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PHYSICOCHEMICAL CHARACTERISTICS AND BIOREMEDIATION POTENTIALS OF GROUND WATER IN KADUNA REFINERY ENVIRONMENT

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ABSTRACT

Underground water pollution by petroleum hydrocarbon may affect the quality of drinking water and water for other domestic uses, posing a threat to the aquatic ecosystem. This study was aimed at providing data on the physicochemical characteristics of groundwater in the vicinity of Kaduna Refinery and Petrochemical Company (KRPC), for bioremediation strategy in the area. Groundwater collected at six (6) sites were analysed for physicochemical characteristics, using standard methods. The village well water was slightly acidic (5.67–6.17), while the monitoring wells were slightly alkaline (7.14-7.67). Temperature was found to be within the range favourable for Bioremediation. The dissolved oxygen (DO) levels in the sites (6.70 – 7.69mg/l) are not limiting to hydrocarbon biodegradation. Low levels of nitrate and phosphate are limiting for bioremediation. High sulphate concentration in one of the dump sites wells (350mg/l) is indicative of pollution and corrosion problems. High NTU, chloride concentrations, BOD Levels and electrical conductivity are indicative of pollution.

Keywords: Bioremediation, Physicochemical, Water, Petroleum, and Hydrocarbon

INTRODUCTION

Subsurface contamination by petroleum hydrocarbons has been documented as a widespread and very troublesome problem (Obukohwo *et al.*, 2020, Qianwei *et al.*, 2020). The most common sources of

ground water contamination by petroleum hydrocarbons include oil and gas plants, refining processes, underground storage tanks, accidental spills and sludge dump sites. In Kaduna refinery, there are different categories of wastes; process solids, effluent treatment solids and general waste (Al-Amin, 2013). Waste generated generally consists of oil, organic and inorganic chemicals in particular acids, alkalis, hydrocarbons, sulphide, phenols and other sulphur containing compounds with suspended solids (Al amin, 2013). Although these wastes are treated, yet they constitute sources of environmental contamination. In 1988 a world bank sponsored study reported that the refinery was polluting a river near the refinery, where the effluent from the refinery is discharged. Amadi *et al*., (2014) reported that in some locations near the refinery, the soil and the groundwater are slightly polluted with heavy metals. Other researchers have also indicted the refinery of environmental pollution. (Al amin, 2013; Adeniyi *et al*., 2017). In the refinery there is no solid waste treatment and disposal facility, rather there is a dump site where oil, only sludges and hazardous waste from the refinery are dumped.

Contamination associated with release of petroleum hydrocarbons and waste into the environment include pollution of soil, surface water and groundwater, contaminated land, food quality issues, reduction in agricultural produce, and atmospheric pollution. Groundwater is one of the most precious natural resources across Africa (Aniefiok *et al.,* 2018; Khan *et al*., 2018*).*

Human exposure to petroleum hydrocarbon may occur through inhalation of hydrocarbons in ambient air, direct ingestion of contaminated water, indirectly via consumption through accumulation in crop plants, and dermal contact with hydrocarbon in water, soil and sediments. (*Aniefiok et al., 2018*).

The major pollutants in drinking water supplies fall into three general classes; petroleum hydrocarbons, halogenated hydrocarbons, and taste-and-odour compounds which comprises of algae and bacteria (*Aniefiok et al, 2018*). Petroleum hydrocarbons consists of polycyclic aromatic hydrocarbons (PAHS), volatile organic compounds (VOC's): benzene, toluene, ethyl benzene, and xylenes (BTEX) (Mohamadi *et al*.,2015). Apart from PAHs and VOC's petroleum hydrocarbons contain heavy metals and radioactive isotopes that can have various potential effects on human health. (Okonkwo *et al*.,2015, Olobaniyi and Omo-Irabor, 2016).

Acute exposures to high concentration of (VOCs) such as toluene is most times linked with central nervous system toxicity, resulting in symptoms such as headaches, fatigue, dizziness The immune system can be impaired by chronic exposure to (VOCs) (Aniefiok *et al*, 2018).

Exposure to benzene, a known human carcinogen is most times linked with hematopoietic system disorders (Smith, 2010). Symptoms such as nausea, vomiting skin and eye irritation following acute high-level exposures are caused by PAHs.

Decreased birth weight and impaired child development have been linked to exposures

to PAHs during pregnancy (Benka- Coker and Ojumagiri, 1996). Dose – dependent increased risks of certain types of cancers, including lung, skin and bladder cancer have been associated with chronic occupational exposures (Aniefiok *et al.*, 2018).

In view of the above it is important to remediate petroleum contaminated environment. There are several options ranging from simple physical removal to more expensive treatments e.g., incineration. These treatments most times do not remove the contaminant or may leave behind a toxic residue which has to be disposed of in other ways (Philp et al., 2005). The ability of microbes to degrade organic contaminants into harmless constituents has been explored as a means to biologically treat environments. This is referred to as bioremediation. Bioremediation is eco-friendly and cost effective. Bioremediation technology can be broadly classified as ex situ or in situ. The ex-situ approach is carried out above ground by physically extracting the impacted medium (Okpokwasili 2005). In situ approaches include bioventing, intrinsic bioremediation, biostimulation of indigenous microbial populations in aquifer, biosparging and bioenhancement through vertical circulation wells (Mohammed *et al*. 1996; Okpokwasili, 2005,).

Bioremediation efficiency could be accelerated either by stimulating the metabolic activity of native microorganisms by nutrient amendments and /or by alterations in physicochemical conditions (biostimulation) or by introducing more efficient microbes from exogenous or endogenous sources (bioaugumentation) (Roy *et al*., 2018).

Several reports have indicated the need for bioremediation in the KRPC area (Buggu *et al*., 2020; Obukohwo *et al*., 2020). Al-Amin, (2013) reported high concentration of heavy metals in both water and soil samples in KRPC area and recommended that bioremediation and clean-up of contamination should be implemented. Amadi *et al*., (2014) also reported that the soil and the groundwater in the area have been affected by oil spillage and improper disposal of untreated effluents from petroleum product leading to their enrichment with heavy metals.

The major reasons for the control of water pollution are public health concerns, environmental conservation and the cost of decontamination. This study was aimed at characterization of ground water in the study in the area chemically and physically since, site characterization is a very important approach to a successful bioremediation.

MATERIALS AND METHODS

STUDY AREA

The study area is Kaduna Refinery and Petrochemical Company (KRPC) located at kilometre 16 along Kaduna-Kachia highway and occupies an area of 2.89 square kilometres. It lies between Latitudes 10^0, 24^1,05^{II} N and 10^0 25^1 20^{11} N and Longitudes 7^0 28^1 49^{11} E and 7^0 30^1 01^{II} E. (Buggu *et al*., 2020).

Six sampling stations were selected. The stations were from the following area:

- Sludge dump site within the Kaduna refinery premises. The sampling

stations were coded DSW1 (Dump site Well I), DSW11II (Dump site well II) DSW111 (Dump site well III). The wells are located near the sludge dump pit site.

- Chidunu/Rido village (A neighbouring settlement close to the sludge dump pit area). Three wells were selected and coded CRWI, CRWII and CRW III. The wells are the source of drinking water and water for other domestic activities in the community.

SAMPLE COLLECTION

Sampling was carried out by lowering the water container into each well with the aid of a rope tied round the neck of the container, just as the villagers obtain water from the wells. Each sample was transferred into pre-sterilized bottle. Samples were stored in an ice box and transported to the Laboratory for analysis.

DETERMINATION OF THE PHYSICOCHEMICAL PARAMETERS.

pH

The pH of the water was determined using a pH meter (Horiba m-13). The pH meter wasstandardized using buffer solution prior to taking readings.

Temperature

The water temperature was measured using Horiba M-13 temperature instrument.

Electrical conductivity

The conductivity of each water sample was measured using a microprocessor conductivity meter (Hanna Instruments H19932). The conductivity cell was rinsed with, and then charged with each water sample. The required result which displays on the digital meter was recorded as microsiemens per centimetre (us/cm).

Turbidity

Turbidity was determined with automated turbidity meter (Hanna LP2000). The instrument was first standardized with the standard reference sample. After which each sample was thoroughly mixed and used to rinse cell before filling it with the sample. The sample was allowed to stand two to three minutes to allow air bubbles to disappear. The Lid of the turbidity instrument was then closed, and the test button was pressed. Upon display on the turbidity meter, the result was recorded in nephlometric units (NTU).

Phosphate

Phosphate was determined by the ammonium molybdate-vanadate method. Fifty (50) ml of sample was poured into 250ml beaker, followed by 25ml of ammonium molybdate-vanadate solution. The content of each beaker was thoroughly mixed, and 2 minutes allowed for color development. The absorbance was measured at 400nm with a spectrophotometer (Cecil). Distilled water was used as blank.

Orthophosphate mg/l (ppm) = Absorbance x calibration constant x 50.

Sulphates

This was determined using HACHDR/2010 spectrophotometer with stored programme for sulphate

(SO_4^{2+}). After entering the stored programme, a clean sample cell was filled with 25ml of the Sample. 5ml of conditioning reagent was added to the sample cell and mixed. After which 0.3g of barium chloride crystals were added and the content swirled to dissolve. The shift timer was pressed to start a five (5) minute reaction period. The cell was allowed to stand undisturbed. After 5 minutes a second sample cell was filled with 25ml of the blank. The blank was placed in the cell holder and the light shield closed. Within five minutes after the timer beeped, the prepared sample was placed in the cell holder, and the light shield closed. On pressing read, the display showed the results in mg/L SO_4^{2-}

Sulphide

Sulphide was also determined using HACH DR/2010 spectrophotometer. After entering the programme, 50ml of sample was measured into a clean beaker. 50ml of 4% sodium hydroxide solution was added, followed by the addition of 0,5ml of ammonium hydroxide solution. They were mixed together and 25ml of the prepared sample was pipetted into a clean sample cell. The blank was prepared as described above for the sample, except that 50ml of distilled water was used instead of 50ml of the sample. The shift timer was pressed to start a 5-minute reaction, when the timer beeped, the display showed mg/L S^{2-}. The blank was placed in the cell holder, and the Light shield closed. After zeroing, the prepared sample was immediately placed in the cell holder, and the light shield closed. Read button was pressed and the display showed the result in mg/L sulphide (S^2) which was recoded.

Ammonia-nitrogen (NH_3-N)

This was equally determined using HACH DR/2010 Spectrophotometer. The stored program number for ammonia nitrogen was entered, and a 25ml clean sample cell was filled to the mark with sample. Another 25ml sample cell was filled to the mark with distilled water and served as the blank. Two (2) drops of disodium dihydrogen ethlyenediaminetetraacetate solution (500glL) was added to each sample cell. The sample cell was stopped and inverted several times to mix. Then 0.1ml of Nessler reagent was pipetted into each sample cell. The sample cell was stopped and inverted several times to mix. The shift timer was pressed to start a one-minute reaction period. When the timer beeped, the display showed mg/l NH_3-N. The blank was placed in the cell holder and the light shield closed. After zeroing, the prepared sample was placed in the cell holder and the light shield closed. Read button was pressed and the display showed the result in mg/L ammonia expressed as nitrogen (NH_3-N). The results were recorded.

Nitrate

Nitrate was measured using HACH DR/2010 spectrophotometer. The stored programme number. Nitrate Nitrogen (NO_3^- - N) was entered; a clean sample cell was filled with 25ml of sample. Another sample cell was filled with 25ml of distilled water (the blank). 1ml of Brucine-sulfanilic acid reagent was added to each cell and the cell stooped.

The shift timer was pressed to start a one-minute reaction. The reaction mixture was shaken until the timer beeped. When the timer beeped, the display showed mg/L NO_3^- -NMR. The blank cell stopper was removed, and the blank placed in the cell holder. The light shield was closed tightly. After zeroing the prepared sample was placed in the cell holder and light shield closed. After pressing read, the display showed the reading in mg/L Nitrate expressed as Nitrogen (NO_3^- -N). The result was recorded.

Chloride

The silver nitrate method of chloride analysis was used to measure chloride in each water sample using digital titrator. (HACH Digital Titrator Model 16900). The sample volume was selected and 0.2256N AgNO titration cartage was used. A clean delivery tube was inserted into the titration cartridge and the cartage attached to the titrator body. The delivery knob was turned to eject a few drops of titrant. The counter was reset to zero and the tip wiped. The sample was transferred into a 250ml conical flask and lmL of potassium Chromate indicator solution, added. The delivery tube tip was placed in the solution and flask swirled. Titration was carried out with the silver nitrate ($AgNO_3$) from a yellow to red –brown colour. The number of digits required was recorded.

Mg/L chloride = Digits required x Digit multiplier.

Biochemical Oxygen Demand (BOD_5)

This was determined using titrimetric method. Duplicate BOD bottles (300ml) were filled half-way with aerated water. One set of seeded bottles were incubated at 20^oc and used after five days to determine, the dissolved oxygen (DO) concentration. The other set was used to determine DO_o (dissolved oxygen before incubation). Two (2mls) of manganese sulphate (MnSO4) solution and 2ml of alkaline-iodide sodium azide solution were added to each bottle respectively, the bottles were stopped and inverted several times to mix contents thoroughly. After the floc had settled, leaving a clear supernatant solution, the mixing was repeated. When the floc had settled leaving at least 100ml of clear supernatant, the stopper was removed. Then 2ml of concentrated H_2SO4 was added. The bottles were re-stopped andcontents mixed by inversion until dissolution was complete. Thereafter 200ml was dispensed from each BOD bottle into 500ml conical flask 2ml of starch was added to it as indicator. This was followed by titration with 0.025N $Na_2S_2O_3$ (Sodium thiosulphate) to a colourless end point from blue-black colour. For the titration lm of 0.0225N of sodium this sulphate is equivalent to 0.2mg of dissolved oxygen.

$$\textbf{DO (ppm)} = \frac{(TX\ 0.2\ X\ 1000)}{Capacity\ of\ bottle\ (vol)}$$

T = millilitres of 0.02N $Na_2S_2O_3$ solution required for the titration

$$\textbf{BOD (ppm)} = \frac{(DO0-DO5)X\ C}{V}$$

DO_0 = dissolved oxygen before incubation of diluted water sample

DO_5 = dissolved oxygen after incubation of diluted water sample.

C = Capacity / Volume of incubation bottle

V = Volume of water sample.

RESULTS AND DISCUSSION

The Chidunu/Rido village well water (CRWI- CRWIII) were slightly acidic (5.67 – 6.17), while the dump site wells were slightly alkaline (7.14 – 7.67). (Fig.1). This result is similar to the report of Amadi *et al*., (2014) who recorded a pH range of 5.63 -7.50, for ground water and soil near Kaduna refinery area.

The acidic nature of the village well water could be due to microbial activities, and possibly the presence of ionic constituents. Amadi *et al*., (2014) found that in some locations near the refinery, the soil and the groundwater were slightly polluted with heavy metals, which they attributed to natural enrichment of groundwater through weathering of bedrock in the course of groundwater migration and anthropogenic via dumping of untreated effluents from the refinery and petrochemical into the nearby soil and the surface water. It is not clear why the monitoring well water was alkaline. However, it was observed during sample collection, that the monitoring wells were poorly constructed. They were neither lined nor covered with any material. Thus, the wells were exposed to different kinds of refuse material, including dumped catalysts.

In general, microbial activity is influenced by ph. Bamfort and Singleton (2005) reported that 40% of phenathrene degradation was observed for *Burkholderia cocovenenans* at pH 5.5, while at neutral pH in the same conditions the degradation was 80%. The adequate pH for hydrocarbon degradation depends on microorganisms. A degradation of PAH in acidic contaminated environment (pH 2) by indigenous microorganisms has been reported (Margesin and Schinner 2001). Leahy and Colwell, (1990) observed that the degradation of naphthalene by microorganisms decreased at pH 5.0 compared to the highest rate of degradation observed at pH 7. The efficiency of some microorganisms for instance *Pseudomonas* to degrade hydrocarbon at alkaline pH has been reported (Bamforth and Singleton 2005). Obukohwo *et al*., 2020 found that the pH of the medium throughout their period of bioremediation studies on Kaduna refinery effluent remained slightly acidic (6.56-6.90). Their finding is comparable to the report of Uzoekwe and Oghosanine (2011) who recorded a pH of 6.5 -8.5 from Warri Refinery effluent during bioremediation study. Khaled *et al*., (2016) reported that optimized conditions of pH 6.0 – 7.0 greatly influenced the efficiency of bioremediation.

It is important to note that the maximum permissible limit for pH of water for domestic purposes is 6.5-8.5. Hence, the pH of the village well water (5.39- 6.17) is indicative of pollution.

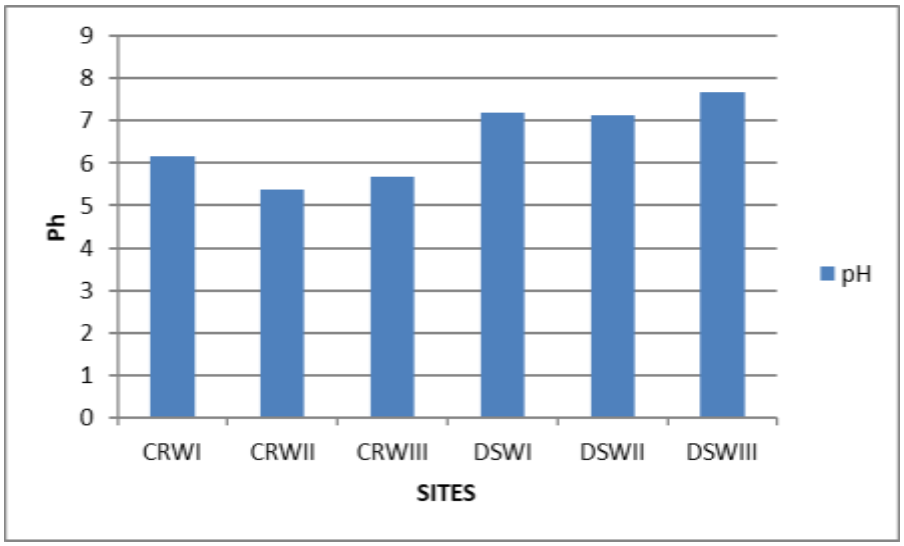


Fig. 1: pH of the ground water study sites.

KEY: CRWI (Chidunu/ Rido Well Water I); CRWII (Chidunu/ Rido Well Water II); CRWIII (Chidunu/ Rido Well Water III); DSWI (Dump Site Well Water I); DSWII (Dump Site Well Water II); DSWIII (Dump Site Well Water III).

The range of the water temperature was between 26.40 and 27.65C. The temperature of the groundwater which favour microbial growth during bioremediation (Fig.2) fell within the range which favour microbial growth in bioremediation. According to Boopathy (2000) the degradation of pollutant in mesophilic temperatures is better and more efficient than the degradation at very low or high temperatures, although there are exceptions. A very high temperature would decrease oxygen solubility and limit the aerobic microbial biodegradation (*Margesin and Schinner 2001*). At low temperature, the degradation rate is generally observed to decrease, which is thought to be a result of reduced enzymatic activity rates (Bisht *et al*., 2015). Kwaji *et al*., (2020) observed successful bioremediation of hydrocarbons from Kaduna refinery effluents at room temperature using *ladosporium sp*.

The electrical conductivity (Fig. 3) varied between 46.35 and 716µs/cm. It is not surprising that relatively higher levels of electrical conductivity were observed in each monitoring well water (474.05 -716 µs/cm), however, the EC levels of the village well water in particular CRW1 (196.70µs/cm) is astonishing and revealing. The EC Level signifies the possible presence of organic pollutants in the well water. It has been reported in literature (Adeniyi, *et al*., 2017) that crude oil consists of hydrocarbon, water in organic salts, water soluble trace metals, organic sediments and other impurities which are most times removed before the refining process to prevent corrosion, catalyst poisoning, plugging and fouling of equipment. In KRPC, during the process, the desalted water, which is rich in organic waste, inorganic salt, trace metals and other waste water generated are sent to waste water treatment plant for treatment before discharge into River

Romi, the receiving water body. The oily sludge containing various hydrocarbons and other recalcitrant compounds is disposed of in the sludge dump site. This is probably the reason why the electrical conductivity, BOD and chlorides are high in the ground water. Amadi *et al*., (2014) observed conductivity range between 40.50 and 301µs/cm.

The values for turbidity varied from 30.76-292.0 NTU. (Fig.4). the least was recorded in dump site well I, while the highest was (26.40-27.65) in the village well water (CRWIII). The maximum permissible limit for water is 5NTU for both the Nigerian National Standard and World Health Organization (WHO). The NTU for both the village well water and the dump site well water exceeded the limit.

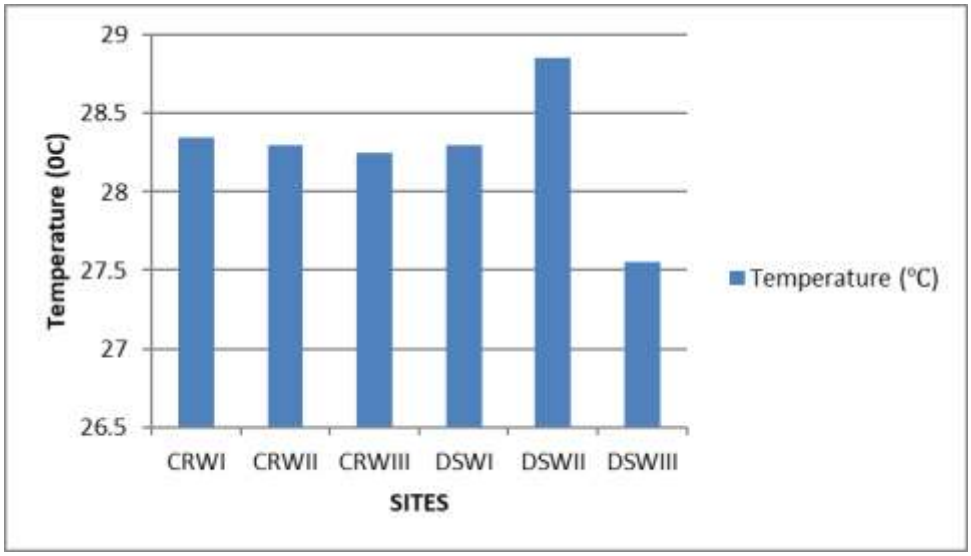


Fig. 2: Temperature of the ground water study sites.

KEY: CRWI (Chidunu/ Rido Well Water I); CRWII (Chidunu/ Rido Well Water II); CRWIII (Chidunu/ Rido Well Water III); DSWI (Dump Site Well Water I); DSWII (Dump Site Well Water II); DSWIII (Dump Site Well Water III).

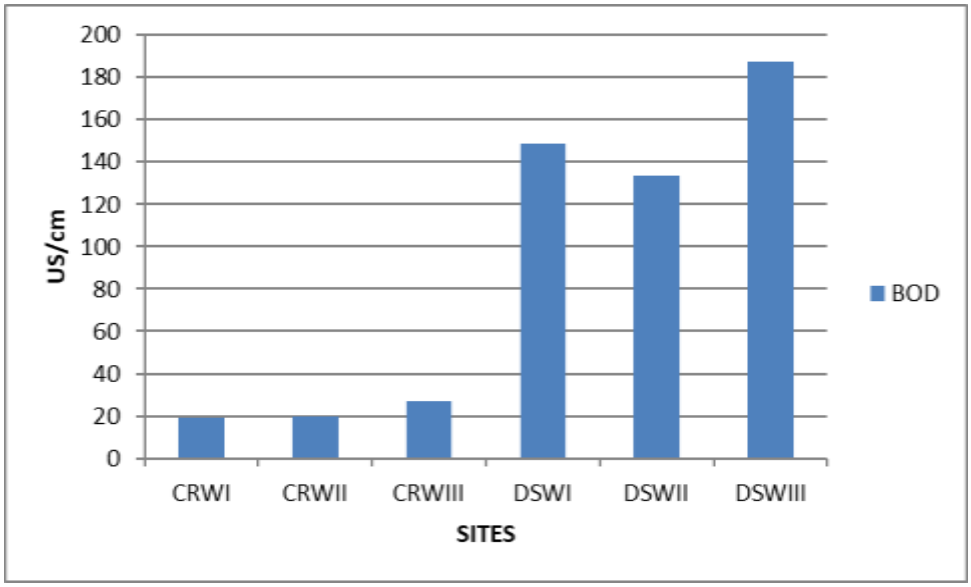


Fig. 3: Conductivity of the ground water study sites.

KEY: CRWI (Chidunu/ Rido Well Water I); CRWII (Chidunu/ Rido Well Water II); CRWIII (Chidunu/ Rido Well Water III); DSWI (Dump Site Well Water I); DSWII (Dump Site Well Water II); DSWIII (Dump Site Well Water III).

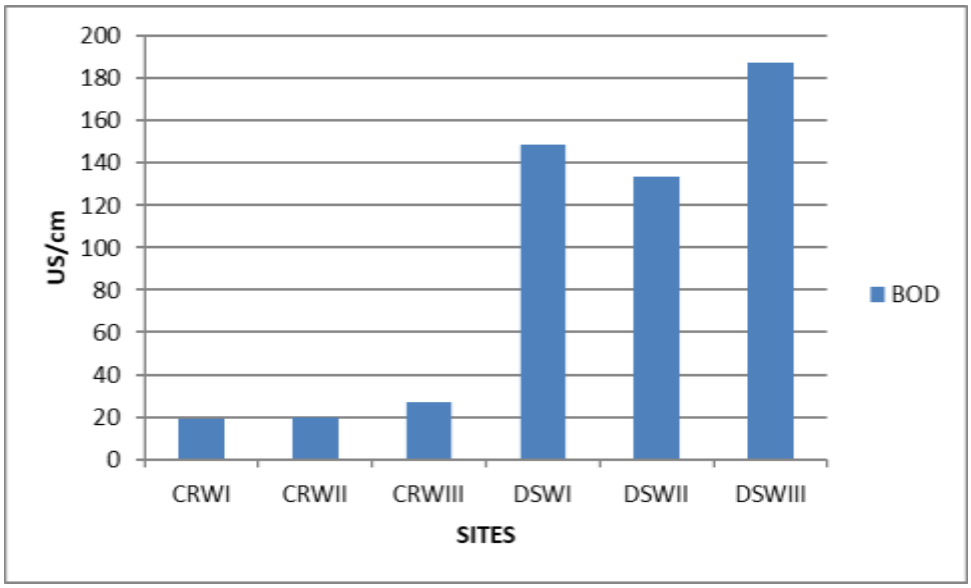


Fig. 4: Turbidity of the ground water study sites.

KEY: CRWI (Chidunu/ Rido Well Water I); CRWII (Chidunu/ Rido Well Water II); CRWIII (Chidunu/ Rido Well Water III); DSWI (Dump Site Well Water I); DSWII (Dump Site Well Water II); DSWIII (Dump Site Well Water III).

The well water is the source of drinking water and water for other domestic activities for residents in the village. The phosphate concentration (Fig. 5) was low in all the ground water samples except CRW III water. This is attributable to phosphate run off from fertilizer application in farmland by the well. It was observed during sample collection that the well (CRW III) is not concrete lined. The availability of nutrients, especially nitrogen and phosphorus, within the area of hydrocarbon degradation is critical

(Theresa *et al.*, 1998, Adeyinka and Urum, 2001; Atlas and Bartha 1992; Ijah *et al*., 2008). Inorganic sources such as phosphorus nitrogen are essential for microbial metabolism and affect the growth and the activity of microorganisms (Bamforth and Singleton 2005). The ratios of carbon/nitrogen or carbon/phosphorus are considered as a determining factor for bioremediation rates and are high in hydrocarbon contaminated sites. They limit and affect the degradation rate (Breedveld and Sparrevik, 2000). Bako et al., (2008) in their study on bioremediation of refinery effluents by strains of *Pseudomonas aeruginosa* and *Penicillium janthinellu* observed that in the case of phosphates only the colonies irradiated at 254nm for 10 minutes showed significant biodegradation. While the effectiveness of bioaugumentation, biostimulation and/or synergistic potentials of combined microbial cultures in bioremediation was observed in the cases of nitrates, ammonia and sulphates.

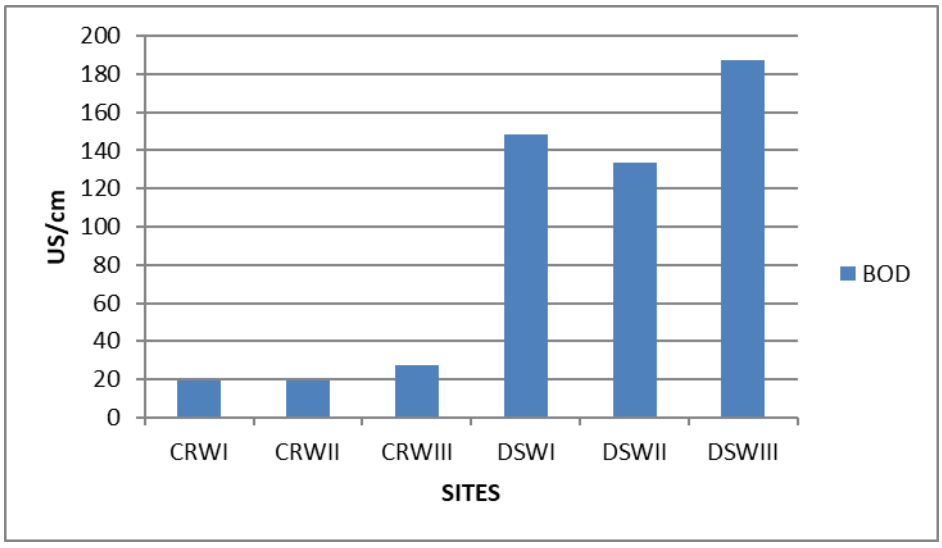


Fig. 5: Phosphate of the ground water study sites.

KEY: CRWI (Chidunu/ Rido Well Water I); CRWII (Chidunu/ Rido Well Water II); CRWIII (Chidunu/ Rido Well Water III); DSWI (Dump Site Well Water I); DSWII (Dump Site Well Water II); DSWIII (Dump Site Well Water III).

The mean sulphate (Fig.6) value ranged between 1.50-350.00mg/l. Highest sulphate (350.00mg/l) was recorded in dump site well I.

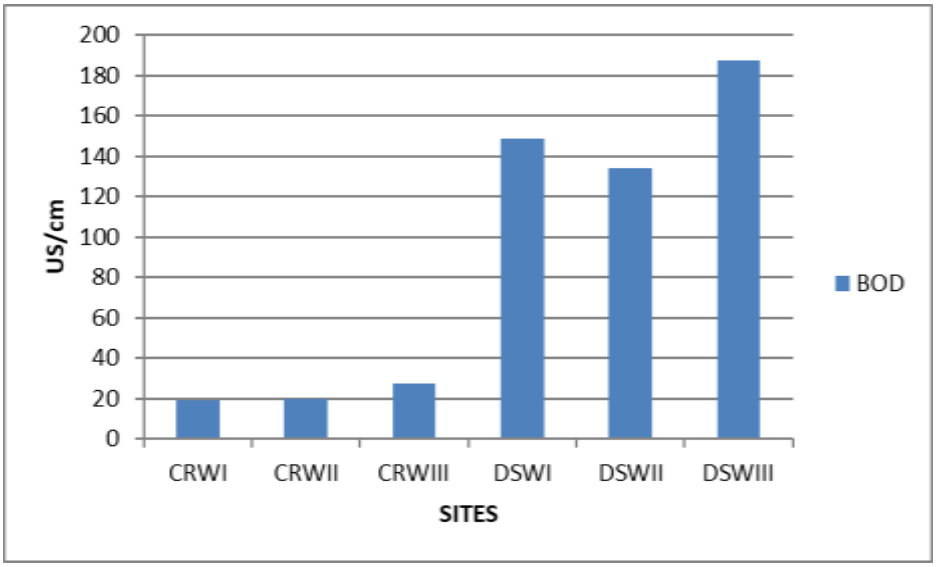


Fig. 6: Sulphate of the ground water study sites.

KEY: CRWI (Chidunu/ Rido Well Water I); CRWII (Chidunu/ Rido Well Water II); CRWIII (Chidunu/ Rido Well Water III); DSWI (Dump Site Well Water I); DSWII (Dump Site Well Water II); DSWIII (Dump Site Well Water III).

High sulphate concentration (350.00mg/l) observed in dump site well I (DSWI), could be due to sludge disposal activities in the area where the dump site wells are located. Problems caused by sulphates are oftentimes related to their ability to form strong acids which changes the ph. Sulphate ions are equally involved in complexing and precipitation reactions. These affect solubility of metals and other substances. In addition, highSulphate concentration can also lead to increase in the population of sulphate reducing bacteria (SRB) which are associated with microbial induced corrosion (MIC) in and on pipelines, metal structures and equipment Mohor *et al*., 2021), thus corrosion resistant plumbing materials such as plastic pipe would be more suitable in the site. Low sulphide concentrations (0.01 – 0.06mg/L) (Fig.7) observedwould need to be further investigated to find out what it indicates. (Adnan *et al*., 2018). Low nitrate concentrations (Fig. 8) observed in the groundwater is limiting to biodegradation Adnan *et al*., 2018). Floodgate (1979*)*, in considering the limitations of nutrients to biodegradation of hydrocarbons in the sea proposed the concept of determining 'nitrogen demand' similar to the concept of biochemical oxygen demand.

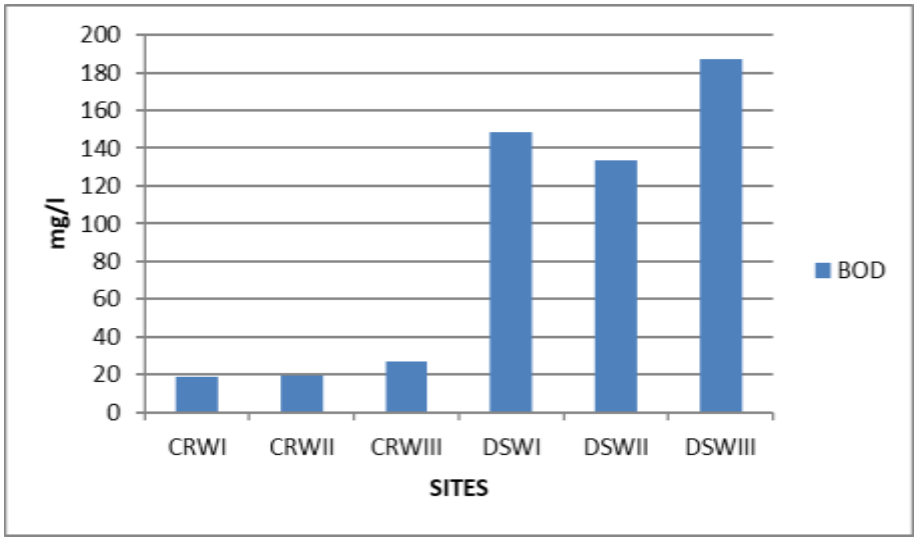


Fig. 7: Sulphide of the ground water study sites.

KEY: CRWI (Chidunu/ Rido Well Water I); CRWII (Chidunu/ Rido Well Water II); CRWIII (Chidunu/ Rido Well Water III); DSWI (Dump Site Well Water I); DSWII (Dump Site Well Water II); DSWIII (Dump Site Well Water III).

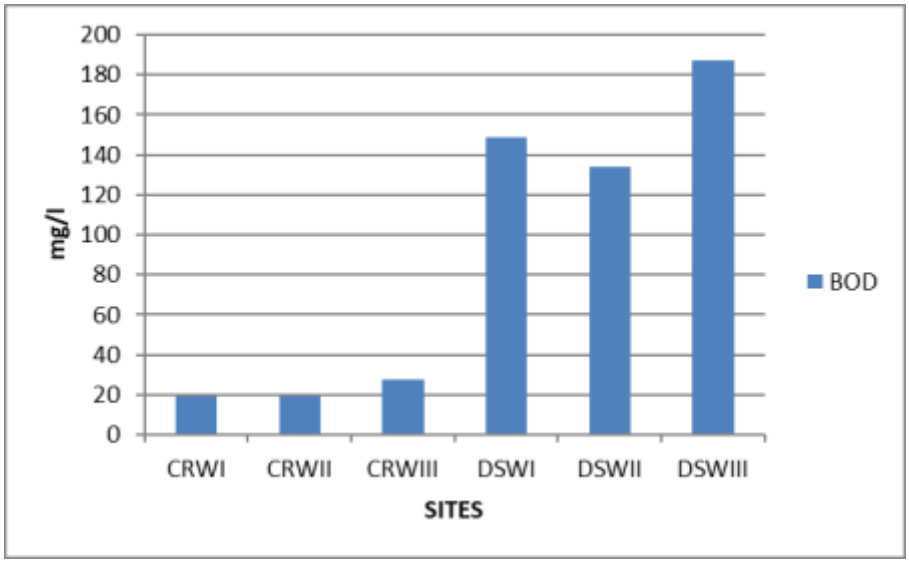


Fig. 8: Nitrate of the ground water study sites.

KEY: CRWI (Chidunu/ Rido Well Water I); CRWII (Chidunu/ Rido Well Water II); CRWIII (Chidunu/ Rido Well Water III); DSWI (Dump Site Well Water I); DSWII (Dump Site Well Water II); DSWIII (Dump Site Well Water III).

Ammonia nitrogen (Fig.9) varied between (0.27 and 5.40mg/L). The least was observed in village well water (CRW II) and the highest in dump site well (DSWIII). Although certain bacteria can utilize nitrate or nitrogen gas, the general rule in bioremediation is that nitrogen must be present in the form of ammonia (Jing et al., 1997). Hence the observed higher ammonia nitrogen in DSWIII signifies that the preferential nutrient is more available in this site, the simple fact is that bacteria are able to utilize ammonia for direct incorporation into amino acids, while nitrate must first be reduced to ammonia for use, or nitrogen gas must be fixed by reduction to ammonia. These reactions converting

nitrate and nitrogen to ammonia are a waste of energy for the hydrocarbon utilizing microbe and will slow the process of bioremediation (King *et al*., 1997). However, ammonia nitrogen is toxic. The chloride concentration (Fig.10) for the village well water observed in this study (11.08 – 33.75 mg/l) is high. High chloride concentration in the ground water is indicative that the dominant microflora would be halophic organisms. Micronutrients such as chlorine are required by microorganisms but at a very low concentration (Mahjoubi *et al*., 2018). High salinity of many environments disrupt cell membranes, denatures enzymes and results in desiccating osmotic pressures that are detrimental to many waste treatment microorganisms (Nweke & Okpokwasili 2003). Qin et al., (2012) cited by Adnan et al. (2018) suggested that salinity had a major influence on bioremediation and biodegradation processes, and it also affects microbial growth and diversity. Salinity has an adverse influence on the activity of some key enzymes implicated in the process of hydrocarbon degradation. (Ebadi *et al*., 2017).

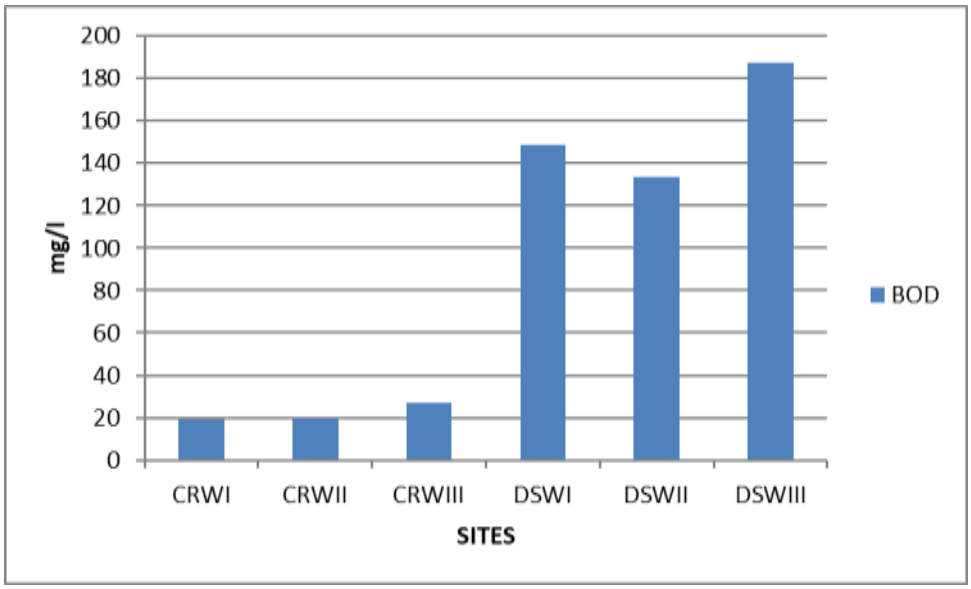


Fig. 9: Ammonia Nitrogen of the ground water study sites.

KEY: CRWI (Chidunu/ Rido Well Water I); CRWII (Chidunu/ Rido Well Water II); CRWIII (Chidunu/ Rido Well Water III); DSWI (Dump Site Well Water I); DSWII (Dump Site Well Water II); DSWIII (Dump Site Well Water III).

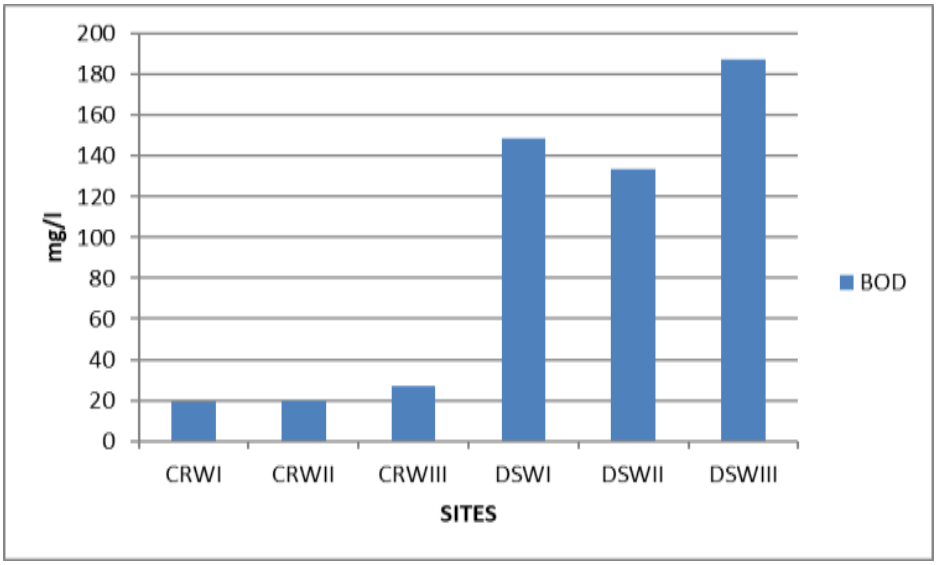


Fig. 10: Chloride of the ground water study sites.

KEY: CRWI (Chidunu/ Rido Well Water I); CRWII (Chidunu/ Rido Well Water II); CRWIII (Chidunu/ Rido Well Water III); DSWI (Dump Site Well Water I); DSWII (Dump Site Well Water II); DSWIII (Dump Site Well Water III).

Dissolved oxygen (Fig.11) was found to be between 6.70 and 7.69mg/l. This is not limiting for bioremediation. The importance of oxygen for hydrocarbon degradation is indicated by the fact that the major degradation pathways for both saturated and aromatic hydrocarbon involve oxygenases and molecular oxygen (Nwachukwu *et al*., 2001). It has been reported that aerobic degradation is the most attractive of the microbial processes for degradation of gasoline component in groundwater because it proceeds at a more rapid rate and does not produce the noxious by products associated with anaerobic decomposition (Mohammed *et al*.,1996; Mahjoubi *et al*., 2018).

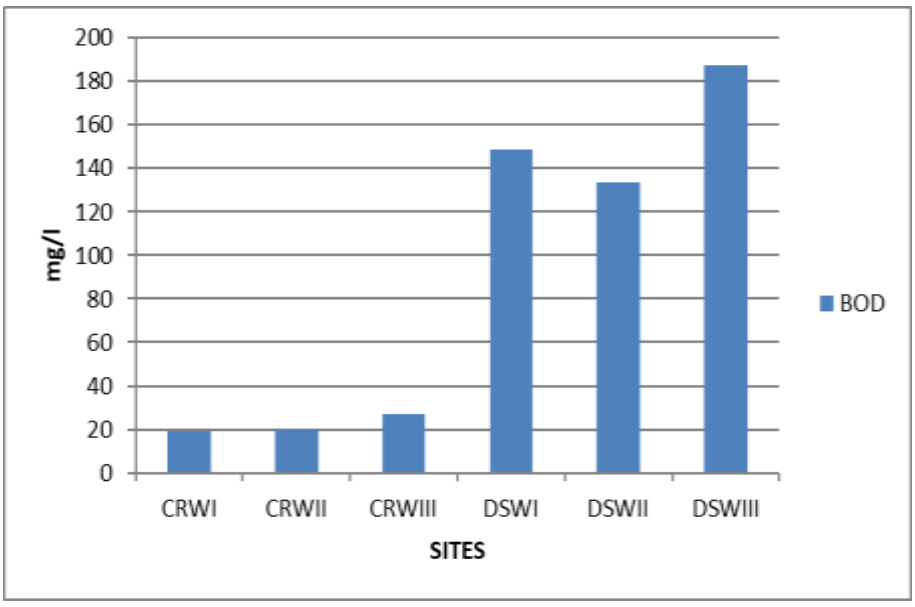


Fig. 11: DO of the ground water study sites.

KEY: CRWI (Chidunu/ Rido Well Water I); CRWII (Chidunu/ Rido Well Water II); CRWIII (Chidunu/ Rido Well Water III); DSWI (Dump Site Well Water I); DSWII (Dump Site Well Water II); DSWIII (Dump Site Well Water III).

The mean BOD (Fig.12) varied from 19.11 to 187.44mg/l. The dump site wells had higher BOD (133.77-187.44mg/l). The BOD observed in the study is far above 10mg/l standard recommended by WHO (2006) and Nigerian National standard BOD signifies the extent of biodegradable organic matters in the site. Thus, more oxygen will be needed to degrade the organic matter to carbon dioxide and water, and this can cause a decrease in oxygen of the water, which in turn is detrimental. Since BOD levels signifies the extent of biodegradable organic matter, the dump site well (DSWIII) had the highest amount of biodegradable organic matter. High BOD level of the dump site wells (137.77 -187.44mg/l) is attributable to sludge disposal activities in the area, and the highly significant ($p<0.01$) correlation that exists between hydrocarbon utilizing fungi (HUF) and BOD ($r=0.657$) in the wells (unpublished) is indicative that probably biodegradable organic matter in the sites is suitable nutrient for Hydrocarbon utilizing fungi.

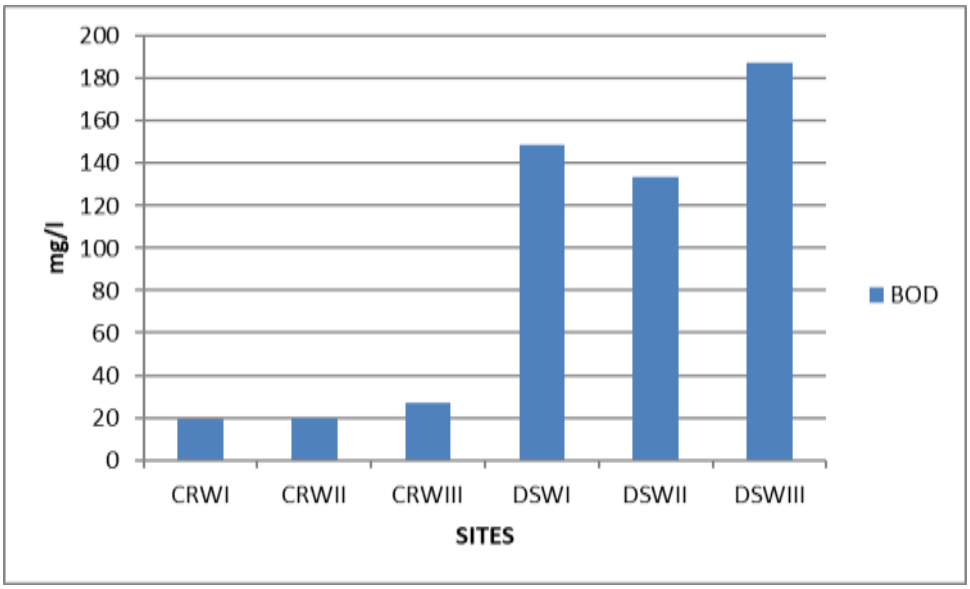


Fig. 12: BOD of the ground water study sites.

KEY: CRWI (Chidunu/ Rido Well Water I); CRWII (Chidunu/ Rido Well Water II); CRWIII (Chidunu/ Rido Well Water III); DSWI (Dump Site Well Water I); DSWII (Dump Site Well Water II); DSWIII (Dump Site Well Water III).

CONCLUSION

The study showed that the pH of the village well water was slightly acidic (5.67-6.17), while the dump site wells were slightly alkaline (7.14-7.67). This is indicative of pollution. The neutral pH of the dump site well water is more favourable for bioremediation by bacteria. The temperature and dissolved oxygen (D0) levels were within the range reported to be favourable for bioremediation strategy. Low levels of phosphate and nitrate are limiting for bioremediation. High sulphate concentration in the dump site well are indicative of pollution and corrosion problems. High NTU, chloride concentrations, BOD levels and

electrical conductivity are indicative of pollution.

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