

# Groundwater Quality Assessment in X-17 Field, Sapele, Niger Delta Basin

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**Abstract**-Quantitative analysis of chemical components of environmental and health concerns in fifteen groundwater samples from X-17 Field located in the Niger Delta area, in order to evaluate groundwater resource quality in the area of study has been presented in this work. Percussion drilling method enabled the retrieval of undisturbed sediment samples that were described for lithologic characteristic of the near-surface sedimentologic environment. Twelve parameters (turbidity, TSS, DO, BOD, COD, Alkalinity, Hardness, Salinity, Nitrate, Phosphate, Heavy Metals and TPH) were analysed and quantified for this study. A comparative assessment of quantitative values of the different chemical parameters analysed against regulated standards showed that the values were generally below or within the accepted environmental limits for these parameters with some exceptions. Values of the ambient groundwater temperature, Fe and Pb show exceedences in some parts of the study area, indicating contamination of groundwater by probably oil exploration and exploitation activities which is the main industrial activity in the area of study

**Keywords**-Groundwater Quality, Groundwater Contaminants, Niger Delta, Environmental Standards, Pollution

## I. INTRODUCTION

The quality of groundwater is a function of its chemical and biochemical constituents which in turn determine its usefulness for domestic, industrial and agricultural use. Dissolved constituents in groundwater may be from the natural geologic environment or contributed by anthropogenic activities that have been introduced into the hydrologic cycle. Where the dissolved constituents are anthropogenic in nature, the quality of groundwater is compromised. As a result of our consumptive way of life, the groundwater environment is being assaulted with an ever-increasing number of soluble chemicals (Freeze and Cherry, 1979). Several sources exist through which the natural chemical balance of groundwater can become altered. These include, mostly in the Niger Delta area, the burning of fossil fuels, unconventional wastes disposal, and oil spillage etc.

In recent years much emphasis has shifted from groundwater supply to considerations of groundwater quality both in industrialized and third world nations. The vast subsurface reservoir of fresh groundwater that was only a few decades ago relatively unblemished has become highly

degraded and in most parts of the Niger Delta, completely unfit for domestic use due to man's activities and lack of environmental best practices in the industrial and domestic domains. The challenges posed by groundwater quality degradation have been evident for a long time in oil producing regions worldwide. These have been the result of mostly oil spillage onto the land area and acid rain both of which ultimately ends up in the subsurface water reservoir upon which man depends.

Although solutions to the problem of groundwater pollution is expected to have been found in the effective implementation of local legislations [e.g the Environmental Guidelines and Standards for Petroleum Industry in Nigeria (EGASPIN), Federal Ministry of Environment (FMEnv), Department of Petroleum Resources (DPR), Federal Environmental Protection Agency (FEPA) etc.] for discontinuing contaminant emissions, the problem seem to continue unabated in most parts of the Niger Delta region. Unfortunately, not until samples from the aquifers are obtained and potential contaminants identified and quantified in studies of this nature, information about the quality of the subsurface water resources can hardly be defined and ascertained. One of the huge challenges in the assessment of groundwater quality and an understanding of the way and manner potential contaminants move in the subsurface is mainly due to the poor understanding of facies heterogeneity of components sediments and the stratigraphic arrangements of the different beds. Freeze and Cherry, [1979] noted that because of these heterogeneities inherent in subsurface systems, zones of degraded groundwater can be very difficult to detect.

The purpose of this study is to quantify with reference to approved environmental standards of regulating agencies, the chemical constituents that may have been introduced into the natural hydrologic cycle in and around X-17 field in the Sapele area of Delta State, Nigeria. The geologic material present in the area of study is the Sombreiro deltaic plain alluvium (fig. 1).

## II. GEOLOGY AND STRATIGRAPHY OF THE NIGER DELTA

The study area lies within the Benin Formation in the Niger Delta area in Southern Nigeria. The Niger Delta basin is situated on the Gulf of Guinea in equatorial West Africa, between latitudes 4o and 7oN and longitudes 3o and 9oE [Whiteman, 1982] (fig. 1). It is one of the world's largest, with

the subaerial portion covering about 75,000km<sup>2</sup> in southern Nigeria and extending more than 300km from apex to mouth [Doust and Omatsola, 1990] with a regressive wedge of clastics which is thought to reach a maximum thickness of about 12km. The Niger Delta basin is bounded in the south by the Gulf of

Guinea and in the North by older (Cretaceous) tectonic elements which include the Anambra basin, Abakaliki uplift and the Afikpo syncline. In the east and west respectively, the Cameroon volcanic line and the Benin Hinge Line mark the extent of the Delta.

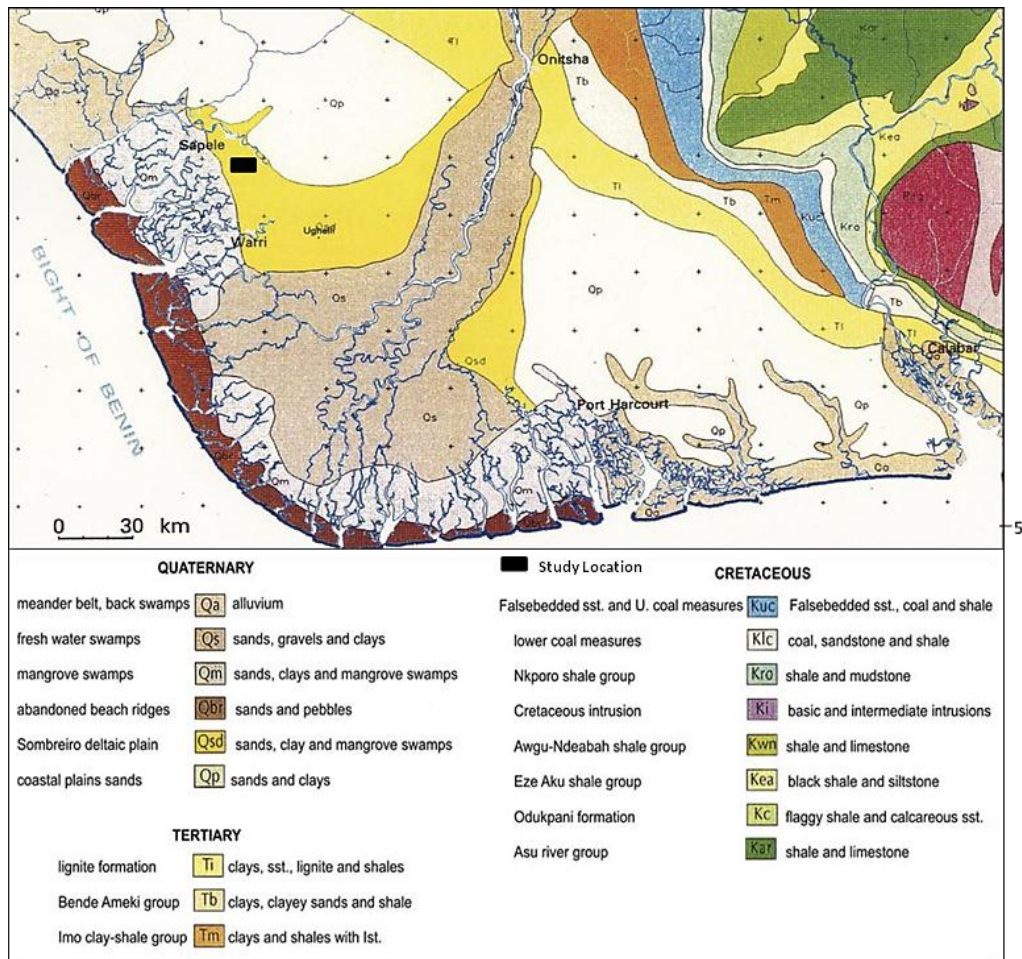


Figure 1. Geologic map of the Niger Delta Basin showing study location in the Sombreiro deltaic plain sediments [Modified after Reijers 2011]

The Cenozoic Niger delta complex developed at the point of a triple junction [Grant, 1971]. The triple junction was formed during the split up of the African and South American plates in the Albian times [Doust and Omatsola, 1990 & Whiteman, 1982]. Two of the arms, which followed the southwestern and southeastern coast of Nigeria developed into collapsed continental margins of the South Atlantic, whereas the third failed arm developed into the Benue Trough Grant, [1971]. The Niger Delta has built over the collapsed continental margin, and its core is located above the collapsed continental margin at the site of the triple junction formed during the middle Cretaceous [Doust, 1989]. The true delta, however, began developing in the Paleocene when sediments began to accumulate in the troughs between basement horst blocks of the northern flank of the present delta area [Whiteman, 1982]. The Cenozoic development of the delta is

believed to have taken place under approximate isostatic equilibrium and the evolution of the delta is controlled by pre- and synsedimentary tectonics [Doust, 1989].

From the Eocene to the present, the delta has prograded southwestward, forming depobelts that represent the most active portion of the delta at each stage of its development [Doust and Omatsola, 1990]. The first progradation of the Niger Delta occurred during the Eocene, probably in response to epeiorogenic movements along the Benin and Calabar flanks, [Evamy et al., 1978] and this continued to the present time during which time strata were deposited along an unstable progradational margin. This was later seen to result from paralic deposition into a series of depobelts which succeeded each other in time and space, leading to a regular step-like southward progression of the delta referred to as “escalator regression” by Knox and Omatsola [1989].

The development of the proto-delta was terminated in the Paleocene by a major sea transgression [Weber and Daukoru, 1975] which was followed by a regressive phase in the Eocene as the sea progressively moved southwards. The regressive phase has continued until the present and this fact coupled with the absence of tectonic event and frequent interruption by generally minor transgressions has ensured the continued development of the delta [Whiteman, 1982].

The delta has also undergone structural and stratigraphic evolution over time. Its morphology changed from an early stage spanning the Paleocene to early Eocene to a later stage of delta development in Miocene time. During the Tertiary evolution of the delta, there were substantial changes in its morphology and internal geometry which reflect increasing sediment supply, variations in sediment distribution pattern and changes in slope stability over time [Doust and Omatsola, 1990]. In the early stages of the delta growth (Paleocene to early Eocene), the coastline was concave to the sea and the distribution of deposits were strongly influenced by basement topography however by mid- to late- Eocene the regression was well established, and the concavity of the coastline disappeared [Whiteman, 1982].

The Niger Delta has tripartite lithostratigraphic units reflecting the overall regression of depositional environments within the Niger Delta clastic wedge [Short and Stauble, 1967]. The base of the sequence consists of massive and monotonous marine shales, the Akata Formation which grade upward into inter-bedded shallow marine and fluvial sands, silts, and clays, the Agbada Formation that forms the typical paralic facies portion of the delta [Short and Stauble, 1967]. The formations reflect a gross coarsening-upward progradational clastic wedge [Short and Stauble, 1967], deposited in marine, deltaic, and fluvial environments [Weber and Daukoru, 1975; Weber, 1986].

### III. METHODS OF INVESTIGATION

#### A. Field Sampling Procedures

Data acquisition was carried out through drilling of 15 percussion boreholes and careful sampling of groundwater as an environmental component and subsequent laboratory analyses in accordance with Federal Ministry of Environment regulations (FMEnv) and Department of Petroleum Resources (DPR) Guidelines and Standards Part VIII D (2). Two seasons (wet and dry) sampling of groundwater was carried out. Prior to commencement of drilling, trial holes were excavated to 1m below ground level (bgl.) at each borehole location using a hand auger tool prior to drilling. The auger holes were subsequently drilled using a pre-mobilized cable percussion tool to produce 150mm diameter boreholes. In order to avoid the risk of cross contamination, clean drilling techniques were employed at each borehole location, Visual and olfactory observations of drill cuttings were also noted during drilling.

Subsurface samples were collected at 0.5m intervals during drilling to enable a comprehensive assessment of the strata encountered. All boreholes were subsequently back-filled with drill cutting to prevent the introduction of potential surface contaminants into the subsurface at all borehole location.

Groundwater samples were recovered from the boreholes for further laboratory analysis.

Standard methods and procedures were adhered to in the course of this study. QA/QC procedures were implemented during sample collection, labelling, analyses and data verification. Chain of custody procedures including sample handling, transportation, logging and crosschecking in the laboratory were implemented. Laboratory analysis involved the determination of physicochemical parameters and heavy metal concentration in the groundwater samples.

To reduce error, measurements were replicated and numbers of specially distributed samples were composited before sub-sampling for analyses. To avoid sample contamination and deterioration, sampling tools and containers were pre-sterilized, pre-treated and preserved in ice-cooled chest (<4°C) and transported to the laboratory. They were stored in refrigerator pending subsequent analyses especially for parameters having short holding time such as total hydrocarbon, microbiological and heavy metal analyses.

#### B. Laboratory Analytical Procedures

Some parameters required for the water samples were determined in-situ as is required to ensure the accuracy of the measurement. After in-situ determinations, proper records of the reading for each sample were immediately noted. Samples were analysed in the laboratory using the appropriate standard methods for each parameter as specified by the DPR [1991], ASTM [1982] and APHA [1985]. All appropriate analytical procedures (Table1) were followed while the associated QA/QC protocols for the different parameters were strictly adhered to.

TABLE I. LABORATORY METHODS ADOPTED IN ANALYSIS OF THE GROUNDWATER SAMPLES

Parameter	Method
Turbidity	Turbidimetry (APHA2130 B)
TSS	Filtration/Gravimetry (APHA 2540D)
DO	Winkler's Titrimetry
BOD	DO meter/Winkler's Titrimetry – Dilution Method
COD	Titrimetry/Visible Spectrophotometry
Alkalinity	Titrimetry
Hardness	EDTA Titrimetry
Salinity	Titration (Argentometry)
Nitrate	Visible Spectrophotometry (Brucine method),
Phosphate	Visible Spectrophotometry
Heavy metals	AAS (APHA 3111B)
Total Petroleum Hydrocarbon	Gas Chromatography (GC)

Turbidity levels of the water samples were analysed (In-Situ) using a HACH Ratio Turbidimeter in accordance with APHA2130 B. The salinity was determined titrimetrically in accordance with APHA 4500-Cl and salinity as chloride is reported in mg/L after required calculations. Titrimetric method is based on the reaction of silver with chloride ions

using potassium chromate as indicator. Silver chloride is precipitated quantitatively before red silver chromate is formed. A total suspended solid (TSS) was determined in accordance with APHA 2540D, by filtering a well-mixed aliquot (100-ml) of the sample through a dried and pre-weighed Millipore filter paper using vacuum filtration apparatus. The filter paper was then dried at 105% °C to constant weight. The difference in weight of the filter paper represents the total suspended solids and was reported in mg/l after calculation.

Nitrate was determined with the HACH Spectrophotometer using the cadmium reduction method in accordance with APHA 4600-NO3-B. 25-ml of the sample was put in the sample cell of one HACH Nitri Ver 5. Nitrate reagent power pillow, which is gentisic acid, was added. A five-minute reaction time was allowed after which the concentration of Nitrogen-Nitrate was read with the Spectrophotometer at a wavelength of 400 nm using deionized water as blank reagent. Results were reported as mg/L Nitrate.

The sulphate content of all the samples was determined by the turbidimetric method in accordance with APHA 4500-SO4-E. The sulphate ion was precipitated in an acetic acid medium with barium chloride (BaCl<sub>2</sub>) to form barium sulphate crystals of uniform size. Light absorbance of the barium sulphate suspension was measured by a spectrophotometer at 450 nm and the SO<sub>4</sub><sup>2-</sup> concentration in mg/l was determined by comparing the observed reading with the previously prepared calibration graph.

Phosphate was determined in accordance with APHA 4500-P-D, also a colorimetric method, but based on a blue complex induced by the addition of stannous chloride. The sample was analysed at a wavelength of 690nm with Unicam UV/Visible Spectrophotometer as the source of energy, while Nitrate was determined colorimetrically using Unicam UV/Visible spectrophotometer. 1ml of the sample was analysed directly, using brucine sulphate as a complexing agent in the presence of sulphuric acid, and measured at a wavelength of 470nm (Ademoroti, 1997)

### C. Biochemical Oxygen Demand (BOD)

This is dependent on oxygen uptake by bacteria and was determined using the dilution method according to APHA-507. The amount of oxygen consumed during a fixed time period (usually 5 days) is related to the amount of organic matter present in the original sample. Dissolved oxygen of the samples was first determined using the Winlab model Dissolved Oxygen meter and then incubated for five (5) days at 20°C. DO was again measured after a period of five days and BOD in mg/l was determined from the following calculation and reported accordingly:

$$\text{BOD (mg/l)} = \frac{[\text{DOB} - \text{DOA}] - [\text{DOSB} - \text{DOSA}]}{D}$$

Where, D= Dilution factor usually 0.5 or ½

DOB = DO of sample before incubation

DOA = DO of sample after incubation

DOSB = DO of sample blank before incubation

DOSA = DO of sample blank after incubation

### 1) Chemical Oxygen Demand:

Chemical Oxygen Demand (COD) was used as a measure of the oxygen equivalence of the organic matter content of the sample which was susceptible to oxidation by a strong chemical oxidant. COD was determined using the open reflux method where a sample was refluxed and digested in a strongly acidic solution with a known excess of potassium dichromate (K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>). After digestion, the excess un-reacted potassium dichromate was read with a spectrophotometer at 600-nm and results reported in mg/L in accordance with APHA 508. Results were also verified by titrating with a standard solution of ferrous ammonium sulphate.

### 2) Total Petroleum Hydrocarbon (TPH):

TPH levels in the samples were determined in accordance with APHA 6200C, after extraction with hexane/dichloromethane mixture, using Gas Chromatograph interfaced with hydrocarbon quantitation and quantification software.ix) Metals

Heavy metals and exchangeable metals (Na, K, Mg, and Ca) were determined in accordance with APHA 3111B, using Atomic Absorption Spectrophotometer, Bulk Scientific, (VGS 210 America, 2008) interfaced with CHEMSTATION analytical software. Mercury were determined using cold vapour technique.

## IV. RESULTS AND DISCUSSION

A lithologic representative geologic section for the study area is presented in figure 2. In this section, clayey very fine to medium grained sand occur from surface to about 20 meters below the surface across the area with slight variation at different well locations. This lithologic pattern is punctuated by mottled silty clayey very fine to medium grained sand at a shallow depth of about 1.5 meters to about 5 meters below the surface across the area. At depths of about 20 meters to the base (40 meters), the lithologic components are composed mainly fine to pebbly sands. This section actually represents the unconfined aquiferous zone in the subsurface of this area.

Results of the wet and dry season groundwater physicochemical and heavy metal properties of the study area are presented in Tables 2 and 3, while the summary of the minimum, maximum and mean values of both seasons with regulatory limits are presented in Table 4.

Wet and dry seasons groundwater temperatures ranged from 27.40 - 30.50 (mean = 28.99) and 27.80 - 30.10 (mean = 29.16) (Table 4) in the study area respectively, with the highest groundwater temperature (30.50°C) recorded in the wet season at water borehole 5, north of Well-5 (Table 2), slightly exceeding the DPR limit of 30.0°C.

Groundwater in the study area is generally characterized by low pH (acidic), ranging from 4.30 - 7.30 (mean = 5.57) for the wet season and 4.60 - 7.40 (mean = 5.77) for the dry season samples (Table 4), except for boreholes 8 (wet season pH = 7.20, dry season pH = 7.40) and 13 (wet season pH = 7.30) (Tables 2 and 3) where pH values indicate slightly alkaline groundwater condition and falls within the DPR limit. The



dissolved oxygen levels is relatively low, with wet season values ranging from 4.55 - 4.75 (mean = 4.65) and dry season values ranging from 3.20 - 4.30 (mean = 3.66) (Table 4).

Wet season groundwater turbidity ranged from 0.00 - 19.00 NTU (mean = 5.17 NTU) and a range of 0.00 - 10.05 NTU (mean = 3.77 NTU) was recorded for the dry season indicating lower dry season values. Total suspended solids (TSS) ranged from 0.50 - 27.00 (8.37) for the wet season and 0.50 - 17.50 (mean = 7.91) (Table 4). During the dry season when a marked drop in precipitation is recorded, groundwater storm flow that enhances the volume of TSS gives way to laminar flow, during which time particulate materials around sand grains remain attached, hence leads to lower TSS that is reflected in the dry season values from this study area (Table 3). Electrical conductivity ranged from 9.00 - 435.00  $\mu\text{S}/\text{cm}$  (mean = 90.32  $\mu\text{S}/\text{cm}$ ) for the wet season samples and ranged from 16.54 - 562.10  $\mu\text{S}/\text{cm}$  (mean = 124.26  $\mu\text{S}/\text{cm}$ ) for the dry season, with borehole 15 having the highest values during the wet and dry seasons. Total dissolved solids (TDS) ranged from 5.76 - 278.40 mg/l (mean = 57.80 mg/l) for the wet season and 8.00 - 283.50 mg/l (mean = 66.24 mg/l) for the dry season. Samples from boreholes 14 and 15 recorded the highest TDS values

(Table 3), but generally TDS values across the area of study is low and falls well below the DPR EGASPIN limit. Wet season colour was low in boreholes 1 – 6 and high in boreholes 7 – 15 (above 1 Pt co), well above the recommended environmental limit (Table 4).

Wet season biochemical oxygen demand (BOD) ranged from 3.04 - 3.32 mg/l (mean = 3.18 mg/l) and dry season values of 3.00 - 3.61 mg/l (mean = 3.29 mg/l) (Table 4). Groundwater salinity measured as chloride content was found to be generally low across the study area, except for values from boreholes 14 and 15 which were observed to be far higher than values from other boreholes (Tables 2 and 3). Values of wet season dissolved oxygen (DO) ranged from 4.55 - 4.75 mg/l (mean = 4.65 mg/l) and dry season values of 3.20 - 4.30 mg/l (mean = 3.66 mg/l) well below the DPR limit. These concentrations indicate that the groundwater in the vicinity of this study is relatively fresh.

The cations were dominated by Sodium ( $\text{Na}^{2+}$ ) (range = 1.60 - 77.23, mean = 16.07), Potassium ( $\text{K}^{+}$ ) (range = 0.20 - 9.75, mean = 2.02) and Calcium ( $\text{Ca}^{2+}$ ) (range = 0.16 - 7.82, mean = 1.62) (Table 4).

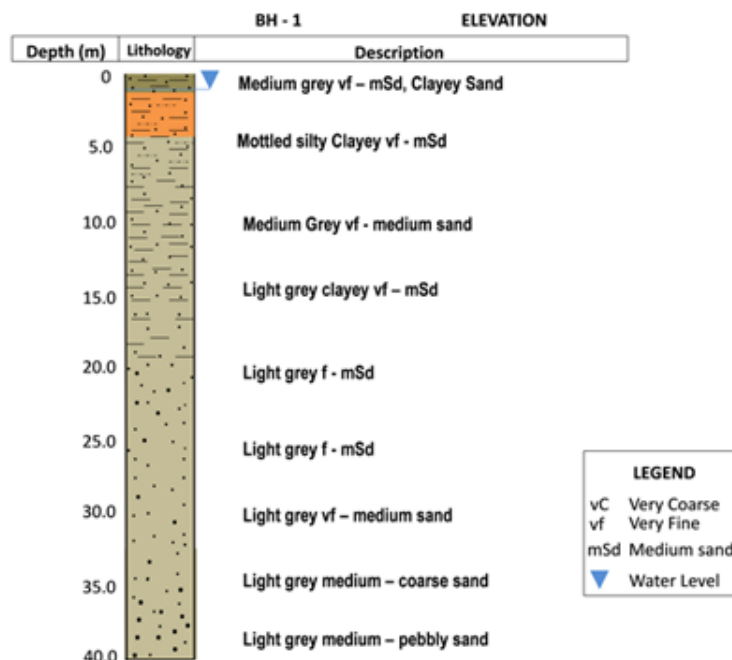


Figure 2. Representative Lithologic Well Section of the Study Area Assessed from Borehole 1 in the Study Area

The levels of the following heavy metals were below zero and also below the DPR limits in all the groundwater samples: Chromium (Cr), cadmium (Cd), Zinc (Zn) and Mercury (Hg) (Table 4). The concentration of Vanadium and Nickel were below zero in all sample locations. The wet and dry seasons groundwater concentration of Iron (Fe) was less than zero in all boreholes, lower than the WHO/FMEnv/DPR limit of 1.00 mg/L in all samples, except in borehole 8 where the wet season concentration of 1.365 mg/l is noticed to be higher than the

DPR Limit for Iron concentration in groundwater. The concentrations of lead (Pb) was generally higher than the DPR maximum permissible levels of 0.05 mg/l in ten (10) borehole locations (BH-1, 2, 3, 4, 5, 6, 7, 13, 14 and 15) and within the permissible limit in five borehole locations (BH-8, 9, 10, 11 and 12) (Tables 2, 3 and 4). Wet and dry seasons concentration of copper (Cu) ranged from 0.04-0.08 (mean = 0.060) and 0.02-0.07 (mean = 0.044) well below the DPR maximum permissible level 15 mg/L.

Wet season Total Hydrocarbon Content (THC) ranged from 0.05-0.32 (mean = 0.13), while dry season concentration was below the detection limit of the instrument, an indication that the groundwater in the sampled area was not contaminated

with hydrocarbons. Total Petroleum Hydrocarbon (TPH) and Oil & Grease were below DPR limits in both wet and dry season groundwater samples in the area of study.

TABLE II. RESULT OF WET SEASON PHYSICO-CHEMICAL PROPERTIES OF X-17 FIELD GROUND WATER SAMPLES

PARAMETERS	BH 1	BH 2	BH 3	BH 4	BH 5	BH 6	BH 7	BH 8	BH 9	BH 10	BH 11	BH 12	BH 13	BH 14	BH 15
Physico-chemical															
pH	4.50	5.20	4.50	4.60	4.70	4.30	4.90	7.20	6.10	6.30	5.90	6.60	7.30	5.70	5.70
Electrical Conductivity, $\mu\text{S}/\text{cm}$	18.00	30.00	20.80	12.30	15.80	22.40	9.00	70.00	12.50	29.00	15.00	75.00	180.00	410.00	435.00
Total Suspended Solids (TSS), mg/l	0.50	2.50	4.50	1.00	3.00	0.50	4.50	14.00	27.00	7.00	14.00	16.00	13.00	14.00	4.00
Total Dissolved Solids (TDS), mg/l	11.52	19.20	13.31	7.87	10.11	14.34	5.76	44.80	8.00	18.56	9.60	48.00	115.20	262.40	278.40
Dissolved Oxygen (DO), mg/l	4.70	4.65	4.68	4.75	4.70	4.65	4.55	4.60	4.60	4.58	4.65	4.62	4.74	4.58	4.70
Temperature ( $^{\circ}\text{C}$ )	30.00	30.10	28.50	29.10	30.50	28.90	28.60	28.90	29.30	29.20	28.80	29.00	27.40	28.20	28.30
Color, Pt-Co	0.00	0.00	0.00	0.00	0.00	0.00	2.00	87.00	80.00	28.00	18.00	62.00	29.00	47.00	6.00
Salinity as Chloride, mg/l	4.96	8.93	5.88	2.18	4.23	6.41	2.28	22.17	3.14	8.60	3.96	23.82	55.57	130.69	140.96
Biochemical Oxygen Demand (BOD), mg/l	3.30	3.20	3.20	3.25	3.28	3.15	3.10	3.16	3.28	3.32	3.10	3.15	3.12	3.10	3.04
Turbidity, NTU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.50	19.00	10.00	8.00	11.50	9.00	9.50	2.00
Redox Potential,	115.00	72.00	116.00	112.00	110.00	132.00	98.00	-42.00	20.00	11.00	39.00	-11.00	-45.00	40.00	42.00
Organics, mg/l															
Total Hydrocarbon Content (THC)	0.08	0.08	0.14	0.09	0.09	0.05	0.06	0.09	0.12	0.09	0.15	0.18	0.32	0.28	0.19
Total Petroleum Hydrocarbon (TPH)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Oil & Grease	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Anions (ppm)															
Sulphate, ( $\text{SO}_4^{2-}$ )	0.655	1.058	0.675	0.415	0.469	0.734	0.276	2.711	0.417	1.110	0.540	3.028	7.494	17.066	18.125
Phosphate, ( $\text{PO}_4^{3-}$ )	0.025	0.031	0.029	0.016	0.051	0.047	0.005	0.052	0.016	0.015	0.022	0.082	0.095	0.061	0.046
Nitrate, ( $\text{NO}_3^-$ )	0.105	0.109	0.131	0.157	0.196	0.119	0.094	0.217	0.185	0.135	0.108	0.326	0.362	0.598	0.569
Cations (ppm)															
Calcium, ( $\text{Ca}^{2+}$ )	0.323	0.538	0.373	0.220	0.283	0.401	0.161	1.254	0.224	0.520	0.269	1.344	3.226	7.347	7.795
Ammonium, ( $\text{NH}_4^+$ )	0.011	0.011	0.013	0.016	0.020	0.022	0.009	0.026	0.019	0.014	0.011	0.033	0.046	0.069	0.057
Magnesium, ( $\text{Mg}^{2+}$ )	0.164	0.175	1.637	0.566	0.271	0.485	0.164	0.457	0.263	0.274	0.244	0.324	0.972	1.683	1.754
Potassium, ( $\text{K}^+$ )	0.409	0.678	0.472	0.228	0.356	0.501	0.203	1.572	0.289	0.651	0.347	1.683	4.033	9.188	9.745
Sodium, ( $\text{Na}^+$ )	3.20	5.33	3.69	2.18	2.81	3.98	1.60	12.43	2.22	5.15	2.66	13.82	31.96	72.79	77.23
Heavy Metals (mg/l)															
Iron, (Fe)	0.011	<0.006	0.338	<0.006	<0.006	<0.006	0.080	1.365	0.290	0.501	0.300	<0.006	<0.006	<0.006	<0.006
Zinc, (Zn)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.019	<0.001	<0.001	<0.001	0.008	<0.001	0.011	<0.001
Chromium, (Cr)	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006
Lead, (Pb)	0.058	0.176	0.135	0.128	0.085	0.098	0.157	0.036	0.044	0.036	0.021	0.018	0.054	0.094	0.102
Copper, (Cu)	0.045	0.039	0.062	0.049	0.054	0.041	0.049	0.077	0.072	0.084	0.065	0.056	0.069	0.081	0.051
Cadmium, (Cd)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Mercury, (Hg)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Vanadium, (V)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nickel, (Ni)	<0.001	<0.001	<0.001	<0.001	0.025	<0.001	<0.001	0.076	<0.001	<0.001	<0.001	0.038	<0.001	0.013	0.029
Microbiology															
Total Heterotrophic Bacteria (THB), Cfu/ml x 10 <sup>3</sup>	1.54	1.45	1.41	1.51	1.47	1.64	1.45	1.53	1.87	1.62	1.98	1.75	1.85	1.90	1.74
Total Heterotrophic Fungi (THF), Cfu/ml x 10 <sup>3</sup>	0.41	0.43	0.44	0.54	0.46	0.51	0.48	0.58	0.64	0.59	0.62	0.61	0.62	0.69	0.67
Hydrocarbon Utilizing Bacteria (HUB), Cfu/ml x 10 <sup>3</sup>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrocarbon Utilizing Fungi (HUF), Cfu/ml x 10 <sup>2</sup>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
Faecal Coliform, Cfu/ml x 10 <sup>2</sup>	0.35	0.31	0.45	0.37	0.39	0.57	0.47	0.85	0.53	0.79	0.64	0.95	0.84	0.66	0.58
E.coli, MPN/100ml	5.80	8.20	5.80	7.60	10.20	5.80	5.80	7.80	7.40	8.80	8.00	9.60	5.80	5.40	8.40

TABLE III. RESULT OF DRY SEASON PHYSICO-CHEMICAL PROPERTIES OF X-17 FIELD GROUND WATER SAMPLES

PARAMETERS	BH 1	BH 2	BH 3	BH 4	BH 5	BH 6	BH 7	BH 8	BH 9	BH 10	BH 11	BH 12	BH 13	BH 14	BH 15
Physico-chemical															
pH	4.90	5.44	4.80	5.00	4.90	4.60	5.10	7.40	6.45	6.50	6.20	6.85	6.40	6.05	5.90
Electrical Conductivity, $\mu\text{S}/\text{cm}$	23.00	43.50	29.20	16.54	21.20	31.90	29.42	110.30	23.75	37.40	25.30	100.30	270.00	540.00	562.10
Total Suspended Solids (TSS), $\text{mg}/\text{l}$	1.50	3.00	5.00	2.00	3.50	0.50	5.50	15.00	8.50	5.50	4.90	17.50	14.00	15.20	17.00
Total Dissolved Solids (TDS), $\text{mg}/\text{l}$	12.49	21.60	15.82	8.00	11.35	15.82	15.61	56.10	15.20	19.24	13.10	55.00	170.80	280.00	283.50
Dissolved Oxygen (DO), $\text{mg}/\text{l}$	3.30	3.90	3.20	3.80	3.60	3.50	3.20	3.70	3.66	3.80	4.30	4.10	3.72	3.70	3.40
Temperature ( $^{\circ}\text{C}$ )	29.70	29.50	29.20	29.50	29.80	29.00	29.00	28.70	28.90	28.40	30.10	29.80	27.80	29.10	28.90
Salinity, PPT	7.61	14.40	9.66	5.57	7.02	10.56	9.74	36.50	7.86	12.38	8.37	33.19	89.36	178.71	186.02
Biochemical Oxygen Demand (BOD), $\text{mg}/\text{l}$	3.52	3.43	3.00	3.35	3.40	3.25	3.00	3.20	3.50	3.61	3.28	3.25	3.19	3.25	3.10
Turbidity, NTU	0.00	0.00	0.50	1.00	0.00	0.00	2.00	4.00	6.50	8.50	10.05	8.00	3.50	9.00	3.50
Redox Potential,	67.00	54.00	84.00	88.00	65.00	78.00	49.00	13.00	19.00	9.00	21.00	12.00	24.00	27.00	33.00
Organics, $\text{mg}/\text{l}$															
Total Hydrocarbon Content (THC)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total Petroleum Hydrocarbon (TPH)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Oil & Grease	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Anions (ppm)															
Sulphate, ( $\text{SO}_4^{2-}$ )	0.957	1.810	1.215	0.701	0.882	1.327	1.224	4.588	0.951	1.556	1.052	4.172	11.232	22.646	23.383
Phosphate, ( $\text{PO}_4^{3+}$ )	0.013	0.024	0.016	0.095	0.112	0.132	0.147	0.233	0.134	0.198	0.124	0.428	1.124	3.004	3.087
Nitrate, ( $\text{NO}_3^-$ )	0.041	0.038	0.029	0.009	0.028	0.017	0.016	0.060	0.013	0.020	0.014	0.055	0.147	0.294	0.306
Cations (ppm)															
Calcium, ( $\text{Ca}^{2+}$ )	0.412	0.780	0.523	0.302	0.380	0.572	0.527	1.977	0.426	0.670	0.453	1.797	4.838	9.677	10.073
Ammonium, ( $\text{NH}_4^+$ )	<0.01	<0.01	<0.01	0.059	<0.01	<0.01	<0.01	<0.01	<0.01	0.029	0.042	<0.01	<0.01	0.304	0.316
Magnesium, ( $\text{Mg}^{2+}$ )	0.352	0.674	0.455	0.261	0.338	0.491	0.457	1.697	0.631	0.577	0.392	1.544	4.518	8.277	8.639
Potassium, ( $\text{K}^+$ )	0.052	0.097	0.065	0.038	0.047	0.071	0.066	0.247	0.053	0.084	0.057	0.225	0.605	1.210	1.259
Sodium, ( $\text{Na}^{2+}$ )	4.083	7.723	5.184	2.990	3.764	5.663	5.221	19.582	4.216	6.640	4.492	17.807	47.935	95.869	99.793
Heavy Metals ( $\text{mg}/\text{l}$ )															
Iron, (Fe)	0.010	<0.006	0.156	<0.006	<0.006	<0.006	0.037	0.851	0.112	0.219	0.174	<0.006	<0.006	<0.006	<0.006
Zinc, (Zn)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.019	<0.001	<0.001	<0.001	0.008	<0.001	0.011	<0.001
Chromium, (Cr)	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006
Lead, (Pb)	<0.005	<0.005	0.003	0.001	0.014	0.028	<0.005	0.011	0.023	0.019	0.010	0.007	0.034	0.051	0.077
Copper, (Cu)	0.049	0.044	0.067	0.051	0.042	0.036	0.028	0.057	0.036	0.055	0.037	0.020	0.049	0.053	0.029
Cadmium, (Cd)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Mercury, (Hg)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Vanadium, (V)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nickel, (Ni)	<0.001	<0.001	<0.001	<0.001	0.025	<0.001	<0.001	0.076	<0.001	<0.001	<0.001	0.038	<0.001	0.013	0.029
Microbiology															
Total Heterotrophic Bacteria (THB), $\text{Cfu}/\text{ml} \times 10^3$	0.96	1.21	0.97	1.36	1.24	1.66	1.01	1.36	1.55	1.69	1.74	1.53	1.77	1.61	1.48
Total Heterotrophic Fungi (THF), $\text{Cfu}/\text{ml} \times 10^3$	0.36	0.24	0.19	0.27	0.22	0.17	0.20	0.24	0.31	0.33	0.41	0.28	0.19	0.15	0.23
Hydrocarbon Utilizing Bacteria (HUB), $\text{Cfu}/\text{ml} \times 10^3$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrocarbon Utilizing Fungi (HUF), $\text{Cfu}/\text{ml} \times 10^2$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
Faecal Coliform, $\text{Cfu}/\text{ml} \times 10^2$	0.49	0.52	0.63	0.41	0.57	0.39	0.33	0.43	0.20	0.47	0.23	0.51	0.39	0.19	0.27
E.coli, MPN/100ml	9.40	11.80	9.40	7.80	10.40	10.20	8.40	9.20	9.80	11.40	10.20	11.40	7.80	8.40	9.80

TABLE IV. STATISTICAL SUMMARY OF SOME PHYSICO-CHEMICAL PARAMETERS OF X-17 FIELD GROUND WATER COMPARED WITH CONTROL AND BASELINE VALUES, DURING WET AND DRY SEASON PERIODS

PHYSICO-CHEMICAL	Wet Season			Baseline Value	Dry Season			Baseline Value	DPR Limit
	Range	Mean	Control (Mean)		Range	Mean	Control (Mean)		
pH	4.30-7.30	5.57	5.45	6.398	4.60-7.40	5.77	5.70	5.370	6.5-8.5
Electrical Conductivity, $\mu\text{S/cm}$	9.00-435.00	90.32	24.00	154.924	16.54-562.10	124.26	33.97	229.224	N/A
Total Suspended Solids (TSS), mg/l	0.50-27.00	8.37	2.00	29.600	0.50-17.50	7.91	3.00	192.00	N/A
Total Dissolved Solids (TDS), mg/l	5.76-278.40	57.80	15.36	82.110	8.00-283.50	66.24	17.60	121.488	1500
Dissolved Oxygen (DO), mg/l	4.55-4.75	4.65	4.63	6.326	3.20-4.30	3.66	4.46	5.250	6
Temperature ( $^{\circ}\text{C}$ )	27.40-30.50	28.99	28.45	31.020	27.80-30.10	29.16	29.05	29.90	30
Salinity as Chloride, mg/l	2.18-140.96	28.25	22.14	27.892	5.57-186.02	41.13	11.24	53.332	N/A
Biochemical Oxygen Demand (BOD), mg/l	3.04-3.32	3.18	3.13	3.578	3.00-3.61	3.29	3.16	4.688	N/A
Turbidity, NTU	0.00-19.00	5.17	7.50	104.862	0.00-10.05	3.77	1.50	161.608	N/A
Redox Potential,	-45.00-132.00	53.93	61.00	-	9.00-88.00	42.87	52.00	-	N/A
Organics, (mg/l)									
Total Hydrocarbon Content (THC)	0.05-0.32	0.13	0.04	0.000	0.00	<0.01	<0.01	0.00	N/A
Total Petroleum Hydrocarbon (TPH)	0.00	<0.01	<0.01	0.000	0.00	<0.01	<0.01	0.000	<5.00
Oil & Grease	0.00	<0.01	<0.01	0.000	0.00	<0.01	<0.01	0.000	10
Anions (ppm)									
Sulphate, ( $\text{SO}_4^{2-}$ )	0.28-18.13	3.65	0.80	1.856	0.70-23.38	5.18	1.41	3.288	N/A
Phosphate, ( $\text{PO}_4^{3-}$ )	0.01-0.10	0.04	0.02	0.604	0.01-3.09	0.59	0.02	0.173	N/A
Nitrate, ( $\text{NO}_3^-$ )	0.09-0.60	0.23	0.05	0.418	0.01-0.31	0.07	0.03	0.564	N/A
Cations (ppm)									
Calcium, ( $\text{Ca}^{2+}$ )	0.16-7.82	1.62	0.43	5.238	0.30-10.07	2.23	0.61	9.872	N/A
Ammonium, ( $\text{NH}_4^+$ )	0.01-0.07	0.02	0.01	0.000	0.03-0.32	0.15	0.02	1.446	N/A
Magnesium, ( $\text{Mg}^{2+}$ )	0.16-1.75	0.63	0.33	-	0.26-8.64	1.95	0.52	-	N/A
Potassium, ( $\text{K}^+$ )	0.20-9.75	2.02	0.54	7.048	0.04-1.26	0.28	0.08	22.606	N/A
Sodium, ( $\text{Na}^{2+}$ )	1.60-77.23	16.07	4.26	19.144	2.99-99.79	22.06	6.03	25.030	N/A
Heavy Metals (mg/l)									
Iron, (Fe)	0.01-1.37	0.41	0.43	0.058	0.01-0.85	0.22	0.21	1.622	1
Zinc, (Zn)	0.01-0.02	0.013	<0.001	0.043	0.01-0.02	0.013	<0.001	0.340	1.5
Chromium, (Cr)	0.00	<0.006	<0.006	0.000	<0.006	<0.006	<0.006	0.001	0.05
Lead, (Pb)	0.02-0.18	0.083	0.02	0.000	0.00-0.08	0.023	0.01	0.000	0.05
Copper, (Cu)	0.04-0.08	0.060	0.03	-	0.02-0.07	0.044	0.03	-	15
Cadmium, (Cd)	<0.002	<0.002	<0.002	0.000	<0.002	<0.002	<0.002	0.000	0.01
Mercury, (Hg)	<0.001	<0.001	<0.001	0.000	<0.001	<0.001	<0.001	0.000	0.01
Vanadium, (V)	<0.001	<0.001	<0.001	0.000	<0.001	<0.001	<0.001	0.000	N/A
Nickel, (Ni)	0.01-0.08	0.036	<0.001	0.000	0.01-0.08	0.036	<0.001	0.000	N/A
Microbiology									
Total Heterotrophic Bacteria (THB), Cfu/ml x 103	1.41-1.98	1.65	0.78	0.866	0.96-1.77	1.41	0.58	0.804	N/A
Total Heterotrophic Fungi (THF), Cfu/ml x 103	0.41-0.69	0.55	0.24	0.602	0.15-0.41	0.25	0.14	0.632	N/A
Hydrocarbon Utilizing Bacteria (HUB), Cfu/ml x 103	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.000	N/A
Hydrocarbon Utilizing Fungi (HUF), Cfu/ml x 102	0.00-0.01	0.00	0.00	0.000	0.00-0.01	0.00	0.00	0.000	N/A
Faecal Coliform, Cfu/ml x 102	0.31-0.95	0.60	0.20	-	0.19-0.63	0.40	0.36	-	N/A
E.coli, MPN/100ml	5.40-10.20	7.36	4.60	27.00	7.80-11.80	9.69	6.50	29.00	N/A

Comparative analysis of wet and dry season TDS values of groundwater samples from various borehole locations across the study area and baseline values show same trend. Both season TDS values increased correspondingly from borehole 12 towards borehole 15 (fig. 3A-B). Comparative wet and dry season pH values of groundwater samples with baseline

groundwater data show similar trend from boreholes 1 – 7. Trends presented by values from boreholes 8 – 15, show some level of dissimilarity. This is visible in the wet season pH value from BH-8 which increased above the baseline value, as opposed to a lower dry season value which fell below the baseline data. Wet season values from boreholes 9, 11, 14 and



15 recorded pH values lower than the baseline data (Table 2). All dry season samples from boreholes 9 – 15 presented pH values higher than the baseline data set (Table 3, fig. 3C-D).

A cross plot of electrical conductivity versus total dissolved solids for both wet and dry season showed a similar trend with a 100% correlation for the wet season and a 99% correlation for the dry season values (fig. 3E-F).

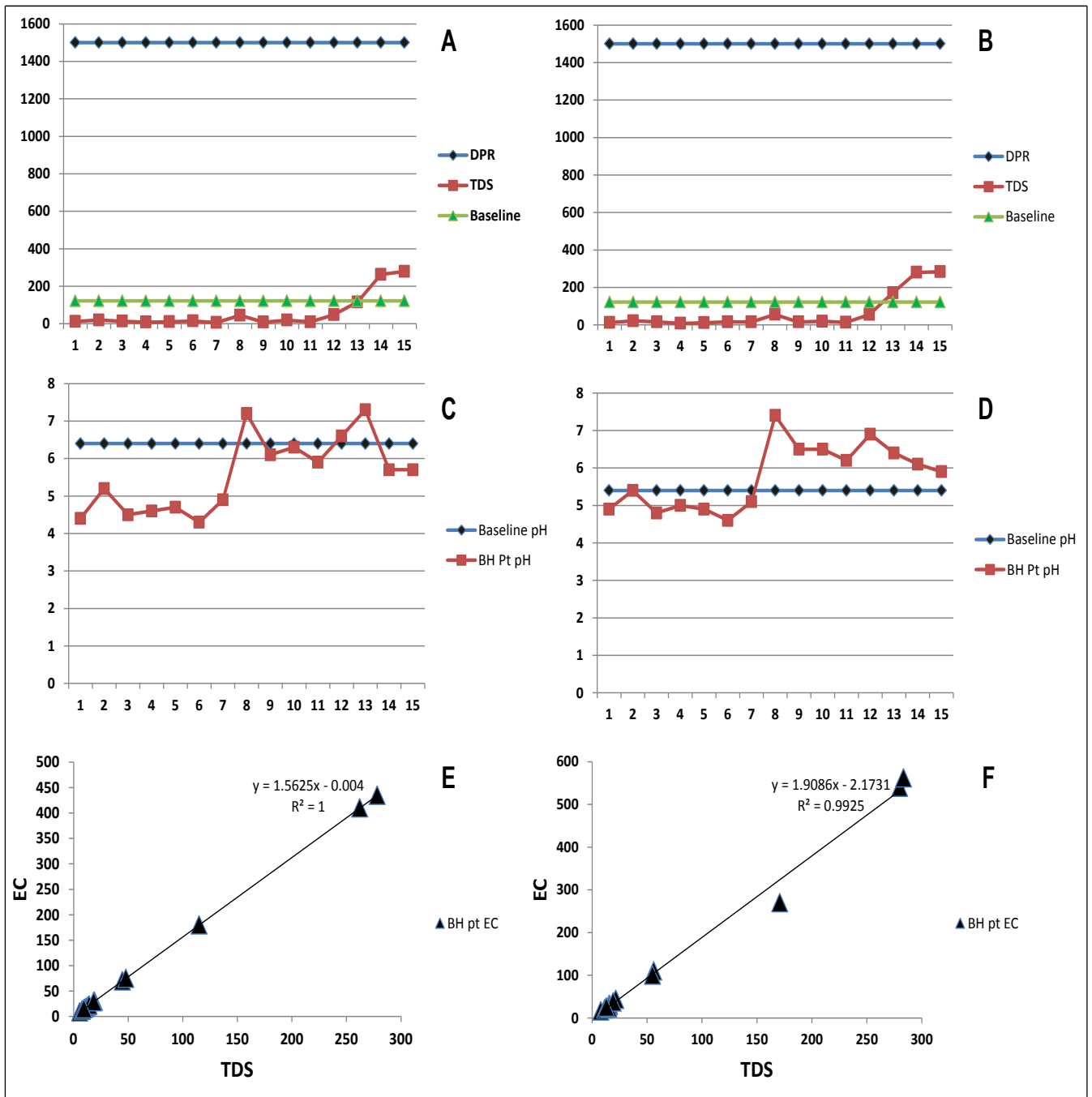


Figure 3. Plots of Total Dissolved Solids and Base Line data with regulated limits (A&B), Plots of groundwater pH from studied borehole locations and baseline station pH (C – D), and Electrical Conductivity and TDS (E – F)

## V. CONCLUSION

Although many of the chemical components analysed and quantified in the groundwater samples seem to be generally lower and within the regulated standards, there exist a concern as regards the quantitative values and trends noticed in some parameters. That the groundwater temperature of the study area show an increase, and higher than the baseline data value, is a signal that the ambient condition is being affected by activities that may not be unrelated to gas flaring. The quantitative distribution of lead (Pb) and iron (Fe) in the groundwater exceeds the regulated limits for these components in some parts of the study area. Lead as an environmental pollutant and a major culprit in environments polluted by oil and related chemicals, pose serious human health concerns. That an exceedence is observed in the study area is a threat signal that calls for urgent attention to the quality assessment and possible remedial measures of the groundwater body in this area. The exceedence recorded for iron as a chemical component may also not be unrelated to rust from buried pipe works laid in the subsurface for piping crude from this field area. Some of these pipes have been laid for many decades and thus have become rusted thereby impacting seriously on groundwater quality.

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