Journal of Environment and Earth Science
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.5, No.11, 2015

Hydrochemical Investigation of Saline Water Intrusion into Aquifers in Part of Eastern Dahomey Basin, Southwestern Nigeria

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ABSTRACT

This study is a major attempt at delineating presence and lateral extent of saline water intrusions into aquifers at the easternmost part of Dahomey basin which falls essentially in the sedimentary terrain of Ondo State of Nigeria. 61 water samples were collected from hand dug wells, shallow boreholes, and ponds across the study area and analyzed for relevant parameters such as pH, conductivity, total hardness, calcium hardness, magnesium hardness, total dissolved solids, alkalinity and concentrations of the following anions and cations; chloride, calcium, Sulphate, bicarbonate, magnesium and sodium. Equivalent salinity was calculated from the water sample analysis results. The hydrochemical analysis results reveals possible saline water intrusion in the coastal area, especially the southeastern part and Agbabu in the north central part of the study area as evident from high concentration values of chloride (372 - 1500 mg/l), alkalinity (105 - 330 mg/l), equivalent salinity (135 - 2808 mg/l), total dissolved solid (181 - 1005 mg/l), high pH values (4.4 - 8.6 pH) and conductivity values (541 - 1500 µs/cm).

Keywords: Saline water intrusion, saline-freshwater boundary, hydrochemical and equivalent salinity.

1. INTRODUCTION

The larger percentage of Nigerians relies entirely on groundwater abstraction for their domestic and industrial water needs. This heavy reliance on groundwater is perhaps due to the fact that it is available in all seasons and chemically stable. Most Nigerians rely on groundwater abstraction because it is cheaper to develop. Since Nigerians rely heavily on groundwater for various uses, it is important that groundwater potability be guaranteed at all times and therefore must be given serious attention. Groundwater quality is usually compromised, as a result of contamination or pollution deriving from anthropogenic activities, or as a result of saline water intrusion into coastal aquifers proximal to oceans across the world. Contamination of groundwater which could be either pollution or salinity can render groundwater resources useless, unwholesome and unfit for consumption and other purposes.

Saline water intrusion can simply be defined as movement of saline water or sea water into fresh water aquifer or surface reservoir. When the source of the saline water is sea water, then the phenomenon can be referred to as seawater intrusion (Rahaman and Bhattacharya, 2014). Ghyben (1888) and Herzberg (1901) described what happens at fresh-saline water boundary. The fresh-saline water boundary is not sharp but gradational and water within this transition zone is known as brackish water. Since saline water is denser because of its higher concentration of dissolved salt, it will normally remain below fresh water and will only intrude into the fresh water when hydraulic pressure within the saline water is higher than that of the overlying fresh water. Fresh-saline water boundary has also been observed to shift seaward during rainy season, because of strong pressure of fresh water when been recharged by precipitation, while the reversal is the case during dry season. It has also been observed that good drainage system reduces soil salinity (Mohammad, 2014).

The possible sad consequence of consuming saline or brackish water came to light last year when some Nigerians consumed salt solution supposedly to enhance their body immune system against the deadly Ebola virus, few people lost their lives across the country as a result of complications arising from high concentration of salt in the consumed salt solution. This incident clearly showed that consumption of saline or brackish water is dangerous to human health.

Only few works have been done on saline water intrusion in the study area. Omosuyi et. al. (2008) carried out geoelectric sounding, hydrogeochemical and hydrogeophysical studies of the eastern Dahomey basin, and the adjoining basement complex in southern part of Ondo state. Fifty (50) Schlumberger vertical electrical sounding (VES) was carried out across southern part of Ondo State, using maximum current electrode separation (AB/2) of 325 m. From water analysis result it was found out that the TDS in most water samples analyzed are within the World Health Organization acceptable limit with the exception of Arogbo and Igbokoda which are higher. Omoyoloye et al. (2008) carried out 16 VES across Adagbakuja Newtown in southern part of Ondo state, using maximum current electrode separation (AB/2) of 130 - 225 m. Four (4) geoelectric layers were delineated; topsoil (0.4 - 199 ohm-m), mud and peat (0.4 - 102 ohm-m), clayey silts/fine sand (0.4 - 76 ohm-m) and brackish/saline water and sand units (2 - 1528 ohm-m). Brackish or saline water intrusion was delineated within the silt/fine sand substratum. This present work was aimed at delineating presence and lateral extent of saline water intrusion in the study area.

2. DECSRIPTION OF THE STUDY AREA

The study area is generally characterized by flat and gently undulating topography. Topographic elevations vary from about 13 to 83 m above sea level in the mainland and 2 to 10 m in the coastal area (Figure 1). Most part of the coastal area is water logged, which makes the area vulnerable to sea water incursion. The study area is been drain by many tributaries, streams and rivers some of which are connected directly or indirectly to the Ocean and this can facilitates the rate and extent of saline water intrusion. The area cuts across five Local Government areas in the southern part of Ondo State (Odigbo, Irele, Okitipupa, Ese-Odo and Ilaje) and Ogun Waterside Local Government in Ogun State. It is bounded by the following coordinates; longitudes and latitudes, $4^{o}\,22^{'}\,22.5^{''}$ E and $5^{o}10^{'}\,2.0^{''}$ E and $5^{o}\,50^{'}44.1^{''}$ N and $6^{0}\,39^{'}\,39.5^{''}$ N and it cover a total area of about 4,200 km^2.

3. GEOLOGY OF THE STUDY AREA

The study area lies within the easternmost part of Dahomey basin, southwestern Nigeria**.** It is bordered to the north by the crystalline rocks of the southwestern Nigeria Basement Complex and to the South by Atlantic Ocean christened the Bight of Benin (Figure 2). The Dahomey Basin is a combination of inland/coastal/offshore basin that stretches from south-eastern Ghana through Togo and the Republic of Benin to south-western Nigeria. It is separated from the Niger Delta by a subsurface basement high referred to as the Okitipupa Ridge. Its offshore extent is poorly defined (Billman, 1992). The Dahomey Basin covers much of the continental margin of the Gulf of Guinea, extending from Volta-Delta in Ghana in the west to the Okitipupa Ridge in Nigeria in the east. The basin is a marginal pull-apart basin (Klemme, 1975) which developed in the Mesozoic due to the separation of African from Southern American plate in the Mesozoic era (Burke et al; 1971; Whiteman, 1982). The eastern Dahomey basin or the Nigeria sector contains extensive wedge of Cretaceous to Recent sediments, up to 3000 m which thicken towards the offshore. The sediment deposition in the basin follows an east-west trend. The summary of the general stratigraphy succession in the Nigeria section of the eastern Dahomey Basin which covers Ogun State and the southern part of Ondo State and south western part of Edo State of Nigeria is as presented in table 1.

4. METHODOLOGY

A total 61 water samples (Figure 3) were collected across the study area during a period that spans through the dry and wet seasons, from January, 2012 to August 2013. Most of the water samples were obtained from hand dug wells with depth range of 3 to 6 m. Borehole water was obtained at 12 locations which are mainly in the southeastern part of the study area; they are Agbabu, Irele, Okitipupa, Molutehin, Akpovukoko, Odonla, Awoye, Rewoye, Obenla, Ayetoro, Idogun, and Eruna. Surface water (pond) was obtained in 5 locations; Orioke, Asisa, Ugbonla road, Orere-ara road and Ileriayo. 17 primary parameters were determined from the hydrochemical analysis and they includes some of the following; conductivity, pH value, total hardness, calcium hardness, magnesium hardness, sodium, total dissolved solids (TDS), alkalinity, chloride, sulphate, bicarbonate, pH and conductivity. Equivalent salinity was derived from some of the primary hydrochemical parameters. Conductivity and pH were determined insitu using a hand held devices, while other parameters were determined in the laboratory.

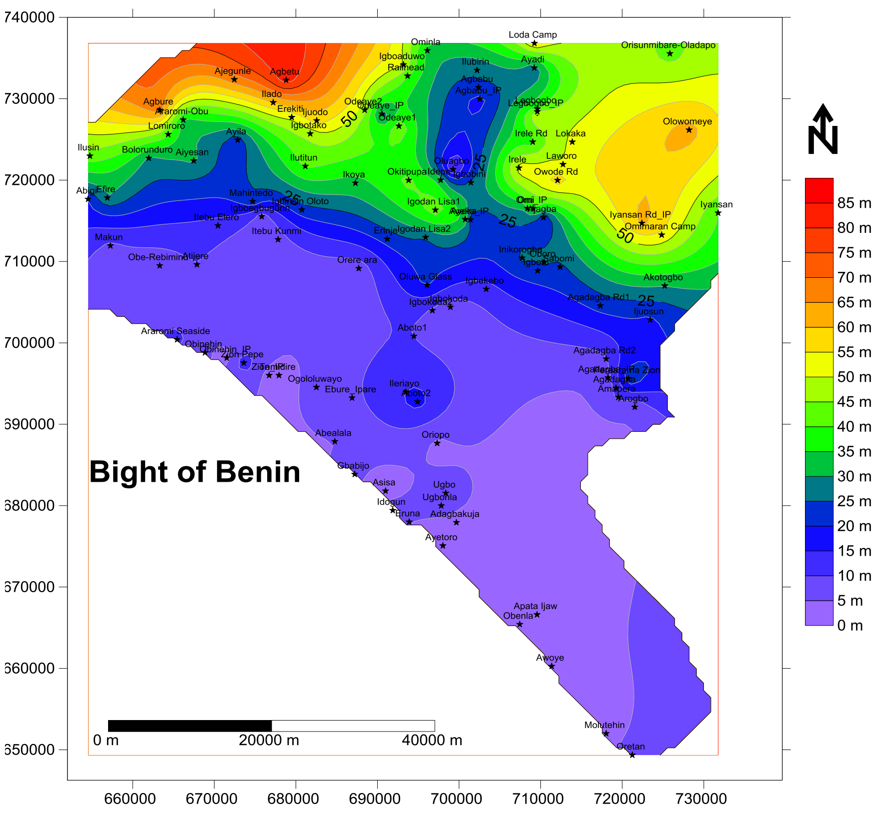

Figure 1: Topographic map of the study area

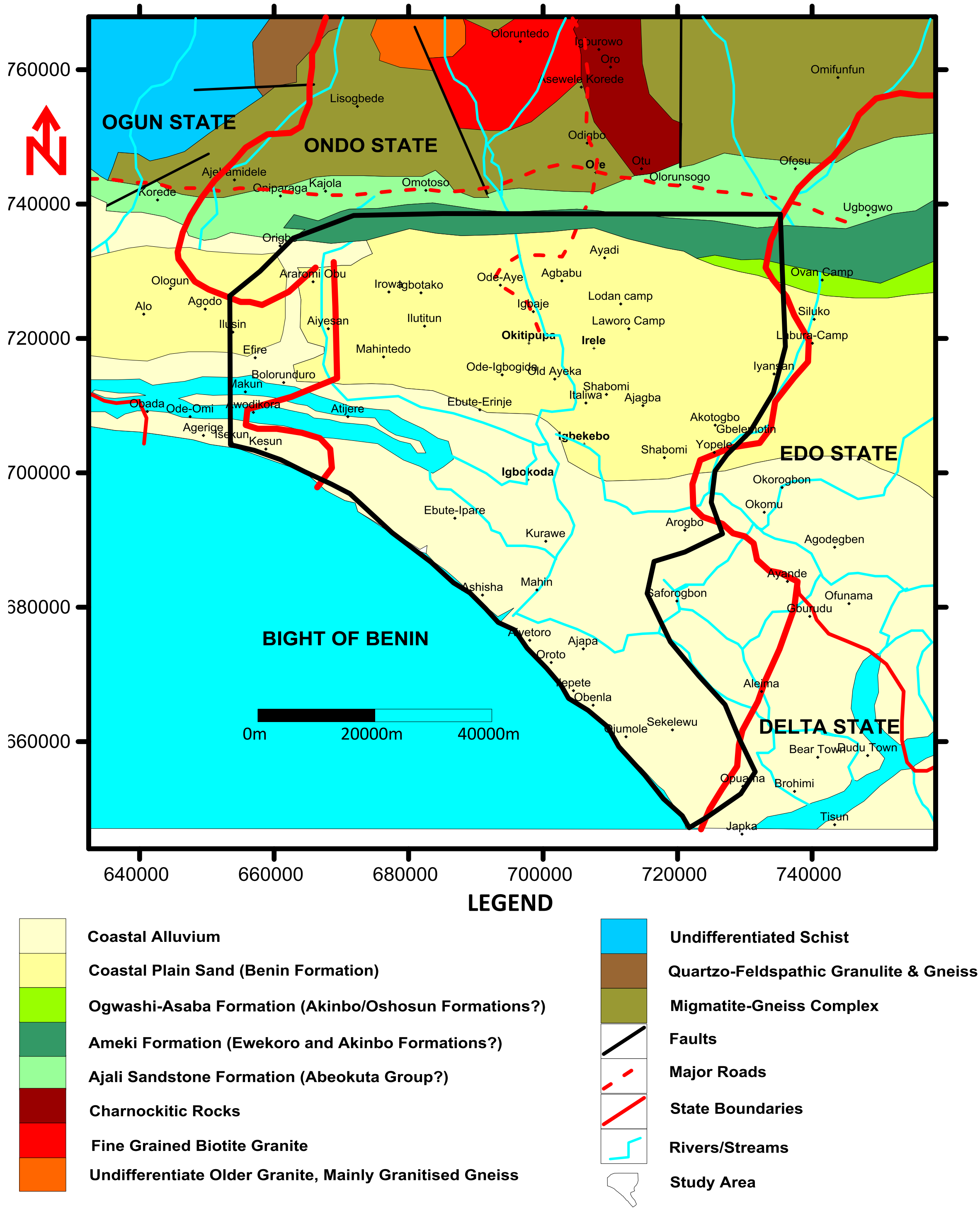

Figure 2: Geological map of the study area (after PTF, 1997)

Table 1: Summary of the Geology of the study area

Group	Formation	Lithology	Age
	Benin	Poorly sorted sands with lenses of clay	Oligocene-recent
	Ilaro	Massive, yellowish poorly consolidated cross-bedded sandstones	Eocene
	Oshosun	Greenish or Beige clay with interbeds of sandstones	Eocene
	Akinbo	Shale and Clayey sequence	Palaeocene-Eocene
	Ewekoro	Limestone with presence of Coralline algae, gastropods, pelecypods, echinoids fossils	Palaeocene
Abeokuta	Araromi	Shales, siltstone with interbedded limestone, marl and lignite	Maastritchian-Palaeocene
		Medium-fine grained sandstone.	
	Afowo	Coarse-medium grained sandstone; Interbedding of shales, siltstones and claystones	Turonian-Maastritchian
	Ise	Coarse-medium grained sands	Neocomian-Albian
		Conglomerates and Grits	
Basement Complex			Precambrian

5. DISCUSSION OF RESULTS

The results of the water analyses were as presented in table 2 and various maps. Although pH usually has no direct impact on consumers, it is one of the most important operational water quality parameters, the optimum required pH values range from 6.5 - 9.5 (WHO, 2008). The pH map (Figure 4) shows that the pH values across the study area range from 4.4 (Asisa) to 8.6 (Araromi Seaside), which is still within the WHO acceptable limit (Table 3). However places like Araromi Obu, Lomiroro and Aiyesan in the northwestern part, Agbabu and Ilubirin in the northcental part and the coastal towns of the study area exhibit high pH values indicating that alkalinity increase towards the coast.

Chloride concentration across the study area varies from 4.28 (Akotogbo) to 1500 mg/l (Orioke and Asisa). The Chloride map (Figure 5) shows that the chloride concentration is high at north central (Agbabu) and southeastern parts (Mahin, Ugbo, Ugbonla, Idogun,) of the study area. The WHO maximum permissible value for chloride concentration is 250 mg/l (Table 3). This value was exceeded at Ugbonla, Idogun, Orioeke, Asisa and Agbabu, where chloride concentration values of 372 to1500 mg/l were obtained.

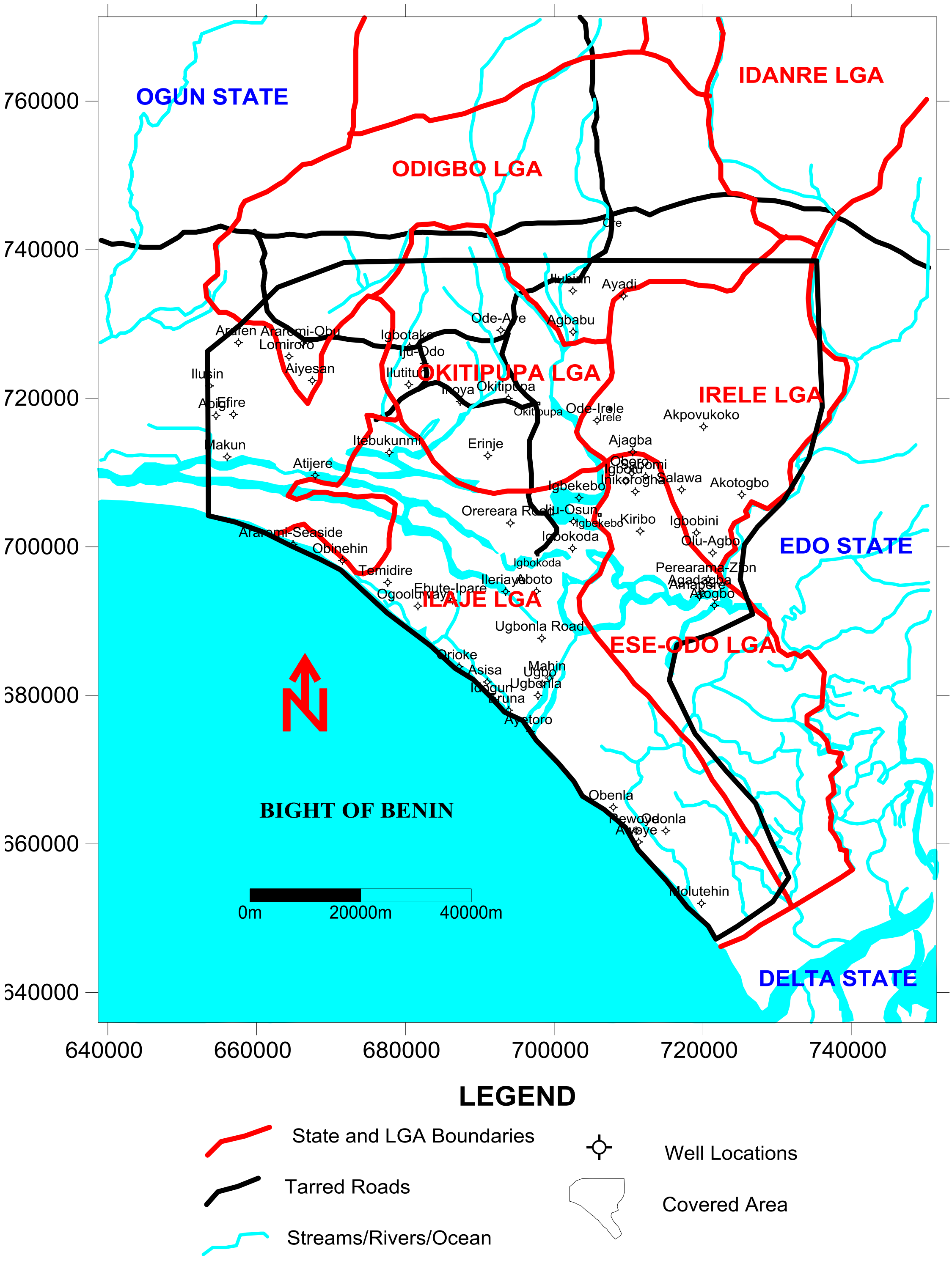

Figure 3: Location map of the study area showing water sampling locations

The alkalinity values derived from all the water samples range from of 4 - 330 mg/l. The minimum value of 4 mg/l was obtained from samples collected from Efire and Erinje, while high alkalinity values above 100 mg/l, which are higher than the WHO maximum permissible limit (Table 3), were obtained from the following locations Mahin and Ugbonla (104 mg/l), Orioke (103 mg/l), Rewoye (120 mg/l), Obenla (130 mg/l), Odonla (166 mg/l), Igbokoda (184 mg/l), Ugbo (196 mg/l) and Agbabu (200 mg/l), Awoye, (205 mg/l), Eruna (258 mg/l), Molutehin (260 mg/l) and Ayetoro (305 mg/l). The alkalinity map (Figure 6) shows that alkalinity is high around the southeastern part of the study area, where Mahin, Ugbo, Ugbonla, Awoye, Molutehin, Obenla, Odonla, Idogun and Ayetoro are situated. Also another high alkalinity area is the north central (or the mainland) part of the study area around Agbabu.

Equivalent salinity values were derived from Sodium (Na^+), Chloride (Cl^-), Calcium (Ca^{+2}) and Sulphate (So_4^{-2}) concentrations, based on the following relationship;

Equivalent Salinity Concentration = $0.81Ca + 0.45SO_4 + (Na+Cl)$ 1

The equivalent salinity values range from 25.8 (Ode-Irele) to 2808 mg/l (Asisa). The equivalent salinity map (Figure 7) shows that high values were obtained from Ugbo, Ugbonla, Odonla, Idogun and Ayetoro area in the southeastern part of the study area and likewise at Agbabu in the north central part of the study area. Though there is no WHO standard for equivalent salinity, however the map correlates well with alkalinity map (Figure 6). These showed that shallow and intermediate aquifers in these areas are yielding saline or brackish water.

Total dissolved solid (TDS) is a useful parameter commonly used in determining saline water intrusion and has been used by many authors (Omosuyi, 2001; Choudhury et al., 2001 and Samsudin et al., 2007). The TDS values across the study area (Figure 8) range from 6.7 to 1005 mg/l. The lowest value of 6.7 mg/l was recorded from OdeIrele, Ajagba, Iju-Osun Akpovukoko, Akotogbo, Agadagba, Igbekebo, Iju-Odo, Efire and Ilusin. High TDS values were obtained at Ugbonla (582.9 mg/l), Ugbo (670 mg/l), Orioke (836 mg/l), Asisa (970 mg/l) and Agbabu (1005 mg/l). In all of these locations, the water samples analysis yielded TDS values well above 500 mg/l which appears to be indicative of saline water intrusion in the study area, however the maximum permissible value of 1500 mg/l is recommended by WHO (2008).

Conductivity has a direct relationship with salinity; increases in salinity will lead to increase in the concentration of current carrying ions in water and consequently increases in conductivity. Therefore an increase in salinity, under a normal condition will corresponds to increase in conductivity, and therefore high conductivity is strongly connected to saline water intrusion. The maximum permissible limit of conductivity is 1200 µs/cm (WHO, 2008). The conductivity map (Figure 9) shows that water samples collected from the northeastern (Odeaye, Ilubirin and Agbabu) and the southeastern (Igbokoda, Ugbo, Awoye, Ugbonla, Idogun, Asisa, Orioke and Ayetoro) parts of the study area yielded relatively higher conductivity values. However in all the samples analyzed, conductivity was still within WHO acceptable limits.

6. CONCLUSION

The hydrochemical analysis results as presented from various maps shows evidence of saline water intrusion in the southeastern part of the coastal and Agbabu in the mainland as evident from high concentration values of chloride (372 - 1500 mg/l), alkalinity (105 - 330 mg/l), equivalent salinity (135 - 2808 mg/l), total dissolved solid (181 - 1005 mg/l), high values of pH (4.4 - 8.6 pH) and conductivity (541 - 1500 µs/cm). In all of these results Orioke and Asisa have the highest values followed by other locations in coastal area and surprisingly Agbabu in the main land. However there is possibility that the whole southern part of the study area have been intruded by saline water. All the sampling points in the southwestern area are either shallow hand dug well (with depth less than 6 m) or surface water; this is due to non-availability of functioning motorized boreholes in this area, while the opposite is the case in the southeastern part of the

Table 2: Hydrochemical analysis results

S/N	Location Name	Conductivity	pH	Total Hardness	Calcium Hardness	Magnesium Hardness	Nitrate	Chloride	Manganese	Alkalinity	Sulpahte	Iron	Sodium	Bicarbonate	Calcium	Magnesium	TDS	SS	ES
1	Ayadi	50	5.9	46	18	28	0.97	12.9	0.015	16	33.4	0.73	8.39	16	7.2	6.8	33.4	16.5	42.152
2	Ode-Irele	10	5.45	18	10	8	0.88	8.57	0.018	12	18.7	0.42	5.57	12	4	1.95	6.7	3.3	25.795
3	Igbobini	50	6.08	34	22	12	11.44	9.99	0.012	14	26.4	0.08	6.49	14	8.8	2.92	33.5	16.5	35.488
4	Olu-Agbo	30	5.77	18	8	10	0.83	8.57	0.017	20	32.4	ND	5.57	20	3.2	2.44	20.1	9.9	31.312
5	Ugbonla Road	666	6.73	54	14	40	0.47	13	0.003	60	1	0.06	8.45	60	5.61	9.76	446	220	26.4441
6	Sabomi	110	6.32	74	64	10	0.48	5.71	0.014	28	42.3	0.28	3.71	28	25.7	2.44	73.7	36.3	49.272
7	Ajagba	10	5.23	20	10	10	0.63	5.71	0.015	8	38.3	0.3	3.71	8	4	2.44	6.7	3.3	29.895
8	Akpovukoko	10	4.95	18	12	6	0.74	7.86	0.021	20	18.9	0.06	5.11	20	4.8	1.46	6.7	3.3	25.363
9	Akotogbo	10	4.87	20	10	10	0.81	4.28	0.02	16	43.4	0.61	2.78	16	4	2.44	6.7	3.3	29.83
10	Iju-Osun	10	4.92	18	10	8	0.86	4.99	0.015	10	56.5	0.73	3.24	10	4	1.95	6.7	3.3	36.895
11	Agadagba	10	5.14	18	8	10	0.97	4.99	0.011	9	44.6	0.09	3.24	10	3.2	2.44	6.7	3.3	30.892
12	Amapere	50	5.21	20	14	6	0.47	12.9	0.017	14	42.4	0.01	8.39	14	5.6	1.46	33.5	16.5	44.906
13	Igbekebo	10	4.99	20	10	10	0.68	4.28	0.015	22	64.3	0.22	2.78	22	4	2.4	6.7	3.3	39.235
14	Ode-Aye	680	5.88	118	92	26	0.74	67.8	ND	20	28.4	ND	44.1	20	36.9	6.3	455.6	224.4	154.569
15	Ikoya	50	4.55	22	10	12	1.11	9.28	0.018	16	16.9	0.28	6.03	16	4	2.9	33.5	16.5	26.155
16	Ilutitun	40	5.49	18	12	6	0.64	7.14	0.009	10	24.3	0.35	4.64	10	4.8	1.5	26.8	13.2	26.603
17	Iju-Odo	10	5.05	34	20	14	0.78	5.71	ND	12	36.2	ND	3.71	12	8	3.4	6.7	3.3	32.19
18	Igbotako	60	4.51	18	10	8	0.86	14.3	ND	12	17.9	ND	9.3	12	4	1.9	40.2	19.8	34.895
19	Okitipupa	80	4.45	32	14	18	0.48	10.7	ND	16	52.4	ND	6.96	16	5.6	4.4	53.6	26.4	45.776
20	Igbokoda	600	6.89	180	143	37	0.25	59.3	0.015	184	63.4	0.67	38.5	184	57.3	9	402	198	172.743
21	Mahin	270	7.11	136	110	26	1.76	17.9	ND	104	28.7	0.32	11.6	104	44.1	6.3	180.9	89.1	78.136
22	Ugbo	1000	7.3	368	232	133	1.08	132.8	0.012	196	46.4	0.14	86.3	196	92.9	32.5	670	330	315.229
23	Ugbonla	870	7.15	438	302	132	1.24	372	ND	104	19.8	ND	241.8	104	121	32.2	582.9	287.1	720.72
24	Aboto	60	6.01	28	14	14	1.2	15.7	0.008	24	26.7	1.2	10.2	24	5.6	3.4	40.2	19.8	42.451
25	Aiyesan	70	7.21	34	16	18	8.36	11	0.012	6	34.2	0.96	7.15	6	6.41	4.39	46.9	23.1	38.7321
26	Lomiroro	160	5.6	38	14	20	3.24	26	ND	8	28.6	0.62	16.9	8	5.61	4.88	107	53	60.3141
27	Efire	10	6.93	30	20	10	4.84	9.99	0.013	4	43.2	0.61	6.49	4	8.02	2.44	6.7	3.3	42.4162
28	Atijere	90	7.82	98	54	44	4.4	17	0.016	12	25.1	0.93	11.1	12	21.6	10.7	60.3	29.7	56.891
29	Makun	200	7.74	94	72	22	ND	24	0.008	20	41.9	0.69	15.6	20	28.9	5.37	134	66	81.864
30	Araromi-Obu	60	8.23	37	18	19	1.28	12	0.01	14	32.7	0.61	7.8	14	7.21	4.64	40.2	19.8	40.3551

Table 2: Hydrochemical analysis results (continued)

31	Arafen	30	7.27	32	12	20	4.84	12	0.028	8	23.8	0.39	7.8	8	4.81	4.88	20.1	9.9	34.4061
32	Ilusin	10	5.04	10	6	4	3.78	7.99	0.013	8	37.4	0.45	5.19	8	2.4	0.98	6.7	3.3	31.954
33	Abigi	30	5.6	10	4	6	5.12	12	ND	8	19.8	0.55	7.8	8	1.6	1.46	20.1	9.9	30.006
34	Erinje	40	5.63	10	4	6	2.98	5.99	0.02	4	54.2	0.67	3.89	4	1.6	1.46	26.8	13.2	35.566
35	Agbabu	1500	7.34	316	162	154	6.6	384	0.018	200	41.7	0.67	250	200	64.9	37.6	1005	495	705.334
36	Ileriayo	60	7.24	78	24	54	3.56	12	0.011	22	38.2	22	7.8	22	9.62	13.2	40.2	19.8	44.7822
37	Ebute-Ipare	300	8.07	128	116	12	ND	20	0.016	40	45.3	40	13	40	46.5	2.93	201	99	91.05
38	Ogooluwayo	90	7.93	102	56	46	8.1	11	ND	14	29.7	14	7.15	14	22.4	11.2	60.3	29.7	49.659
39	Temidire	190	7.89	84	30	54	2.29	8	0.005	12	18.6	12	5.2	12	12	13.2	127	63	31.29
40	Araromi-Seaside	220	8.6	128	106	22	3.01	7	0.015	30	44.7	30	4.55	30	42.5	5.37	147	73	66.09
41	Obinehin	350	8.05	218	150	68	4.23	21	0.019	76	53.2	76	13.7	76	60.1	16.6	235	115	107.321
42	Perearama-Zion	50	7.14	38	16	22	1.76	8	0.014	14	29.7	14	5.2	14	6.41	5.37	33.5	16.5	31.7571
43	Igbotu	201	6.9	80	44	36	1.89	14	0.01	64	X	0.08	9.1	X	17.6	8.78	135	X	ND
44	Inikorogha	30	6.57	20	140	6	0.7	8	0.01	12	X	0.01	5.2	X	5.61	1.46	20	X	ND
45	Oboro	10	5.82	28	14	14	2.11	8.57	0.021	22	X	0.69	5.57	X	5.61	14	6.7	X	ND
46	Salawa	220	7.25	84	60	24	17.6	11.9	0.022	54	X	0	7.73	X	24	5.85	147	X	ND
47	Itebukunmi	10	5.71	12	8	4	0	6.99	ND	16	X	0	4.54	X	3.21	0	6.7	X	ND
48	Kiribo	50	6.78	34	26	8	2.21	12.9	ND	66	X	0	8.39	X	10.4	1.95	33.5	X	ND
49	Ilubirin	541	6.1	68	46	22	0.43	40	0.001	32.5	0	0.03	26	32.5	18.4	5.37	362	179	80.904
50	Molutehin	312	7.71	68	39	29	0.07	98	0.001	260	1	0.09	63.7	260	15.6	7.08	209	103	174.336
51	Awoye	687	7.6	48	32	16	0.09	83	0.002	205	0	0.02	54	205	12.8	3.9	460	227	147.368
52	Odonla	326	7.4	58	18	40	1.32	140	0.003	166	0	0.07	91	166	16	3.42	218	108	243.96
53	Rewoye	505	7.42	58	18	40	2.05	90	0.002	120	0	0.04	58.5	120	7.21	9.76	338	167	154.3401
54	Obenla	412	7.2	90	34	56	0.78	75	0.003	130	1	0.06	48.8	130	13.6	13.7	276	136	134.816
55	Ayetoro	196	7.6	146	76	70	0.08	87	0.002	305	0	0.08	56.6	305	30.5	17.1	131	64.7	168.305
56	Orioke	1013	6.7	1421	327	1102	1.76	1500	0.003	105	2	0.09	1200	105	131	267	678	836	2806.11
57	Asisa	1176	4.4	1647	267	1380	1.26	1500	0.002	30	2	0.07	1200	30	134	337	788	970	2808.54
58	Idogun	474	6.7	190	84	106	0.07	1052	0.003	330	1	0.05	684	330	33.7	25.9	245	121	1763.297
59	Eruna	212	7.6	148	76	72	0.09	539	0.002	258	0	0.04	350	258	30.5	17.6	142	70	913.705
60	Orereara Road	68	6.8	52	24	28	0.32	30	0.001	50	0	0.05	17.5	50	9.62	6.83	46	22	55.2922
61	Arogbo	100	6.2	100	58	32	0.1	103	ND	40	32	0.15	18	X	X	X	70	ND	121

Note;

TDS = Total Dissolved Solid; CBR = Chloride-Bicarbonate Ratio; X = Not Tested

ES = Equivalent salinity; SS = Suspended Solid ND = Not Detected

Table 3: Water Physico-Chemical Standards (After WHO, 2008)

S/N	PARAMETER	WHO STANDARDS	
		Highest Desirable	Maximum Permissible
1	Odour	Unobjectionable	Unobjectionable
2	Colour	3.0 TCU	15.0 TCU
3	pH at 20^0 C	7.0 – 8.9	6.5 – 9.5
4	Turbidity	5.0 NTU	5.0 NTU
5	Conductivity	900 (μs/cm)	1200 (μs/cm)
6	Total Dissolved Solid (TDS)	500 mg/l	1500 mg/l
7	Total Hardness	100 mg/l	500 mg/l
8	Calcium Hardness $CaCO_3$	Not Specified	Not Specified
9	Magnesium Hardness	20 mg/l	20 mg/l
10	Nitrate (NO_3)	10 mg/l	50 mg/l
11	Iron (Fe)	1 mg/l	3 mg/l
12	Alkalinity	100 mg/l	100 mg/l
13	Manganese (Mn)	0.1 mg/l	0.4 mg/l
14	Calcium (Ca^{2+})	Not Specified	Not Specified
15	Magnesium (Mg^{2+})	20 mg/l	20 mg/l
16	Sulphate (SO_4^{2-})	250 mg/l	500 mg/l
17	Chloride (Cl^-)	200 mg/l	250 mg/l
18	Sodium (Na)	200 mg/l	250 mg/l
19	Bicarbonate (HCO_3)	Not Specified	Not Specified
20	Suspended Solids	Not Specified	Not Specified
21	Aluminium (Al)	0.2 mg/l	0.2 mg/l
22	Ammonia	Not Specified	Not Specified

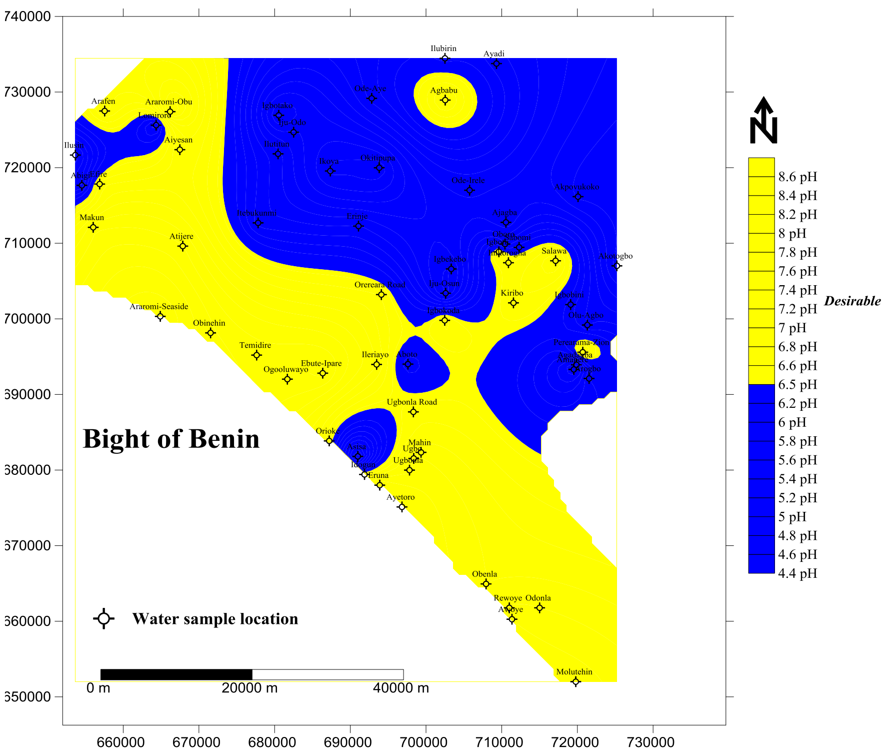

Figure 4: pH map

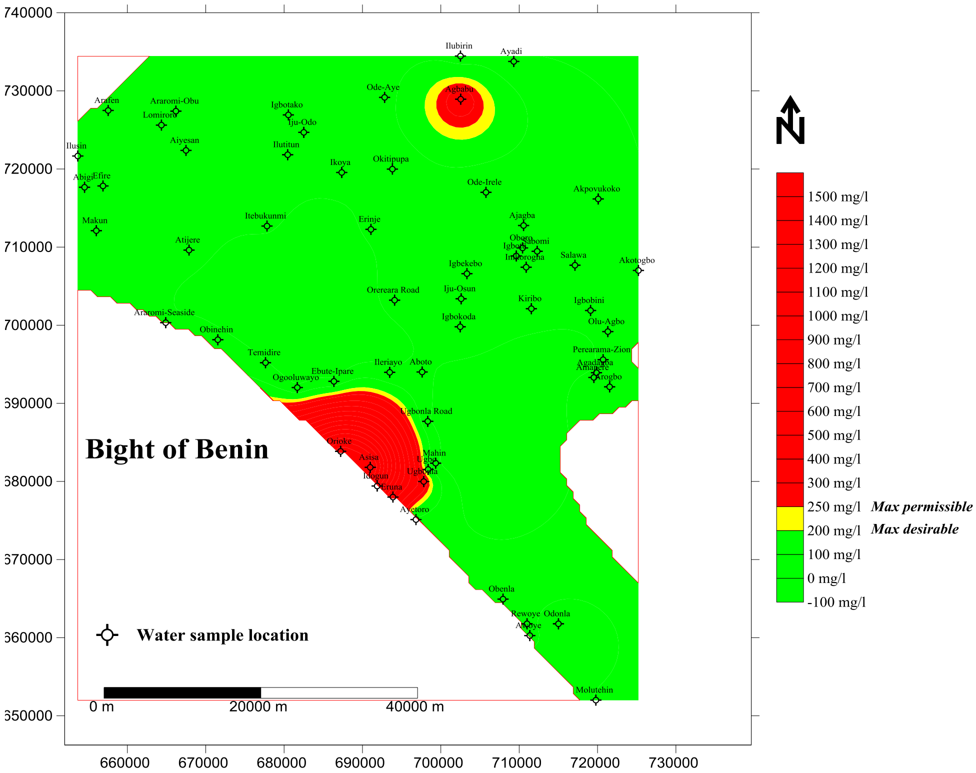

Figure 5: Chloride map

study area, where there are functioning boreholes from which water samples were taken. Perhaps if water samples were taken at the same depth as it was in southeastern part they may likely yield high salinity.

7. RECOMMENDATION

To resolve this ambiguity and to determine the depth to saline-fresh water interface, the lateral extent of saline water intrusion and depth to fresh water in the study area, surface geophysical methods such as vertical electrical sounding and time domain electromagnetic should be employed and every available borehole logs in the area should be analyzed in order to delineate the subsurface layers and their water content.

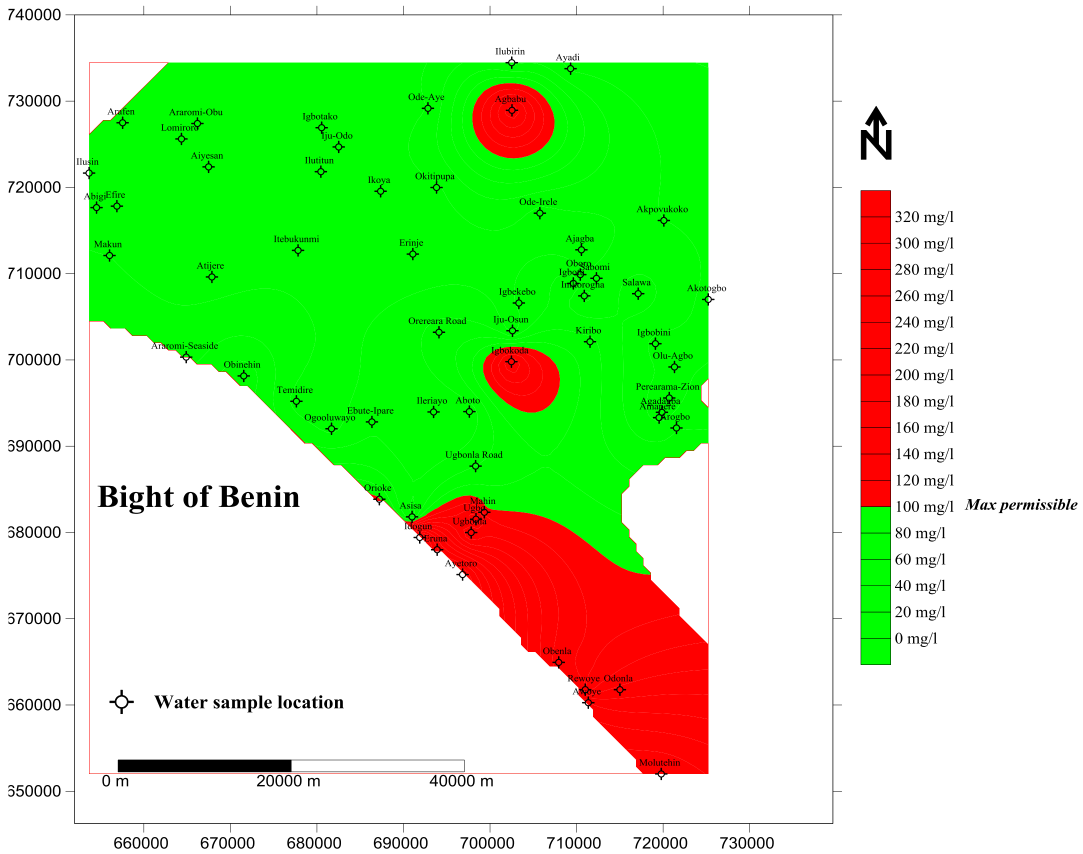

Figure 6: Alkalinity map

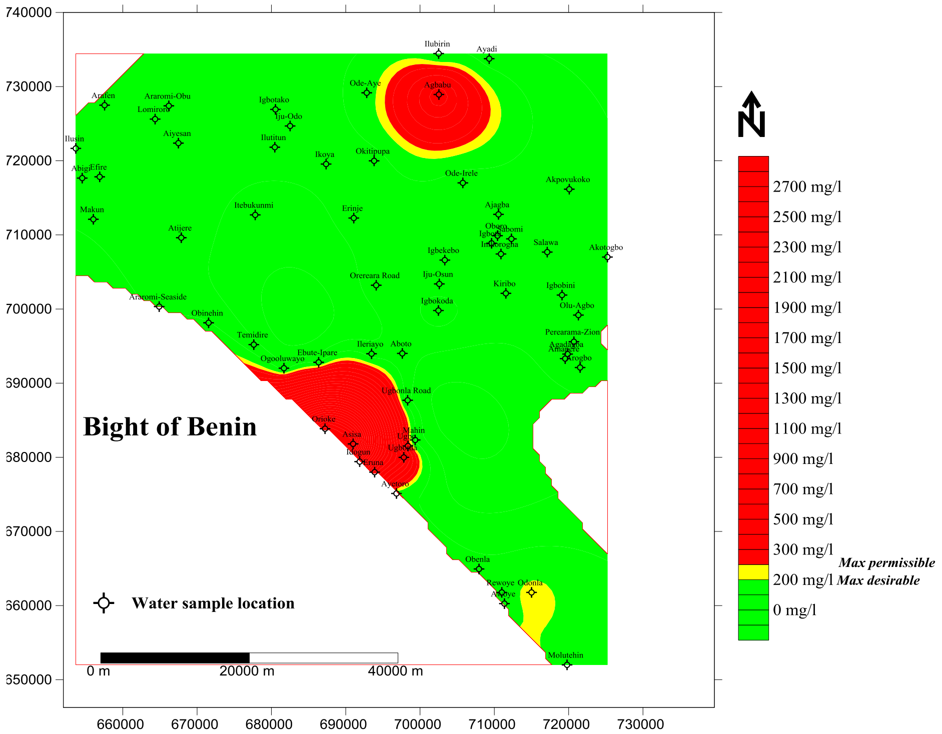

Figure 7: Equivalent Salinity map

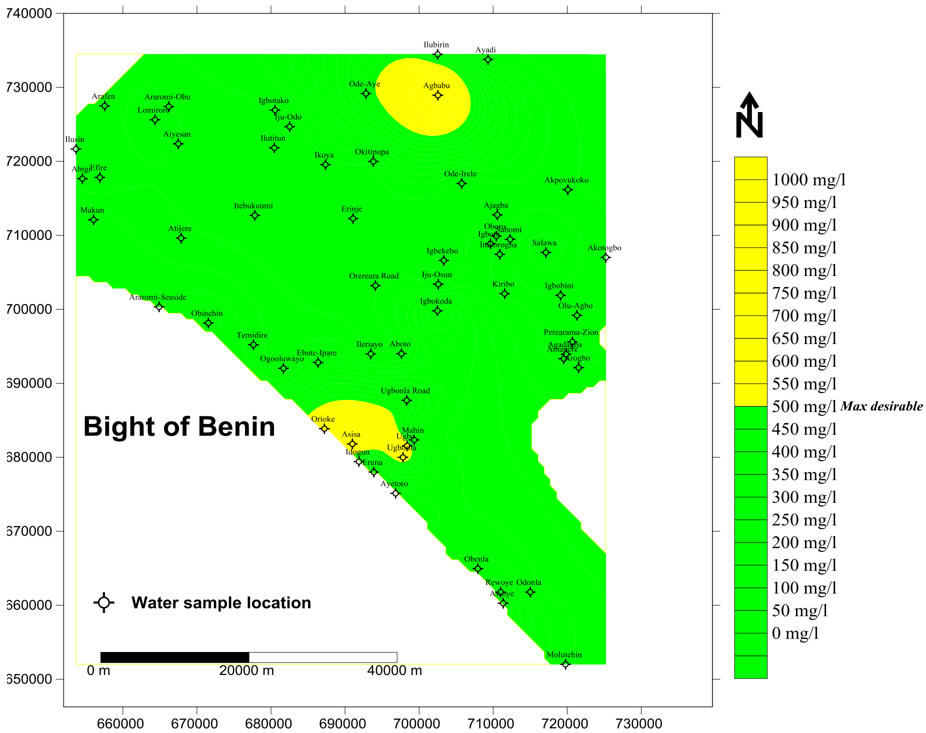

Figure 8: Total dissolved map

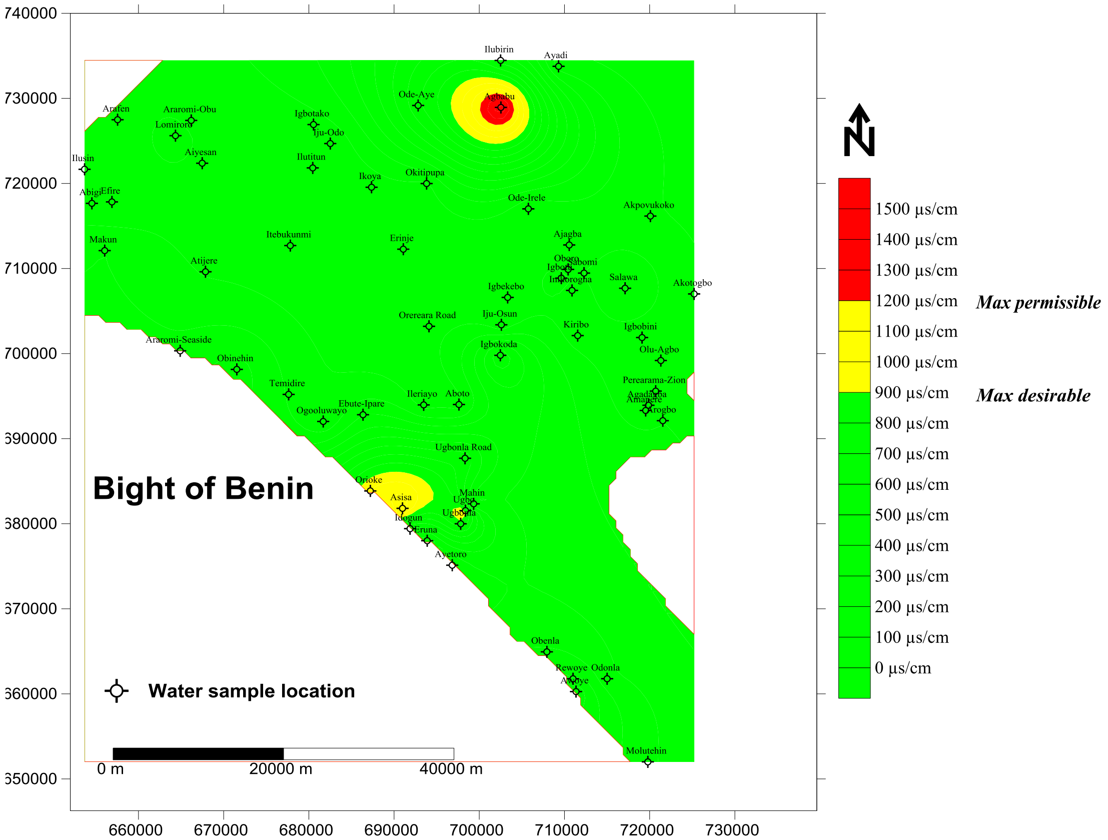

Figure 9: Conductivity map

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