The American Journal of Applied sciences
(ISSN – 2689-0992)
VOLUME 04 ISSUE 07 Pages: 6-29
SJIF IMPACT FACTOR (2020: 5. 276) (2021: 5. 634) (2022: 6. 176)
OCLC – 1121105553 METADATA IF – 7.987

Publisher: The USA Journals

Journal Website: https://theamericanjournals.com/index.php/tajas

Research Article

HYDROCHEMICAL EVALUATION OF GROUNDWATER QUALITY IN HYDROCARBON CONTAMINATED AREAS OF OKOMA COMMUNITY, AHOADA EAST LOCAL GOVERNMENT AREA, RIVERS STATE, NIGERIA

Submission Date: July 05, 2022, **Accepted Date:** July 10, 2022,
Published Date: July 17, 2022 |
Crossref doi: https://doi.org/10.37547/tajas/Volume04Issue07-02

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ABSTRACT

The Hydrochemistry, quality and suitability of the groundwater for drinking, irrigation and industrial purposes in Okoma Community, Ahoada East Local Government Area, Rivers State, Nigeria have been assessed. A total of ten (10) samples of water were collected from hand dug wells in the area and analyzed to determine the physico-chemical parameters. The range values for the parameters are: pH (4.54–5.74), Temperature (28.6–29.8°C), EC (20-150µS/cm), Salinity (0.00–0.05ppt), DO (6.22-15.31ppm), TDS (70–180mg/l), Ca^{2+} (0.003–0.360mg/l), Mg^{2+} (0.048–0.305mg/l), K^{+} (0.405-4.370mg/l), Na^{+} (1.450–10.900mg/l), Fe^{2+} (0.001–0.079mg/l), PO_4^{3-} (0.001– 0.033mg/l), SO_4^{2-} (11.30 –29.70mg/l), NO_3^{-} (0.455–2.380mg/l), Cl^{-} (1.00–24.00mg/l). All parameters analyzed fall within the maximum and permissible limits of both WHO (2011) and NSDWQ (2007) regulatory guidelines except the pH which indicates acidity and therefore unsafe for drinking and industrial purposes. The Water Quality Index (WQI) values which ranges from (201.943–269.780) suggests that the water in the area is 100% of very poor quality and unsuitable for drinking. The Sodium Adsorption Ratio (SAR) values ranging from (1.005–4.787Meq/l) suggests that the groundwater is *good to excellent* for the purpose of irrigation. More and frequent hydro-chemical studies should be carried out in the area to detect any further deterioration of the groundwater quality.

KEYWORDS

Water quality, hydrochemistry, water quality index, contamination, acidity, physic-chemical properties.

INTRODUCTION

Groundwater quality has proved a major requisite for potable water supply, not only in quality but also in quantity. Groundwater potability in its natural state can be greatly affected or altered by both natural processes and anthropogenic activities (Nwankwoala & Udom, 2011). The variation that occurs in groundwater quality for different areas are functions of the physical, bacteriological and chemical components or parameters that are greatly influenced by geological processes and anthropogenic activities (Belkhiri et al., 2010). The very high pressure on groundwater resource and ecosystem generally, in the Niger Delta coastal areas is causing serious threat and degradation of the quality of groundwater, which can likely increase in the future if urgent management policies and measures are not put in place (Nwankwoala, 2011; Nwankwoala et al., 2013). The ability to identify and establish the hydro-geochemical characteristics and the groundwater quality in an area can help to reveal the interaction mechanism between the groundwater and the environment, and to provide us with new insights into water protection practices, management and sustainability (Nag, 2014). Water remains a veritable endowment of nature necessary for life sustenance (Villholth & Rajasooriyar, 2010). Agriculture, industrialization and civilization of mankind all lies on the sustainability of this precious free gift of nature, called water. Unfortunately, unprecedented subjection of these precious resource to exploitation and contamination is due to anthropogenic activities resulting from oil bunkering, artisanal refining of petroleum, agricultural activities, indiscriminate waste disposals and many other activities.

The continuous geometric explosion in human population has really brought about an unprecedented increase in groundwater demand for various human activities and hence placed great importance on water resource, protection and management practices all over the world (Nouri et al., 2006). Human health, the sustenance in agriculture and its growth and the ecosystem in general, the soil and water systems if not effectively managed and protected from all forms of contaminations are all at risk (Akoto et al., 2008).

According to World Health Organization (WHO) (2011), most sickness and disease affecting humans are caused by poor water quality. Pollution of water resources further enhances multiple problems associated with groundwater and put more pressure on the difficulty of finding out available fresh water resources, (Ali et al., 2015). According to Oborie & Nwankwoala (2014), groundwater is the preferred source of drinking water in most developing countries, including Nigeria because of its higher quality and less vulnerability to contamination unlike surface water. Groundwater contamination is simply a process whereby water gradually or suddenly changes its physical, chemical or biological composition and ceases to meet the standard recommended for drinking, agriculture and other purposes (Gay et al., 2010). Groundwater contamination by crude oil, is considered a serious social, economic and environmental problem all over the world, (Duffy et al., 1980).

It is well known that when the chemical constituents or parameters in groundwater exceeds the accepted limits or guidelines, it tends to cause health risks and therefore makes the water not safe or potable for drinking and other uses. According to Udom et al., (1998), groundwater is said to be a major source of potable water supply and its contamination or pollution possess serious environmental risk and health concern to the residents of Niger Delta (Ngerebara & Nwankwoala, 2008). Many health issues and problems as it has been discovered are said to be derived from poor sanitation and poor water management system (Amadi et al., 2012). There is an undeniable fact and assertion that water quality is as important as its quantity in satisfying basic human needs, (Villholth & Rajasooriyar, 2010; Howard, et al., 2006).The Niger Delta is a large and ecologically sensitive region in which various water species (including surface and groundwater, saline and freshwaters) are in dynamic equilibrium (Abam, 1999; Nwankwoala & Ngah, 2014).

Contamination of groundwater is on a steady rise particularly in our urban cities where lots of industrial activities, exponential population growth, commercial agricultural land use, poor waste management system and other factors causing environmental degradation are prevalent (Amadi et al., 2012). The pollution of groundwater will persist if deliberate policies are not put in place to control and manage these environmental degrading activities and factors (Ayotamuno, et al., 2006).

Hydrocarbon contamination of groundwater is prevalent in Okoma community. This is as a result of the aforementioned human activities prevalent in the study area. In the Niger Delta region, especially in the study area where this study is carried out, oil theft, pipe line vandalism, artisanal refining of crude oil and inappropriate waste disposal has been reported to be the main cause (s) of groundwater contamination, thereby affecting the quality of the groundwater as well as causing serious degradation of the environment and posing serious health issues in the region. This study, therefore will be helpful in ascertaining the groundwater status of the area and provide useful data that might be of utmost importance in discovering and solving health related issues prevalent in the area as a result of groundwater contamination. It is therefore necessary to study the groundwater quality and its potability for drinking, irrigation, domestic and agricultural purposes in the area.

THE STUDY AREA

The study area Okoma is a town located in Ahoada East Local Government Area of Rivers State, Eastern Niger Delta, Nigeria. Okoma community is located approximately between latitudes 04°57'20" – 04° 57'45" N and longitudes 006° 38' 25"– 006° 38'39"E in the South South region of Nigeria. Figure 1 is the location map of the study area; while Figure 2 shows the sampling stations within the study area. The study area is about 40 minute drive from Ahoada town and accessible by road. The study area is located in the Niger Delta Rain Forest Vegetation Zone of Nigeria.

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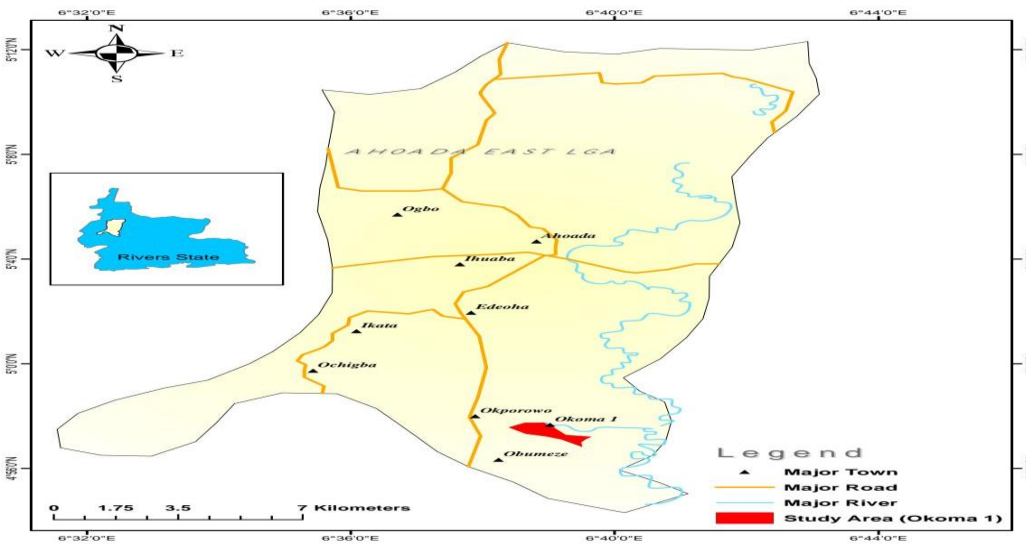

Figure 1: Some Communities in Ahoada East LGA where the study was conducted

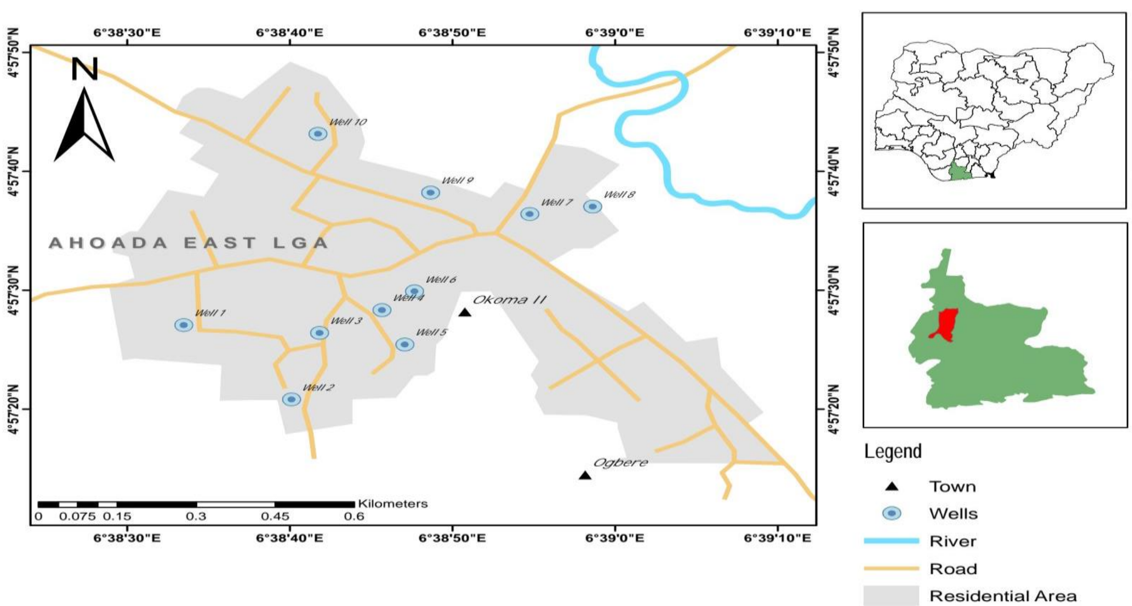

Figure 2: Map Showing the Sampling Locations in Okoma Community

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The study area lies within the Niger Delta Region. So the entire morphology is made up of three dimensional body of marine, transitional, and Continental materials deposited by River Niger during the Tertiary and Quaternary periods. The Tertiary Niger Delta structure is sedimentary, made from regressive complex off-lap sequences of Clastic-sediments ranging in thick stratum of about 9000-1200m (Etu-Efeotor & Akpokodje, 1990). The present day basin of the Niger Delta was formed during the Tertiary period which is a result of the interplay between subsidence and deposition, arising from a succession of transgression and regression of the three-tertiary subsurface litho-stratigraphic units of Akata, Agbada, and Benin formations. There are numerous evidences gotten from samples from various deep wells drilled in the Niger Delta showing that there is a litho-stratigraphic succession in which a regressive sequence is properly defined. (Short & Stauble, 1967), through their various studies carried out in the region have divided the tertiary deltaic complex into three main faces units based on the dominant environmental influences. These three formations have been locally designated (from bottom) as Akata, Agbada and Benin formations, respectively. The Agbada Formation constitutes the main reservoir of hydrocarbon of Niger Delta, the Benin Formation is the main hydrologic unit of the Niger Delta, and the Akata Formation, constitute the source rock of the Niger delta basin because of its abundant microfossils.

The geology of the Niger Delta has been described by various authors like Allen, (1965); Short & Stauble, (1967); Etu-Efeotor, (1981); Azeez (1989); Burker & Dewey, (1972) and Nwankwoala, (2011). Frankl & Cordry (1967) from there earlier investigation provided information on the subsurface distribution of the stratigraphic units of the Niger Delta with deposits comprising of a thick wedge plastic deposits. The Niger Delta is a large ecological region of high sensitivity in which various water species; with the body of water existing in a state of dynamic equilibrium for both surface and sub-surface water (Abam, 1999). The three main sedimentary environments that make up the Niger Delta region are the continental, transitional and marine environment.

The Hydrogeology of the Niger Delta within which the study area is part of have been well researched on and described by various authors; such as Etu-Efeotor, (1981); Edet & Okereke, (2001); Nwankwoala, *et al.*, (2011) and so many others. Etu-Efeotor & Akpokodje, (1990) from their studies concluded that the depth of the water table decreases seawards and varies from 10m (in land) to less than 0.5m at the Coast. The Benin Formation is the water bearing zone (Abam & Nwankwoala, 2020). Benin Formation clayey intercalation has given rise to multi-aquifer system developed due to the interactions of sand and shale (Etu-Efeotor, 1981; Etu-Efeotor & Akpokodje, 1990).

Etu-Efeotor (1981); Nwankwoala *et al.*, (2008) from their investigations delineated in the Niger Delta, into three (3) main aquifer- zones which are upper, middle and lower (Table 1). He further disclosed that the upper zone aquifer materials comprises of sand, gravels and clay, which appeared at shallow depth of approximately 60m, with high yield. Middle zone occurs at lower depth with mangrove and fresh swamps, with having occurrences of clay lenses within the region of aquifers. Marine conditions prevails in the mangrove swamp zone, with thick enclosure of lenses of marine clays. The zone characterized with saline conditions due to the influence of the deltaic front. While in the lower region sand bars and beaches , so boreholes must be deep in order to reach good freshwater aquifers.

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Table 1: Geologic units and Hydro-geologic properties of Niger Delta (Short & Stauble, 1967)

Geologic Unit	Lithology	Age	Hydro-geologic properties
Alluvium (general)	Gravel, sand, clay, silt		
Freshwater backswamp, Meander belt	Sand, clay, some silt gravel		Shallow local aquifers and aquitards, not regionally extensive
		Quaternary	
Mangrove and salt water/backswamps	Medium-fine sands, clay and some silt		
Active/abandoned beach ridges	Sand, clay, and some silt		
Sombreiro-Warri deltaic plain			
	Sand, clay, and some silt		
Benin Formation (Coastal Plain sand)	Coarse to medium sand with subordinate silt and clay lenses	Miocene	Most prolific, regionally extensive aquifer with subordinate lenses of aquitards
Afam clay member	Clay and sandy clay	Oligocene	
Agbada Formation	Mixture of sand, clay and silt	Eocene	Oil & gas reservoirs &aquitards
Akata Formation	Clay	Paleocene	Aquitards

MATERIALS AND METHODS

Groundwater Sample Collection

A total of ten (10) water samples were collected from hand dug wells in the area. Table 2 shows coordinates of Sample locations. Each sample was collected into a 500ml polyethylene bottle. The physical parameters such as temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), and salinity were measured in the field in-situ immediately after sampling (due to the fact that the chemistry of groundwater is very sensitive to environmental variations), using the pH meter, electrical conductivity (EC) meter, total dissolved solid (TDS) meter and the salinity meter. The 500ml polyethylene bottles were completely filled with water to ensure air bubbles were not trapped within the water sample, after first rinsing it with the water from the well in that location. The water samples were also stored at a temperature below 4°C prior to the analysis in the laboratory. Table 3 shows equipment and analytical methods used in their determination.

Table 2: Coordinates of Sample locations/Some key physico-chemical properties

Location	Coordinates	Elevation (m)	pH	Temperature	Salinity (ppt)	TDS (mg/l)	EC (µS/cm)	DO (ppm)
Well 1	4°57’27.07”N 6°38’33.45”E	3.70	4.75	29.2	0.00	70	0.02	7.21
Well 2	4°57’20.81”N 6°38’40.09”E	17.70	4.54	28.6	0.00	100	0.03	8.62
Well 3	4°57’26.41”N 6°38’41.81”E	17.10	4.97	29.1	0.03	140	0.09	15.31
Well 4	4°57’28.34”N 6°38’45.65”E	14.30	5.35	28.7	0.03	160	0.11	11.55
Well 5	4°57’25.44”N 6°38’47.06”E	22.80	4.78	28.7	0.02	140	0.08	6.22
Well 6	4°57’29.91”N 6°38’47.65”E	17.70	4.64	29.3	0.05	180	0.15	9.52
Well 7	4°57’36.41”N 6°38’54.74”E	11.80	5.71	29.8	0.03	150	0.10	9.24
Well 8	4°57’37.04”N 6°38’58.61”E	13.30	5.74	28.8	0.01	90	0.05	9.62
Well 9	4°57’38.21”N 6°38’48.64”E	5.40	4.82	29.1	0.03	130	0.10	8.82
Well 10	4°57’43.15”N 6°38’41.71”E	7.80	4.84	28.7	0.00	80	0.04	9.51

Table 3: Equipment and analytical methods used in their determination

Parameters	Type of Test	Equipment/Analytical Methods	Standards
Temperature	In-situ		
P^H	In-situ	Digital P^H meter	
Electrical Conductivity (EC)	In-situ	Digital conductivity meter	
Total Dissolved Solids (TDS)	In-situ	Digital TDS meter	
Dissolved Oxygen (DO)	In-situ	Digital DO meter	

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Salinity	In-situ	Digital salinity meter	
Sulphate (mg/l)	Laboratory	Turbidimetric Method	APHA 4500-SO_4^{2-}E
Nitrate (mg/l)	Laboratory	Cadmium Reduction method	APHA 4500-NO_3^-E
Chloride (mg/l)	Laboratory	Argentometric method	APHA 4500-Cl^-B
Phosphate (mg/l)	Laboratory	V-12 Spectrophotometer	APHA 4500-P C
Calcium (mg/l)	Laboratory	PG Instrument Atomic Absorption Spectrophotometer method	APHA 3111B
Sodium (mg/L)	Laboratory	PG Instrument Atomic Absorption Spectrophotometer method	APHA 3111B
Magnesium (mg/l)	Laboratory	PG Instrument Atomic Absorption Spectrophotometer method	APHA 3111B
Potassium (mg/l)	Laboratory	PG Instrument Atomic Absorption Spectrophotometer method	APHA 3111B
Iron (mg/l)	Laboratory	PG Instrument Atomic Absorption Spectrophotometer method	APHA 3111B

RESULT INTERPRETATION AND DISCUSSION

The results of the hydro-chemical analysis and evaluation of the various wells in the study area (Table 4) ranges as follows: Temperature (28.6 – 29.8°C) with Mean value of (29.0), SD (0.374) and CV (0.013); pH (4.54 – 5.74) with Mean value of (5.014), SD (0.432) and CV (0.086); EC (20 - 150µs/cm) with Mean value of (68.00), SD (45.166) and CV (0.664); Salinity (0.00 – 0.05ppt) with Mean value of (0.020), SD (0.017) and CV (0.850); DO (6.22 – 15.31ppm) with Mean value of (9.562), SD (2.477) and CV (0.259); TDS (70 – 180mg/l) with Mean value of (124.00), SD (36.878) and CV (0.297);Ca^{2+} (0.003 – 0.360mg/l) with Mean value of (0.101), SD (0.144) and CV (1.432); Mg^{2+} (0.048 – 0.305mg/l) with Mean value of (0.175) SD (0.095) and CV (0.542); K^+ (0.405 – 4.370mg/l) with Mean of (2.322), SD (1.563) and CV (0.673); Na^+ (1.450 – 10.900mg/l) with Mean value of (6.633), SD (3.361) and CV (0.507); Fe^{2+} (0.001 – 0.079mg/l) with Mean value of 0.016), SD (0.023) and CV (1.411); PO_4^{3-} (0.001 – 0.033mg/l) with Mean value of (0.007), SD (0.010) and CV (1.419); SO_4^{2-} (11.30 – 29.70mg/l) with Mean value of (18.610), SD (6.926) and CV (0.372); NO_3^- (0.455 – 2.380mg/l) with Mean value of (1.142), SD (0.714) and CV (0.625); and Cl^- (1.00 – 24.00mg/l) with Mean value of (12.200), SD (6.663) and CV (0.546). From the given data sets above, the pH is the measure of the Acidity or Alkalinity of the water, with its values in the various Well locations in the study area falling below the WHO (2011) and NSDWQ (2007) guidelines, therefore making the water acidic and unfit for drinking purposes. Table 5 shows the descriptive statistics of the analyzed parameters while Table 6 shows the concentration of the various ions in meq/l. Figure 6 shows the relationship between EC, TDS, pH & DO concentrations.

Soluble Sodium Percentage (SSP)

The SSP values from the different Well Locations ranges from (72.09 – 87.91%) with Mean value of (78.79) and SD (4.540) as presented in (Table 11). based on Richards (1954). The SSP values for Well (2 - 5 and 10) shows that the groundwater is poor for irrigation, while Wells (1, 3, 4, 6, 7, 8 and 9) are of fair quality for irrigation sustainability. Therefore the groundwater in the area requires urgent protection and management policy and treatment to curb further deterioration in the area.

Salinity Potential (PS)

The PS values from the different Well Location ranges from (0.555 – 1.241Meg/l) with Mean value of (0.957) and SD (0.242). Based on Doneen, (1964) Scheme of Classification with the PS values of the wells all below 5 indicating they are good for Irrigation Purposes. Higher values of PS above 5 are capable of damaging soils and might generally affect crop yield (Table 13).

Electrical Conductivity (EC)

The analyzed values of EC for the different well Samples in the area ranges from (10 – 100µs/cm) with Mean value of (68.00) and SD (45.166). All the EC values for the different Wells fall below the WHO (2011) and NSDWQ (2007) guidelines as presented in (Table 11), and thereby making the water suitable for Irrigation Purposes.

Total Dissolved Solids (TDS)

The TDS values in the study area ranges from (70 – 180mg/l) with Mean value of (124.00) and SD (36.878) which is lower than that of WHO (2011) and NSDWQ (2007) guidelines which indicates that the water is non – saline and Excellent for Irrigation Purpose (Table 11).

Result Evaluation for Physico – Chemical Parameters

Generally the various physico – chemical parameters for the different well falls below or within the WHO (2011) and NSDWQ (2007) recommended guidelines for drinking water quality except the pH which deviates from the permissible limit of both standards, therefore making the water acidic and unfit for drinking and other domestic uses. Other indices used for calculations using the various parameters indicates that the water is of very poor water quality for drinking purposes but good to efficient for Irrigation purposes and unfit for Industrial purposes. Figure 3 shows the range variation concentrations of physico-chemical parameters.

Result for Cations and Anions

The Chemical parameter analyzed and evaluated comprises of both the cations and anions. For this study five (5) cations and four (4) anions were used. The cations ranges are Ca^{2+} (0.003 – 0.360mg/l), Mg^{2+} (0.048 – 0.305mg/l), K^{+} (0.405 – 4.370), Na^{+} (1.450 – 10.900mg/l), Fe^{2+} (0.001 – 0.079mg/l), with mean ion concentration of the cations in the order (Na^{+}> K^{+}> Mg^{2+}> Ca^{2+}> Fe^{2+}). The Anions which are the negatively charged ions or radicals haves values ranging as follows: PO_4^{3-} (0.001 – 0.033mg/l), SO_4^{2-} (11.30 – 29.70mg/l), NO_3^{-} (0.455 – 2.380mg/l) with Mean value of (1.142), SD (0.714) and CV (0.625); and Cl^{-} (1.00 – 24.00mg/l). With Mean anion concentration arranged in the order (SO_4^{2-}>Cl^{-}>NO_3^{-}>PO_4^{3-}. Figure 4 and 5 shows concentration variation of Cations and Anions while Figures 7 – 16 shows the concentration variations of the Wells 1 - 10.

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Table 4: Laboratory Results of Water Quality Analysis of Okoma Community

Sample ID	Temp. 0C	pH	EC (µs/cm)	Salinity (ppt)	DO(ppm)	TDS(mg/l)	Ca^{2+}(mg/l.)	Mg^{2+}(mg/l.)	Na^{+}(mg/l.)	K^{+}(mg/l.)	Fe^{2+}(mg/l.)	PO_4^{3-} mg/l.)	SO_4^{2-} mg/l.)	NO_3^- (mg/l.)	Cl^- (mg/l)
Well I	29.2	4.75	20	0.00	7.21	70	0.079	0.048	1.450	0.646	0.024	0.001	13.30	0.455	1.00
Well 2	28.6	4.54	30	0.00	8.62	100	0.003	0.051	2.480	0.752	0.005	0.005	26.70	0.545	7.00
Well 3	29.1	4.97	90	0.03	15.31	140	0.003	0.186	8.150	4.070	0.015	0.033	29.70	0.872	15.00
Well 4	28.7	5.35	110	0.03	11.55	160	0.247	0.305	9.160	3.160	0.079	0.018	23.20	2.380	12.00
Well 5	28.7	4.78	80	0.02	6.22	140	0.003	0.125	7.990	2.580	0.005	0.001	19.50	1.090	18.00
Well 6	29.3	4.64	150	0.05	9.52	180	0.003	0.259	10.900	4.370	0.005	0.002	15.30	1.840	24.00
Well 7	29.8	5.71	100	0.03	9.24	150	0.360	0.281	10.400	2.700	0.015	0.002	24.00	2.130	16.00
Well 8	28.8	5.74	50	0.01	9.62	90	0.303	0.240	3.840	0.405	0.005	0.001	11.80	0.945	5.00
Well 9	29.1	4.82	10	0.03	8.82	130	0.003	0.172	7.710	3.830	0.005	0.005	11.30	0.691	12.00
Well 10	28.7	4.84	40	0.00	9.51	80	0.003	0.087	4.250	0.707	0.005	0.005	11.30	0.473	12.00
Minimum	28.6	4.54	10	0.01	6.22	70	0.003	0.048	1.450	0.405	0.001	0.001	11.30	0.455	1.00
Maximum	29.8	5.74	150	0.05	15.31	180	0.360	0.305	10.900	4.370	0.079	0.033	29.70	2.380	24.00
Mean	29.000	5.014	68.000	0.020	9.562	124.000	0.101	0.175	6.633	2.322	0.016	0.007	18.610	1.142	12.200
Std Deviation	0.3742	0.4325	45.166	0.017	2.4775	36.878	0.1443	0.095	3.3612	1.5632	0.023	0.0104	6.9262	0.7141	6.6633
C.V	0.0129	0.0863	0.6642	0.8498	0.2591	0.2974	1.4326	0.5419	0.5067	0.6732	1.4109	1.4193	0.3722	0.6253	0.5462
WHO 2011	28	6.5-8.5	1000	0.07	180	1000	75	50	200	55	0.3	5	500	50	250.00
NSDWQ (2007)	NA	6.5 - 8.5	1000	0.07	180	1000	75	30	200	200	0.3	NA	500	50	250.00

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Table 5: Descriptive Statistics of the Analyzed Parameters

Parameters	Units	Min	Max	Mean	S.D	C.V
Temperature	°C	28.6	29.8	29.000	0.374	0.013
pH		4.54	5.740	5.014	0.433	0.086
Electrical Conductivity	µS/cm	10.00	150.00	68.000	45.166	0.664
Salinity	ppt	0.010	0.050	0.020	0.017	0.850
Dissolved Oxygen (DO)	ppm	6.220	15.310	9.562	2.478	0.259
Total Dissolved Solids (TDS)	mg/l	70.00	180	124.000	36.878	0.297
Calcium (Ca^{2+})	mg/l	0.003	0.360	0.101	0.144	1.433
Magnesium (Mg^{2+})	mg/l	0.048	0.305	0.175	0.095	0.542
Potassium (K^{+})	mg/l	0.405	4.370	2.322	1.563	0.673
Sodium (Na^{+})	mg/l	1.450	10.900	6.633	3.361	0.507
Iron (Fe^{2+})	mg/l	0.001	0.079	0.016	0.023	1.411
Phosphate (PO_4^{3-})	mg/l	0.001	0.033	0.007	0.010	1.419
Sulphate (SO_4^{2-})	mg/l	11.30	29.70	18.610	6.926	0.372
Nitrate (NO_3^{-})	mg/l	0.455	2.380	1.142	0.714	0.625
Chlorine (Cl^{-})	mg/l	1.000	24.000	12.200	6.663	0.546

Table 6: Concentration of the various ions in meq/l

Well ID	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Fe^{2+}	PO_4^{3-}	SO_4^{2-}	NO_3^{-}	Cl^{-}
Well 1	0.0039	0.0040	0.0165	0.0631	0.0009	0.00003	0.2769	0.0073	0.0290
Well 2	0.0001	0.0042	0.0192	0.1079	0.0002	0.0002	0.5559	0.0088	0.1975
Well 3	0.0001	0.0153	0.1041	0.3545	0.0005	0.0011	0.6184	0.0141	0.4231
Well 4	0.0123	0.0251	0.0808	0.3984	0.0028	0.0006	0.4831	0.0384	0.3385
Well 5	0.0001	0.0104	0.0660	0.3475	0.0001	0.00003	0.4060	0.0776	0.5078
Well 6	0.0002	0.0213	0.1180	0.4741	0.0002	0.0001	0.3186	0.0297	0.6670
Well 7	0.0180	0.0231	0.0691	0.4524	0.0005	0.0001	0.4997	0.0344	0.4513
Well 8	0.0151	0.0197	0.0104	0.1670	0.0002	0.00003	0.2457	0.0152	0.1410
Well 9	0.0001	0.0142	0.0980	0.3354	0.0002	0.0002	0.2353	0.0111	0.3385
Well 10	0.0002	0.0072	0.0181	0.1849	0.0002	0.0002	0.2352	0.0076	0.3385

The American Journal of Applied sciences
(ISSN – 2689-0992)
VOLUME 04 ISSUE 07 Pages: 6-29
SJIF IMPACT FACTOR (2020: 5. 276) (2021: 5. 634) (2022: 6. 176)
OCLC – 1121105553 METADATA IF – 7.987
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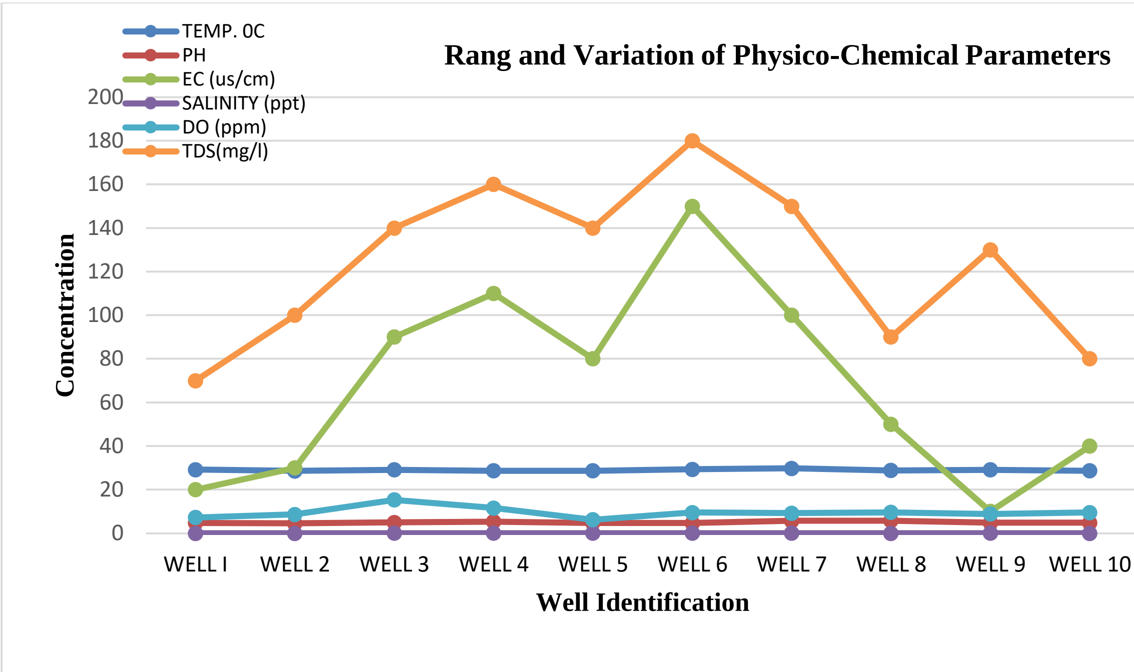

Figure 3: Range variation concentration of physico-chemical parameters

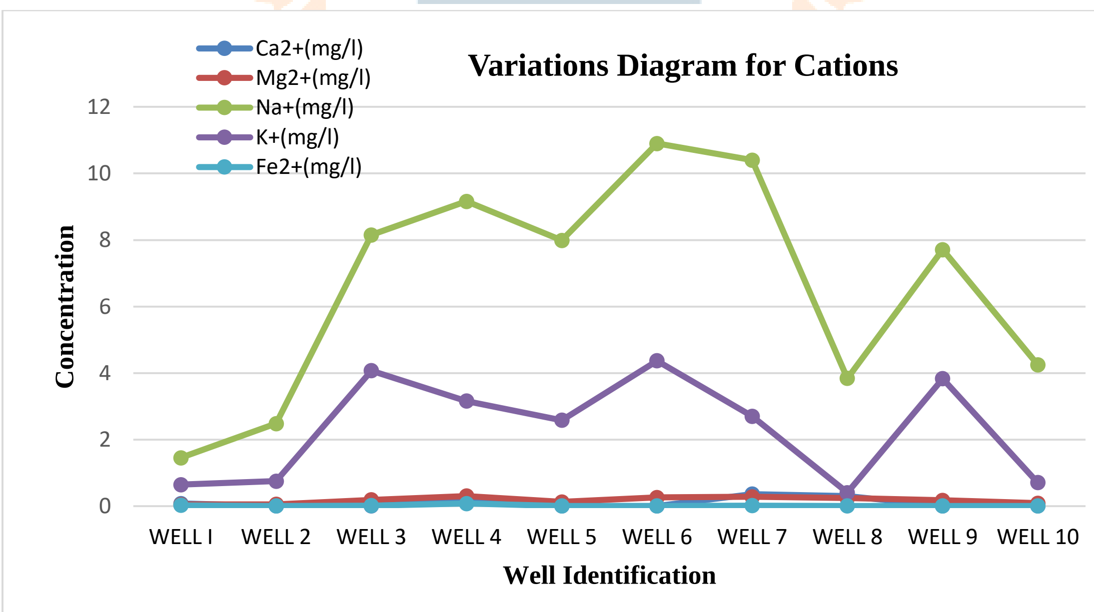

Figure 4: Concentration Variation of Cations

The American Journal of Applied sciences
(ISSN – 2689-0992)
VOLUME 04 ISSUE 07 Pages: 6-29
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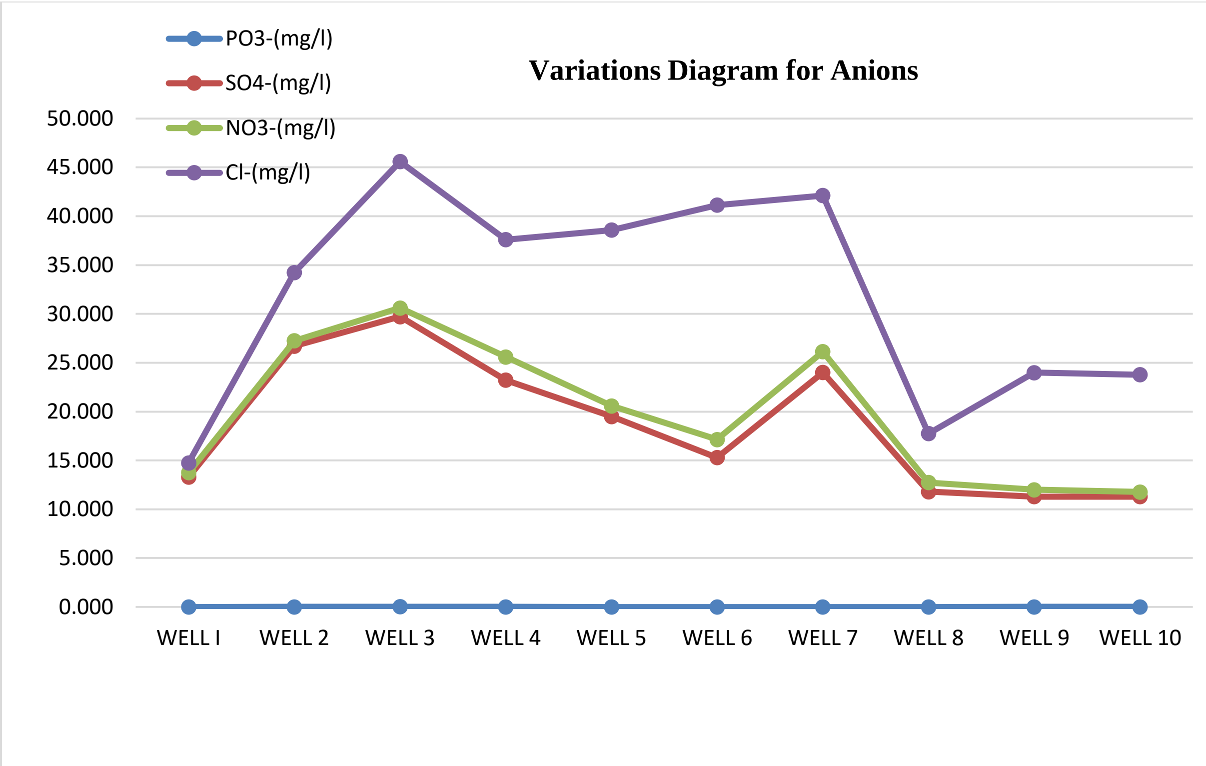

Figure 5: Concentration Variation for Anions

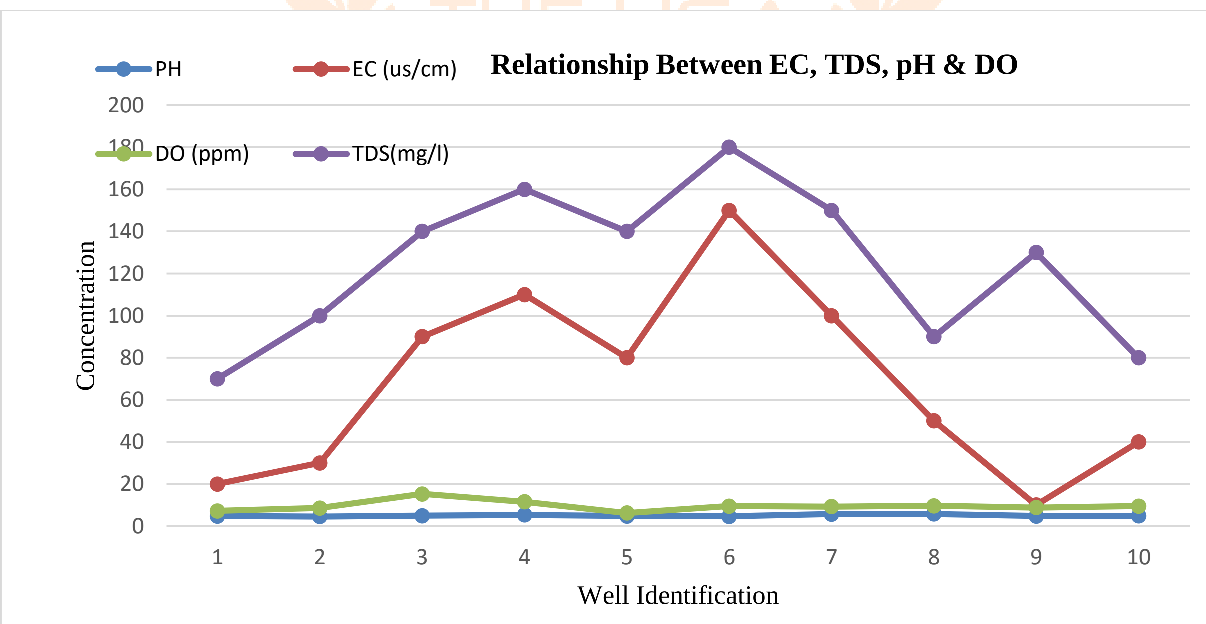

Figure 6: Relationship between EC, TDS, pH & DO concentrations

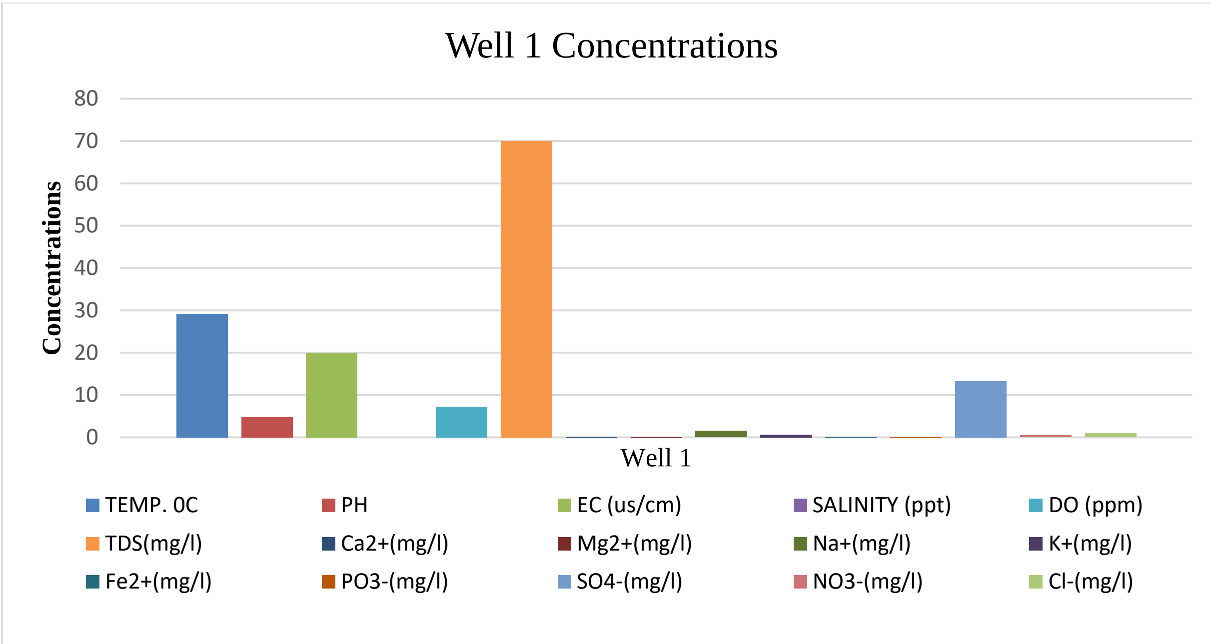

Figure 7: Concentration variation of Well 1 Parameters

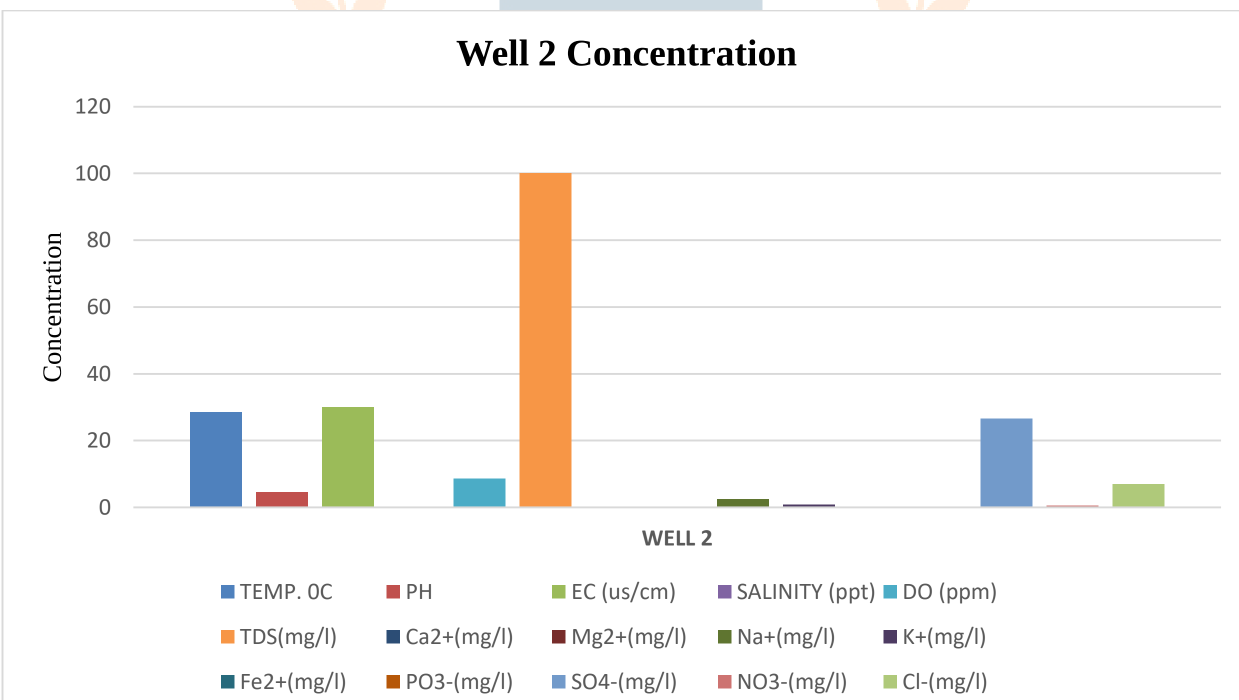

Figure 8: Concentration variation of Well 2 Parameters

The American Journal of Applied sciences
(ISSN – 2689-0992)
VOLUME 04 ISSUE 07 Pages: 6-29
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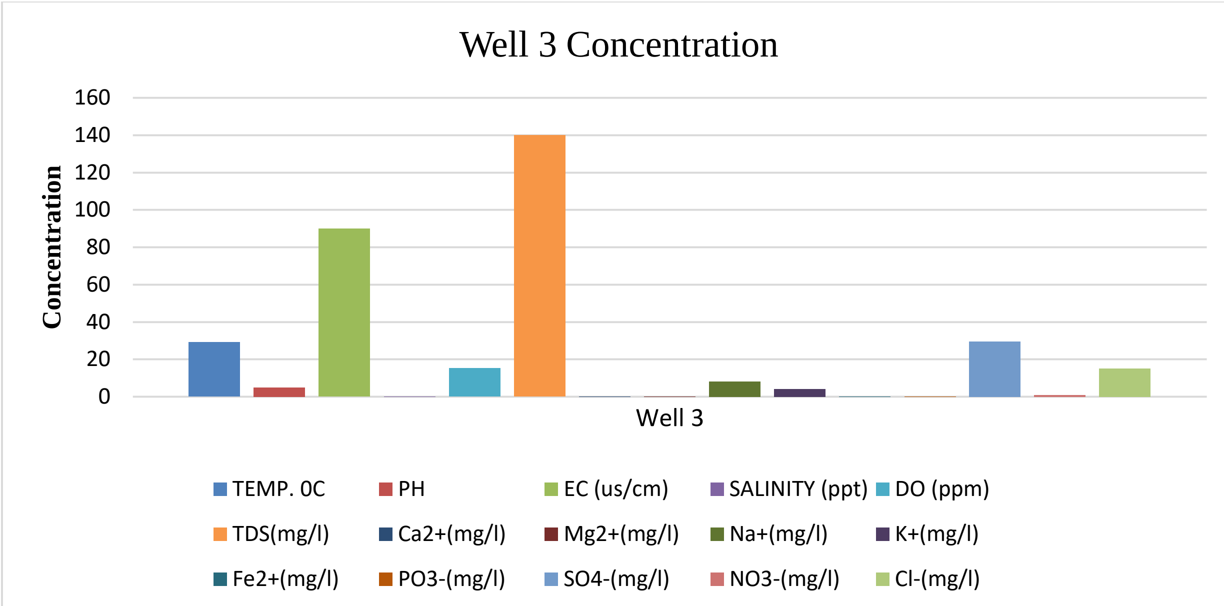

Figure 9: Concentration variation of Well 3 Parameters

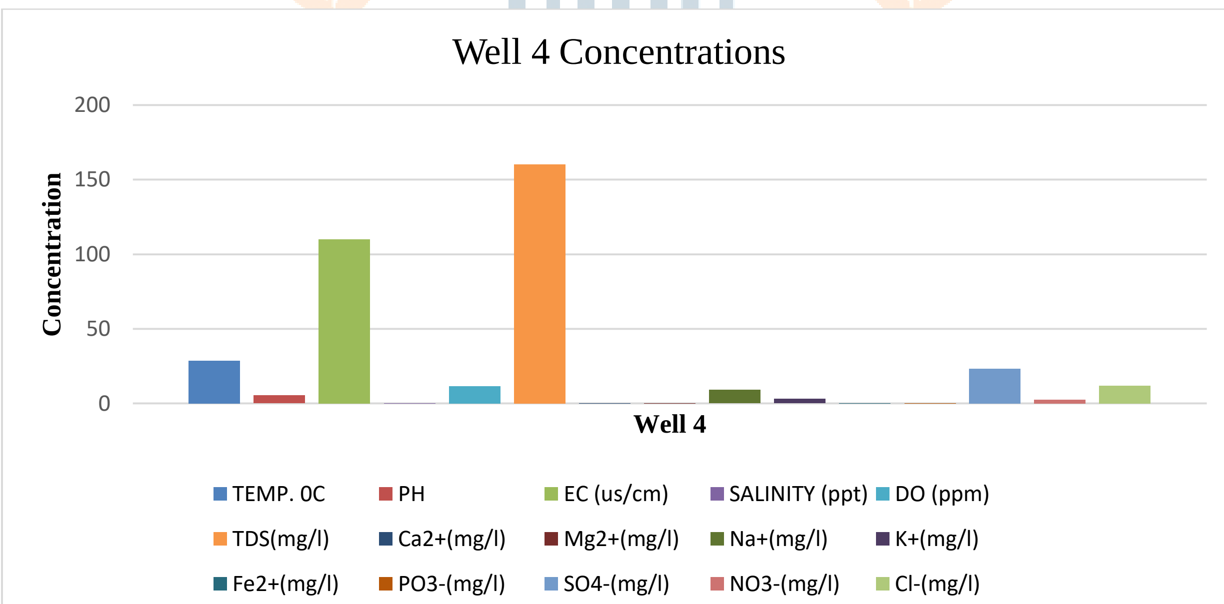

Figure 10: Concentration variation of Well 4 Parameters

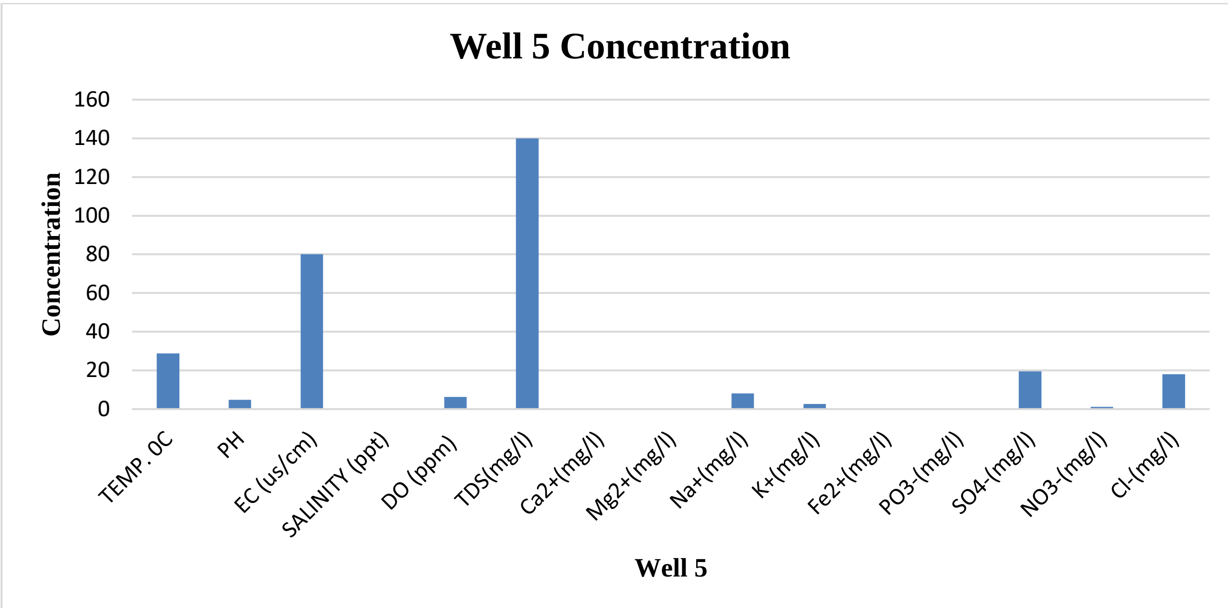

Figure 11: Concentration variation of Well 5 Parameters

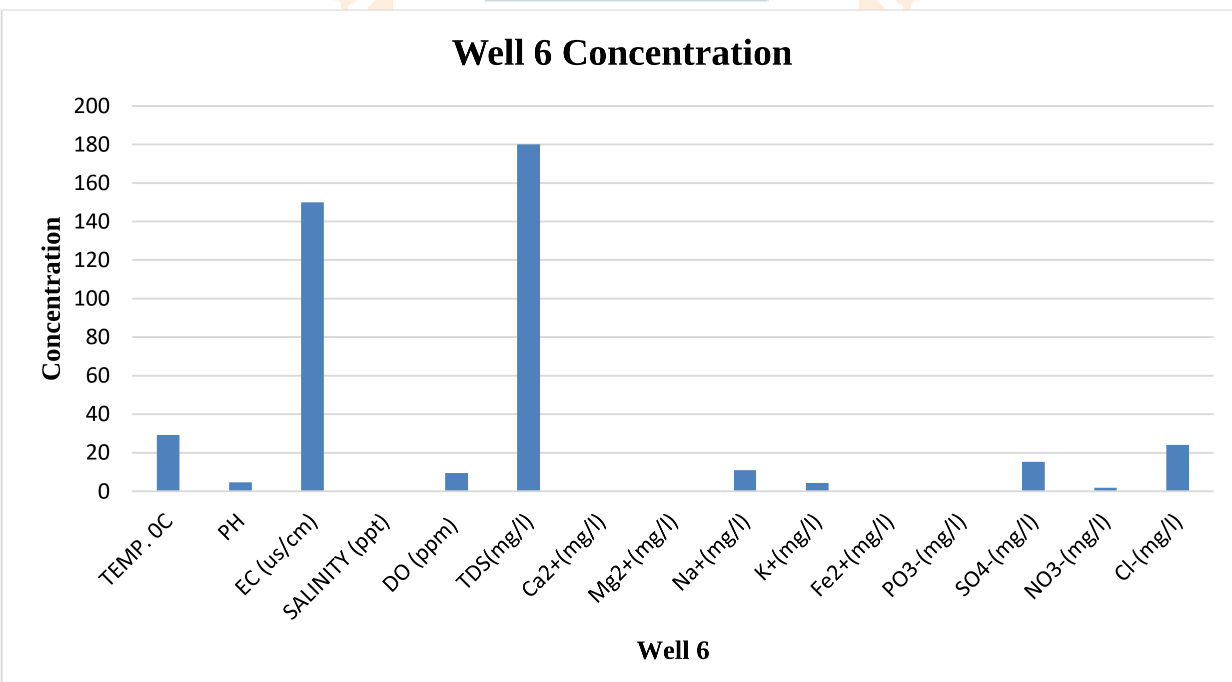

Figure 12: Concentration variation of Well 6 Parameters

The American Journal of Applied sciences
(ISSN – 2689-0992)
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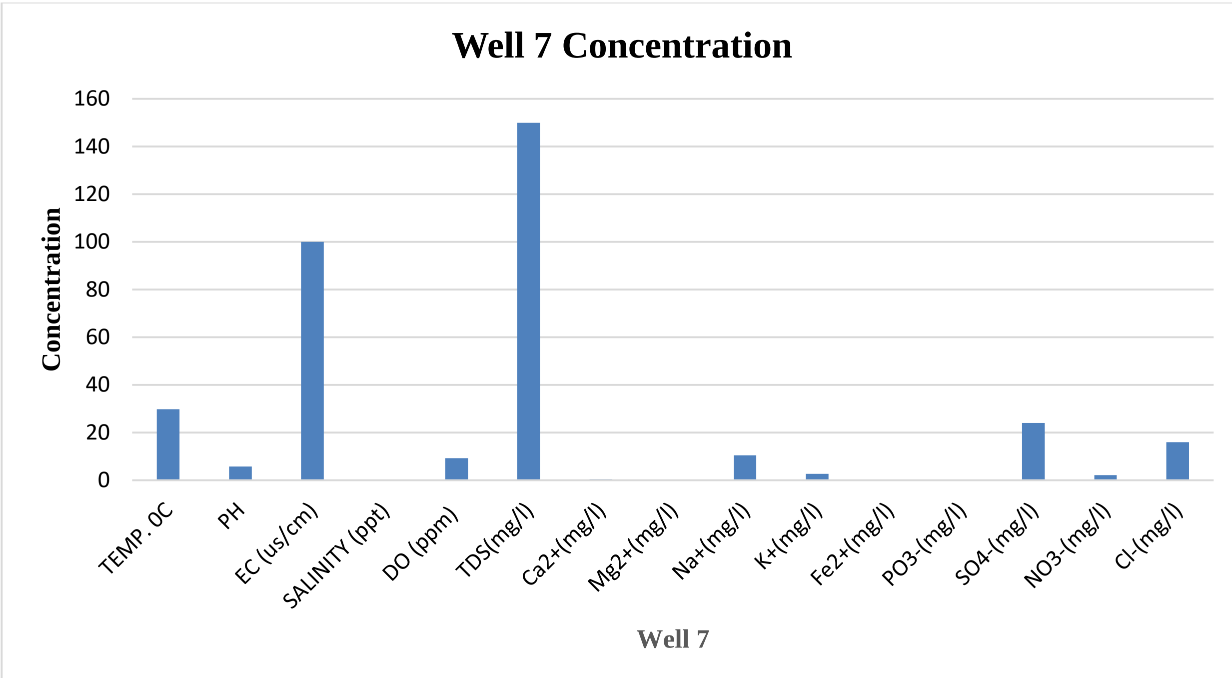

Figure 13: Concentration variation of Well 7 Parameters

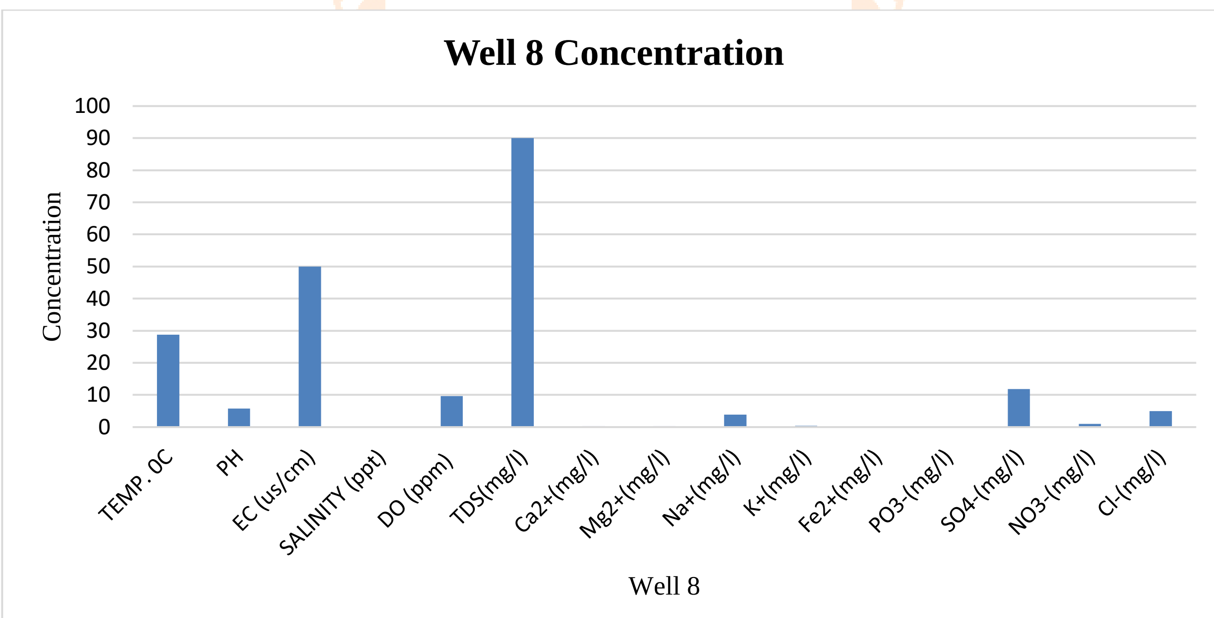

Figure 14: Concentration Variation of Well 8 Parameters

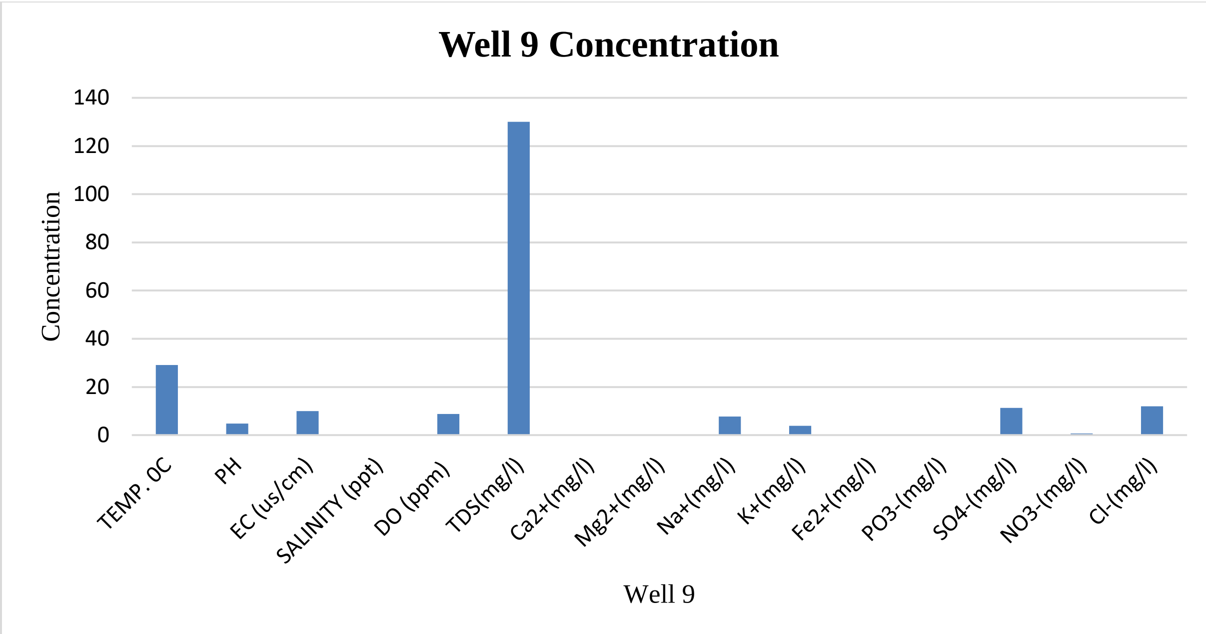

Figure 15: Concentration Variation of Well 9 Parameters

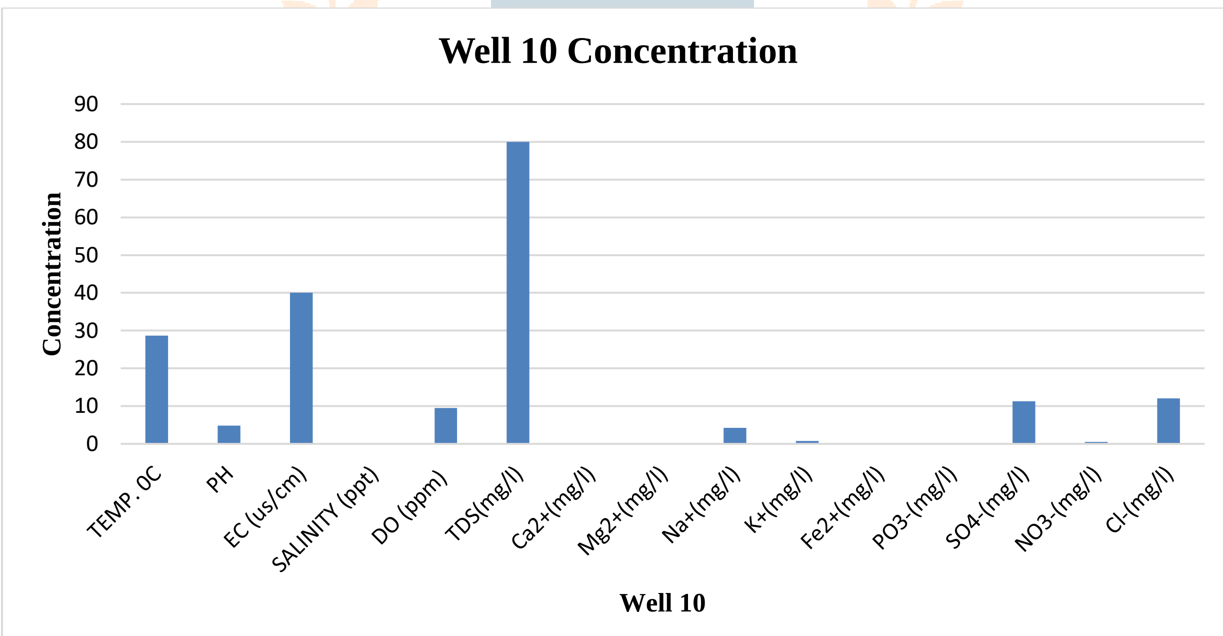

Figure 16: Concentration Variation of Well 10 Parameters

The American Journal of Applied sciences
(ISSN – 2689-0992)
VOLUME 04 ISSUE 07 Pages: 6-29
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OCLC – 1121105553 METADATA IF – 7.987
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Suitability for Industrial Usage

The mean values of some parameters (pH, TDS, Cl^- and Fe^{2+}) were compared with the AWWA, (1971) guidelines for industrial waters, with all parameters falls below the guidelines (Table 7). The pH Mean values are very low making the water acidic and unfit for Industrial usage.

Suitability for Drinking Purposes

For this Study, the Water Quality Index (WQI) was used to delineate the quality of groundwater in the area, and to ascertain its suitability for drinking purposes. The classification of the water quality based on the WQI values is generally classified into five main types of water class: excellent, good, poor, very poor and unsuitable water class as presented in (Table 9). This classification helps to show the groundwater suitability of in the study area for consumption and other purposes. Water Quality Index (WQI) Values were calculated for each of the well locations and compared alongside the Standard WQI Table to ascertain the Water Class the different wells falls into and its suitability. The Mean value for pH shows that the water is acidic and deviates from both the WHO (2011) and NSDWQ (2007) standards indicating that the water is of very poor quality and unsuitable for drinking.

Water Quality Index (WQI)

The WQI is a very effective method and procedure is employed to measure, describe and classify the water quality of an area. The assigned weight (w_i)and calculated Relative Weight (W_i) of WQI are presented in (Table 9), and the results of the determined WQI values, water class and status of the water quality based on (Vasanthavigar *et al*., 2010) scheme for the different wells in the study area is presented in Table 9. The WQI values ranges from (201.943 – 269.780) indicating a 100% very poor water quality and unfit for consumption.

Suitability for Agricultural and Irrigation Purposes

Some Irrigation Indices used for determining the suitability of the groundwater for irrigation and agricultural purposes in the study area are the Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (Na%) and Salinity Potential (PS). The values of these Indices and other irrigation parameters like the (EC) and (TDS) are presented in (Tables 12, 13, 14).

Sodium Adsorption Ratio (SAR)

The SAR values from the different Well Locations ranges from (1.005 – 4.787Meq/l) with Mean value of (3.105) and SD (1.294) as presented in Tables 11 & 12, based on Richards, (1954) Scheme. The SAR values of all the Wells in the Study Area, has values<10 which indicates that the groundwater is excellent for Irrigation purposes and therefore viable for agriculture.

Table 7: Mean Parameters comparison with AWWA (1971) Guidelines for Industrial Water Use.

Parameters.	Units.	Mean.	AWWA (1971)
pH		5.014	6.50 – 8.30
TDS	Mg/l	124	500 – 1500
Cl^-	Mg/l	12.20	20 – 250
Fe^{2+}	Mg/l	0.015	0.10 – 1.00

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Table 8: Assigned Weight, relative weight, Alongside the WHO (2011) and NSDWQ (2007) Standards for each Parameter.

Parameters	Weight (w_i)	Relative Weight (W_i)	WHO (2011)	NSDWQ (2007)
Temperature	1	0.02	NA	NA
pH	3	0.06	6.5 -8.5	6.5 -8.5
EC	2	0.04	1000	1000
Do	3	0.06	180	180
TDS	5	0.10	1000	1000
Ca^{2+}	4	0.08	75	75
Mg^{2+}	4	0.08	50	30
K^{+}	3	0.06	55	55
Na^{+}	5	0.10	200	200
Fe^{2+}	4	0.08	0.3	0.3
PO_4^{3-}	4	0.08	5.0	NA
SO_4^{2-}	5	0.10	500	500
NO_3^{-}	4	0.08	50	50
Cl^{-}	5	0.10	250	250
Total Sum	52	1.04		

Table 9: Water Quality Index Classification based on WQI Value (Ramakrishnaiah *et al.*, 2009)

Water Quality Index (WQI) Value	Water Class	Status of Water Quality
< 50	I	Excellent Water Quality
50 – 100	II	Good water Quality
100 – 200	III	Poor Water Quality
200 – 300	IV	Very poor Water Quality
> 300	V	Unsuitable Water Quality

Table 10: WQI Results for the groundwater analysis for the different wells

Well ID	WQI Values	Status of Water Quality	Class of Water	Interpretation
Well 1	202.535	Very Poor Water Quality	IV	The Water Quality Status in the study area are 100% of very poor quality, since they all fall between the class IV (200 – 300) of the WQI Value
Well 2	201.943	Very Poor Water Quality	IV	
Well 3	242.211	Very Poor Water Quality	IV	
Well 4	269.780	Very Poor Water Quality	IV	
Well 5	224.220	Very Poor Water Quality	IV	
Well 6	249.416	Very Poor Water Quality	IV	
Well 7	254.120	Very Poor Water Quality	IV	
Well 8	218.619	Very Poor Water Quality	IV	
Well 9	216.717	Very Poor Water Quality	IV	
Well 10	255.033	Very Poor Water Quality	IV	

Table 11: Some parameter and model limits for rating Water Quality and its suitability for Irrigation (Ayers & Westcot, 1985; Wilcox, 1950)

Category	SAR (Meq/l)	SSP (Na%)	EC (µs/cm)	TDS (mg/l)	Irrigation Sustainability
I	< 10	< 20	<117.509	< 250	Excellent
II	10 – 18	20 – 40	117.509 – 508.61	250 – 500	Good
III	18 – 26	40 – 80	508.61	500 – 1500	Fair
IV	>26	>80	>508.61	1500 – 5000	Poor

Table 12: Wilcox Modified Water Quality Standard for Irrigation (Todd, 1980)

Water Class	SAR (Meq/l)	Salinity Hazard	EC (µs/cm)	TDS (mg/l)
Excellent	< 10	Low	< 250	< 250
Good	10 – 18	Medium	250 – 750	250 – 500
Permissible	18 – 26	High	750 – 2000	500 – 1500
Doubtful	26 – 30	Very High	2000 – 3000	1500 – 5000

Table 13: Different Parameters and Indices for rating Water Quality and its Suitability for Irrigation.

Well ID	SAR (Meq/l)	SSP (Na %)	PS (Meq/l)	EC (µS/cm)	TDS (mg/l)
1	1.005	72.09	0.555	20	70
2	2.301	82.01	0.943	30	100
3	4.033	74.78	1.210	90	140
4	2.914	77.12	1.034	110	160
5	4.787	81.95	1.145	80	140
6	4.581	78.06	1.241	150	180
7	3.155	80.41	1.158	100	150
8	1.266	78.70	0.637	50	90
9	3.960	74.91	0.824	10	130
10	3.051	87.91	0.823	40	80

Table 14: Summary Statistics of Groundwater Indices for Irrigation

Irrigation Parameters	Minimum	Maximum	Mean	Standard Deviation
SAR (Meq/l)	1.005	4.787	3.105	1.294
SSP (Na %)	72.09	87.09	78.79	4.540
PS (Meq/l)	0.555	1.241	0.957	0.242
EC (µS/cm)	10	150	68	45.166
TDS (mg/l)	70	180	124	36.878

SUMMARY AND CONCLUSION

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This study was designed to investigate the quality of groundwater of the study area and other physico – chemical parameters in comparison with recognized world standards and guidelines for sustainable water for the various usage (s) or purposes. The Water Quality Index (WQI) and pH for this study was employed to ascertain the groundwater suitability in the area for drinking purposes and for other domestic uses. Irrigation Indices such as Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), Salinity Potential (PS), Electrical Conductivity (EC) and Total Dissolved Solids (TDS) were employed to ascertain the viability of the water in the area for Irrigation Purposes. While the Mean values of pH, TDS, Cl^-, Fe^{2+} were used and compared with the AWWA (1971) guidelines for industrial water use.

The groundwater assessment in the study area for the purposes of drinking shows that the water is acidic for all the different well locations exceeding those of WHO (2011) and NSDWQ (2007) regulatory guidelines for potable drinking water, indicating that the water is unsafe for consumption. All other parameters apart from the pH are within the regulatory standards. Also the WQI values shows that 100% of the water status from the different wells are of very poor water class. The groundwater Assessment for Irrigation purposes using the various irrigation indices such as (SAR, SSP, PS, EC and TDS) indicates that the water is fair to excellent for Irrigation Purposes.

The hydro-chemical analysis of groundwater for this study based on the physico – chemical parameters and other water quality has showed that the water in the area is of very poor quality and unsafe for drinking purposes. Regular hydro-chemical studies should be carried out in the area to detect any further deterioration of the groundwater quality. Also, strict measures should be put in place to discourage or minimize the cause (s) of water quality deterioration in the area. The high acidic pH values in the study area should be treated with sodium bicarbonate, to reduce the acidity and keep the water in the area within the regulatory standards and requirement for the various purposes.

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VOLUME 04 ISSUE 07 Pages: 6-29
SJIF IMPACT FACTOR (2020: 5. 276) (2021: 5. 634) (2022: 6. 176)
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