major function, which has influence over the Utility of water for agriculture. There are three basic types of classes such as Class I, Class II and Class III to favourability for agricultural practices (Table 6). The range of values for PI is in between 19.94 and 140.96% (av. 68.33%). The Table 5 shows that 60% of the groundwater falls within the permissible/ marginal category for irrigational utility, while 4% fall within the unsuitable category. The majorities of the samples are represented in Class I and Class II, which represents good and moderate category respectively and rest of them were not suitable for irrigational purpose. RSC is an important parameter to evaluate the suitability of irrigation water [32, 43]. The RSC values in the ground water sample range from −3.60 to 0.02 (av. -0.99) indicating a good water for irrigation. Table 6 also confirms that all the samples fall within the Good category.

Table 5: *Result of the Irrigation Indices*

Location	Easting	Northing	Well No.	RSC	MR	ESC	KR	SAR	%Na	PI
SHABOMI	716964	705876	1 OW.	-2.08	6.99	115.379	0.14	0.29	50.38	30.68
	720318	704925	2 OW.	-2.01	6.81	127.192	0.18	0.38	53.74	33.82
	718794	707303	3 OW.	-0.71	17.18	103.416	0.56	0.76	31.43	67.23
	716049	707303	4 BH.	-1.45	6.45	108.949	0.36	0.65	53.90	44.29
	714524	705163	5 BH.	-1.14	10.22	93.251	0.59	0.93	41.06	53.93
	721843	704449	6 BH.	-0.16	23.76	93.79	1.14	0.96	25.71	110.86
	716659	708492	7 OW.	-0.59	57.26	71.556	0.05	0.07	6.03	65.54
ARAROMI	714829	709444	8 OW.	-0.52	61.25	28.283	0.22	0.30	8.72	74.32
	712390	707779	9 OW.	-0.78	35.83	48.379	0.28	0.39	15.90	56.42
IGBOTU	718489	702309	10 OW.	-1.15	27.19	66.587	0.25	0.41	18.20	44.81
	717574	702071	11 OW.	-2.51	17.41	72.23	0.05	0.12	28.02	19.94
	719708	702546	12 OW.	-2.39	3.66	162.851	0.23	0.52	68.47	30.58
	718489	703022	13 OW.	-0.27	22.25	87.872	0.60	0.58	38.66	97.49
	716964	703260	14 OW.	-2.04	84.92	56.645	0.20	0.42	2.41	29.81
	716659	701833	15 BH.	-1.94	49.99	62.826	0.19	0.40	7.11	35.56
	715744	702784	16 OW.	-1.01	7.37	86.09	0.23	0.39	53.19	54.40
	717269	703022	17 OW.	0.02	27.52	38.386	0.49	0.47	21.17	134.76
	711475	692795	18 OW.	-0.08	48.09	39.087	0.84	0.76	17.37	122.72
IGBEKEBO	712695	693746	19 OW.	-0.26	65.35	141.661	0.89	0.97	4.29	98.40
	713914	693984	20 OW.	-0.38	56.93	40.318	0.51	0.57	5.83	85.44
	715439	693746	21 OW.	-0.11	38.28	61.247	0.68	0.56	11.27	124.46
	715439	692557	22 OW.	0.00	26.85	54.173	0.61	0.52	17.84	140.96
OJUALA	716354	693746	23 OW.	-0.48	55.36	43.344	0.21	0.29	6.17	76.95
	718184	693984	24 OW.	-0.38	30.39	71.473	0.68	0.77	15.78	87.29
	717269	695173	25 OW.	-1.00	17.17	72.887	0.14	0.21	29.79	45.35
	716354	695411	26 OW.	-2.53	26.82	80.286	0.06	0.15	17.58	24.53
	715134	695649	27 OW.	-0.08	36.82	58.946	0.87	0.81	22.71	119.17
	714829	697076	28 ST.	0.01	22.12	52.475	0.66	0.60	37.62	134.22
AKOTOGBO	726722	679476	29 ST.	-0.54	76.12	81.528	0.15	0.22	2.60	71.83
	726417	678287	30 ST.	-1.07	62.43	96.098	0.52	0.80	7.30	52.01
	724892	678287	31 ST.	-0.78	65.48	68.163	0.90	1.22	6.74	68.34
	728857	677336	32 ST.	-0.89	40.82	66.45	0.64	0.93	13.68	62.44
	729771	678525	33 ST.	-0.86	39.02	74.325	0.77	1.14	14.54	68.82
	726417	676622	34 BH.	-0.66	10.59	99.529	0.50	0.70	43.21	71.68
AMAPERE	724892	688990	35 BH.	-2.03	76.81	99.516	0.26	0.57	2.57	40.61
	723063	687563	36 BH.	-3.60	93.50	87.966	0.12	0.34	0.70	23.52
	731296	685184	37 ST.	-0.06	35.98	83.256	1.28	1.30	13.90	113.92
BIAGBENE	728247	686136	38 ST.	-0.37	18.80	82.749	0.62	0.65	29.99	86.20
GBELEJU	725807	687087	39 ST.	-0.49	37.27	110.276	0.56	0.68	14.87	78.38
SHAGBEMI	720928	688990	40 BH.	-1.20	52.11	87.65	0.14	0.23	8.82	33.42
	719098	690655	41 ST.	-1.20	50.22	120.163	0.08	0.13	8.12	32.65
	724587	673530	42 ST.	-1.01	29.68	83.41	0.11	0.17	17.33	44.59
	719098	679000	43 ST.	-0.41	35.08	138.507	2.85	2.99	14.21	92.04
	713610	688276	44 ST.	-1.99	12.67	111.301	0.38	0.77	37.34	38.25
	719098	684946	45 ST.	-1.52	4.78	157.348	0.40	0.79	62.08	52.33
Min				-3.60	3.66	28.28	0.05	0.07	0.70	19.94
Max				0.02	93.50	162.85	2.85	2.99	68.47	140.96
Average				-0.99	36.26	84.17	0.49	0.62	22.41	68.33

Table 6: *Irrigation Indices and their categorization*

Parameter	Sample range	Classification	% of Sample
Na% (meq/l)	0 – 20	Excellent	60%
	20 – 40	Good	22%
	40 – 60	Permissible	9%
	60 – 80	Doubtful	9%
	>80	Unsuitable	-
SAR (meq/l)	0 – 10	Excellent (suitable for all types of crops and soil except for those crops sensitive to Na	-
	10 – 18	Good (suitable for coarse textured or organic soil with permeability	100%
	18 – 26	Fair (harmfully for almost all soils)	-
	>26	Poor (unsuitable for irrigation)	-
RSC (meq/l)	<1.25	Good	100%
	1.25 – 2.50	Medium	-
	>2.50	Bad	-
EC (μs/cm)	<250	Low salinity hazard (good)	51%
	250 – 750	Medium salinity hazard (moderate)	49%
	750 – 2250	High salinity hazard (poor)	-
	>2250	Very high salinity hazard (very poor)	-
PI (meq/l)	>75%	Suitable	36%
	25 – 75%	Marginal	60%
	<25%	Unsuitable	4%
MR (meq/l)	<50	Suitable	71%
	>50	Unsuitable	29%
KR (meq/l)	<1.0	Good	93%
	>1.0	Not Good	7%

The magnesium ratio (MR) of the water samples ranges from 3.66 to 93.50 meq/l and average of 36.26 meq/l (Table 5). From Table 6, 71% of the groundwater samples are suitable for irrigation uses while 29% are unsuitable for irrigation, as much magnesium damages the soil structure, which affects crop yield [24]. The KR values calculated for the water samples is in between 0.05 and 2.85, with a mean of 0.49. This range of values is still within the suitable range of less than 1 [44].

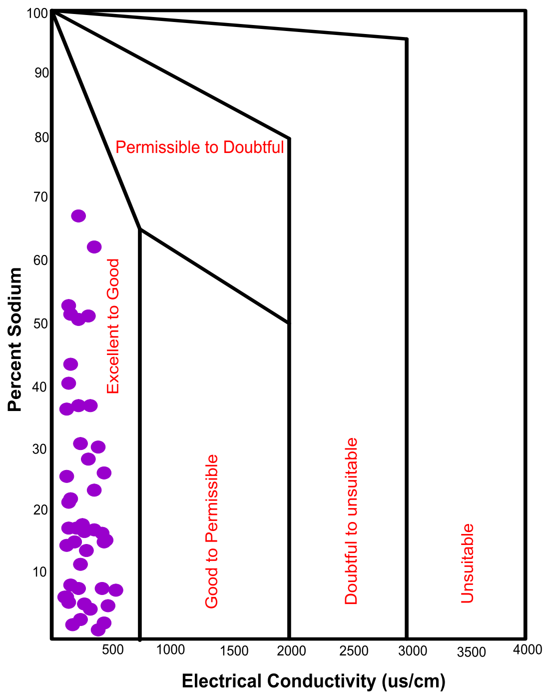

Figure 8: *Wilcox irrigation plot of the water samples*

From Table 6, 93% of the samples fall within Good irrigation water, while 7% belongs to unsuitable category. The equivalent salinity concentration varies between 28.28 and 162.85mg/l (av. 84.17mg/l). Notable relatively high ESC areas are Shabomi, Gbeleju, and Shagbemi with ESC values greater than 100mg/l. Data of the groundwater samples of the area are plotted in the Wilcox's diagram [52] in Figure 8, all the samples plotted within the "excellent. The agricultural yields are generally high in lands irrigated with waters belonging to excellent to good categories.

4 Conclusions

The physico-chemical and bacteriological properties of groundwater of Ese Odo were matched with the water quality standards set drinking and irrigation. The WQI calculations indicated an index values ranging from 34 and 182 (av. 59) with predominantly good water class which accounts for 80% of the study area. All the physical, chemical and microbiological parameters analyzed are within the World Organization Standard even though traces of heavy metal and mineral oil contaminations are observed some of the samples. For irrigation assessment, electrical Conductivity (EC) of collected water samples predominantly fall in the class of low salinity hazard, accounting for 51% of the study area. All the area has "Good" SAR and RSC categorization, the result of %Na and PI show that 60% of the area is characterized by Excellent irrigation water and marginal/ permissible respectively. In addition, suitable water is also observed in the area on the basis of KR (93%) and MR (71%). All the samples are plotted on the "Excellent irrigation class" of Wilcox plot. Consequently, the groundwater in the study area is good and suitable for drinking and irrigation purposes. On this basis, it is therefore recommended that, government should start borehole drilling and development programme coupled with groundwater monitoring for protection of health through efficient water treatment and management planning especially in areas with high water quality indices.

5 Declarations

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5.2 Competing Interests

The authors declare no conflict of interest exist in this publication.

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