MODELING OF SPATIAL AND TEMPORAL DISTRIBUTION OF GROUNDWATER QUALITY PARAMETERS IN WARRI, DELTA STATE, NIGERIA

BY

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A THESIS PRESENTED TO THE POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, OWERRI

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY (Ph.D.) DEGREE IN CIVIL ENGINEERING (WATER RESOURCES ENGINEERING)

MARCH, 2023

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MARCH, 2023

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ABSTRACT

Groundwater quality has deteriorated as a result of its contamination by anthropogenic and natural activities. Inadequate access to potable water has led to the outbreak of various waterborne diseases and ailments. This study investigated the spatial and temporal distribution of twenty-six (26) groundwater quality parameters (temperature, pH, EC, TDS, DO, turbidity, TH, TSS, BOD, COD, total coliform bacteria, Na, K, Ca, Mg, SO_4, NO_3, Cl, HCO_3, NH_4, PO_4, Fe, Cd, Cr, Cu, and Pb) obtained from fifty (50) existing boreholes across Warri, Delta State, Nigeria, during the dry season (December, 2019 – January, 2020) and the wet season (June, 2020 – August, 2020). The data obtained from the field and laboratory analysis of the samples were used as variable inputs to evaluate the temporal (seasonal) variation of groundwater quality and the water quality index (WQI). A geo-database was created for the 50 well locations and the Kriging interpolation geostatistical technique of the ArcGIS 10.6 software was used to determine the spatial distribution of the 26 water quality parameters in the study area and prediction maps are produced. The study revealed that most groundwater quality parameters had higher concentrations in the wet season than in the dry season. However, temperature, BOD, Na, K, Ca, Mg, SO_4, NO_3, Cd, Cr, Fe and Cu had lower concentrations. Cd and Cr had no significant variation in both seasons. From WQI classification, only 34% were placed as Excellent, 44% were Good, 10% were Poor, 10% were Very poor and 2% were unsuitable for drinking purposes in the dry season, while in the wet season 32% were placed as Excellent, 40% were Good, 12% were Poor, 14% were Very poor and 2% were unsuitable for drinking. Results from geostatistics showed that Turbidity, TH, TDS, BOD, Total Coliform, K, Ca, Mg, NH_4, PO_4, Cd and Pb had strong spatial dependence. Temperature, DO, COD, COD, Na, NO_3 and Cl showed moderate spatial dependence, pH, EC, TSS, SO_4, HCO_3, Fe and Cu showed weak spatial dependence in the dry season. However, in the rainy season, pH, TSS, Na, Mg, SO_4, HCO_3, Fe and Cd showed strong spatial dependence, while temperature, EC, Turbidity, COD, Ca, NO_3, Cr and Cu showed weak spatial dependence, and TH, TDS, DO, BOD, Total Coliform, K, Cl, NH_4, PO_4 and Pb showed moderate spatial dependence. The groundwater quality maps showed variation of groundwater quality parameters across the studied area with Jeddo (Refinery Axis), Warri Urban, Osubi, Effurun (Airport Road Axis), Pessu Market and Orhunworun Areas being the most contaminated areas. The spatial output maps will aid policy planners and decision makers for efficient management of the groundwater resources. The application of WQI and GIS is found to be effective for monitoring and mapping the spatial distribution pattern of groundwater quality parameters. Recommendations are made that water from the study area should be subjected to specific treatment before consumption.

Keywords: *Groundwater, Contamination, Water Quality Index, Geostatistics, Spatial Distribution, Kriging.*

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Water is one of the major resources of the world that is vital for man's existence as it is the basis of life on earth (Mahalingam, Ramu & Jayashree, 2014; Subramani, Krishnan & Kumaresan, 2012). The rise in population has resulted to intensive abstraction of groundwater for various uses by man (Todd & Mays, 2005). Groundwater is the world's most extracted, most important and safe source in meeting man'swater needs (drinking, domestic, agriculture, recreation and industrial production of goods) in semi-urban and rural areas of developing countries in arid and semi-arid regions and in the inlands (UNESCO, 2006). Groundwater constitutes an important source of water for about 70 percent of people in Nigeria (Ohwoghere & Adaikpoh, 2013; Orji & Egboka, 2015; Sadat-Noori, Ebrahimi & Liaghat, 2014). The use of groundwater has increased significantly in the last decades due to its overall good quality, high rate of urbanization and high reliability during drought seasons and generally low development costs (Akoteyon, Soladoye, Olaoye & Omotayo, 2011; WHO/UNICEF, 2006). The dependence on groundwater has led to the emergence of various activities with the potential of polluting groundwater (Sundara, Sundara, Ratnakanth & Hanumantha, 2010). Similarly, contamination of groundwater from natural, human activities including the increasing use and disposal of chemicals to the land surface pose a serious threat to groundwater resource and consequently health risk to local resource users and to the natural environment (Milovanovic, 2007). The pollutants in groundwater are virtually limitless and the sources and causes of groundwater pollution are closely related with human activities. Most

groundwater pollutants stem from land uses such as municipal/domestic (i.e. ranging from hydrocarbon contaminant plumes, solid waste, leachates, leakages, liquid waste, cesspools, septic tanks, saline water intrusion and interchange through wells and solid wastes from landfills), industrial (i.e. liquid wastes, tank and pipeline leakages, oil field stockpiles in industrial, construction and brines) and agricultural sources i.e. irrigation return flow which are sometimes saline (Todd & Mays, 2005). The situation is worsened by climate change, urbanization, industrialization, some geological formations, population boom and uncontrolled anthropologic activities at the surface (Causapé, Auqué, Gimeno, Mandado, Quílez & Aragüés, 2004; Nwankwo & Ogagarue, 2011; Oliveira, Dos Santos & Boeira, 2012; Tyagi, Sharma, Singh & Dobhal, 2013). Geochemical conditions also affect the quality of water in the aquifer (Huat, Moayedi, Moayedi, Asadi & Ali, 2011; Orji & Egboka, 2015). The chemical composition of groundwater is regulated by various factors, which include atmospheric input (i.e., sea spray, aerosols, etc.), mineral weathering through rock-water interaction, anthropogenic activities, and biogeochemical processes (Akoteyon, *et al.*, 2011). The weathering of minerals exerts an important control on groundwater chemistry (Milovanovic, 2007; Kim, Chanpiwat, Hanh, Phan & Sthiannopkao, 2011; Orji & Egboka, 2015). This process generally dominates the concentration of the major cations (Ca, Mg, Na, K) in groundwater (Akoteyon, *et al.*, 2011; Kim, Lee, Park, Hwang & Yang, 2005). Natural factors like earthquakes, volcanoes, algal bloom, storms, flooding, sea level rise (salt water intrusion) and river flows also contribute to the contamination of groundwater. Ocheri, Odoma & Umar, (2014), stated that groundwater quality in Nigeria is influenced and controlled by such factors as the geological conditions of the soil through which it flows, geochemical and physical

processes of the environment, heavy metals, bacteriological pollution and climatic factors. All these may therefore result in temporary or permanent loss of this important resource. Pollution of groundwater is a major issue because aquifers and the contained groundwater are inherently susceptible and vulnerable (Thirumalaivasan, Karmegam & Venugopal, 2003). Furthermore, the transport of contaminants in the groundwater system is affected by different processes such as advection, dispersion, diffusion, adsorption and decay (Kim, Chanpiwat, Hanh, Phan & Sthiannopkao, 2011).

The study area (Warri and its environs) is located in the continental shelf of West Africa whose aquifer is unconfined, unprotected, and shallow with a water table of about 6 metres below ground surface depending on the season and as such is generally vulnerable to a high risk of contamination (Ohwoghere & Adaikpoh, 2013; Milovanovic, 2007; Sayyed & Wagh, 2011; Trevisan, Padovani & Capri, 2000; Ogeleka & Uruejoma, 2018). Government's inability to fulfill her constitutional responsibility of providing potable water to residents has resulted to the absence or inadequate municipal water supply services. This has compelled millions of the residents and industries within the study area to seek alternatives by exploiting groundwater through drilling of personal shallow boreholes or hand dug wells without adherence to the standards of the supervising ministry or agencies, thereby leading to compromised water quality that is used untreated for various purposes (Ogeleka & Uruejoma, 2018).

Crude oil exploration and hydrocarbons related activities are the dominant industries in Warri. These activities have put the soil and groundwater at greater risk of contamination that threatens human health and economic development (Sayyed & Wagh, 2011; Tiwari, 2011). The exploration, exploitation, and unscientific management of groundwater

resources and other anthropogenic activities especially from the petroleum industries in the study area have posed a serious threat of reduction not only in quantity but also deterioration in its quality as a result of the presence of different harmful contaminants (Basavaraja, Hiremath, Murthy, Chandrashekarappa, Patel & Puttiah, 2011; Trevisan *et al.*, 2000). The quality of the groundwater in the study area is also affected by overexploitation. These anthropogenic activities have also contributed to climate change that has strong impact on the hydrologic cycle and the environment, resulting in the contamination of both surface and groundwater (Basavaraja *et al.*, 2011; Gyananath, Islam & Shewdikar, 2001; Karthekeyan, Saranya&Sashikkumar, 2013; Strohschon, Wiethoff, Baier, Lu, Bercht, Wehrhahn& Azzam, 2013; Wakode, Baier, Jha, Ahmed & Azzam, 2014). The contamination from natural and anthropogenic activities is deteriorating daily thereby causing numerous water quality problems in both groundwater and surface water systems (Sajal, Majur, A-Elahi & Iqbal Hossain, 2012).

The World Health Organization (WHO) has repeatedly insisted that the single major factor adversely influencing the general health and life expectancy of a population is the lack of ready access to clean drinking water (Kumar, Maroju& Bhat, 2007; Kumar, Kumar, Ramanathan & Tsujimura, 2010). There is a relationship between health and quality of water. Contamination of groundwater results in poor drinking water quality, high clean-up costs, high costs for alternative water supplies and/or potential health problems. Once groundwater is contaminated, organic chemicals, hydrocarbons, pathogenic organisms, inorganic cations and anions will be present in the water at higher conentrations (Balakrishnan, Saleem & Mallikarjun, 2011). The risk of consuming untreated water has posed serious health and environmental issues that result to epidemic in certain areas.

Studies have demonstrated some relationship between diseases outbreaks and septic tank systems that are poorly managed or where high densities of households with septic tanks have already been established (Beller, Ellis, Lee, Drebot, Jenkerson, Funk, Sobsey, Simmons III., Monroe, Ando, Noel, Petric, Middaugh & Spika 1997; Borchardt, Chyou, DeVries & Belongia, 2003b; Craun, 2006 and Groundwater Protection Council, 2007). Low-quality drinking water results in 80% of the incidence of many acute and chronic diseases that cause mortality in many communities (Aly, Abbas, Taha & Gaber, 2013; Milovanovic, 2007). Studies have further shown that contaminants may be hazardous when consumed excessively. In addition to health risks, other problems such as noticeable aesthetic problems, poor crop production, poor production of goods and products and high economic waste, that is, money spent on treatment plants are also associated with the use of contaminated water.

As important as groundwater is, the ministry and agencies responsible for water supply do not have a data base of water quality in Delta State. It is therefore necessary that the quality of drinking water should be monitored at regular time intervals (Ocheri *et al.,* 2014). Optimal and sustainable usage of ground water is possible only when the quantity and quality is properly assessed. Reliance on the physical, chemical and bacteriological characteristics of groundwater as a parameter in assessing its quality is on the increase (Karthekeyan *et al.,* 2013). This has resulted in groundwater being scarcely fragile and under the risk of degradation in both quality and quantity in many parts of the world (Ambiga & Durai, 2013). Although at a glance, it seems that environmental effects on groundwater are less than those on the surface water studies have proved that quantity and quality of groundwater are also affected by environmental factors as much as surface water

resources (DuNing, Li, Song & Yang, 2007). Another important issue in relation with the aforementioned is the spatial variation of groundwater quality parameters that cannot be assumed constant in the whole aquifer; they exhibit considerable spatial variability because the contaminants flow with the groundwater (Sun, Shaozhong, Lia & Zhang, 2009). Groundwater contamination and its spatial distribution have generated growing interest in recent years. Assessment of spatial correlation in hydrogeochemistry is useful for investigating groundwater quality. With finite potable water on one hand and increasing demand on the other, there is great and urgent need to protect and manage groundwater resources properly. Therefore, groundwater quality studies can provide valuable information for stakeholders working on preventing further deterioration of the environment and subsequently groundwater (Earon, 2014).

Groundwater is however not easily contaminated, yet once contaminated, its quality is difficult to restore and furthermore cannot be restored by stopping the contaminants from the source. Also, groundwater pollution is not visible and is detected only when a well or spring becomes noticeably polluted or its pollutants are discharged out from the water surface (Novotny, 2003). Therefore, it has become very important to regulate and monitor the quality of groundwater and to device ways and means of assessing and protecting it (Mufid, 2012). There is thus the need for proactiveness in preventing and controlling groundwater pollution (Narshima, Sudarshan, Srinivasulu, Anitha & Parameshwar, 2013; Zhang, Kinniburgh & Gabos, 2013). Such a need however, is now, because groundwater treatment is difficult and costly. Having a clear view of groundwater quality, decision makers can plan and organize the operation and maintenance of groundwater resources in a much better way (Abbasi, Bahramloo & Movehedan, 2015). This will determine to a large

extent the quality of water, it is this quality that determines the potability of the water. Considering the huge groundwater consumption in Warri and the lack of water quality monitoring, the present study is undertaken in order to determine the extent of groundwater contamination by various contaminants in the study area.

Like any scientific research, studies in groundwater quality parameters and contamination generate a large number of data which are difficult to interpret and represent (Mtetwa, Kusangaya & Schutte, 2013), also these data demand lots of time, and are often difficult to analyze. Understanding the spatial and temporal variation of groundwater quality is a crucial aspect for applying the optimal management of groundwater resources. Reliable data are essential for assessing and monitoring groundwater quality, but in many cases data collection all over the area is time consuming and not possible,so interpolation methods that can save time and money significantly are usually employed (Sahebjalal, 2012). In this study, the water quality index (WQI) is adopted in knowing the present water quality status. Empericl model using both correlation and regression analysis is adopted in predicting groundwater quality parameters of the study area with a view to monitoring its quality for various uses. Many professionals have indicated that groundwater quality mapping over extensive areas is the first step in water resource planning (Todd, 2007). This is usually facilitated by either modeling aquifer vulnerability with computation models or using results of laboratory analysis of groundwater samples. The Geographical Information Systems (GIS) technology which provides suitable alternatives for sufficient management of large and complex database is also used in this study. Groundwater quality modeling represents the spatial distribution of groundwater parameters interpretatively in order to locate optimum areas for high quality groundwater to be utilized for purposes of

drinking as well as other uses. The lack of data in the field of hydrogeology and groundwater especially, makes it necessary to implement some special procedures or estimation techniques to overcome this shortage (Munna, Kibriya, Nury, Islam & Rahman, 2015).

Geostatistical approach was widely used by many researchers for the analysis of spatial variations of groundwater characteristics. Geostatistical methods including the assessment of variograms are usually used to characterize this variability. The spatial distribution of polluted groundwater shows some heterogeneity and the pollutant concentration values are rarely available for every possible location of an area. The measurement of pollutant concentration at every location is not always feasible in view of the time and the cost involved in data collection. Therefore, prediction of values at other locations based upon selectively measured values could be one of the alternatives. In this context, to predict the concentration of pollutants at unmeasured locations, the geostatistical techniques are used. The basic assumption in using geostatistics is that the properties in the earth have some spatial continuity up to a certain lag distance. The geostatistical tool is used to obtain the spatial distribution map of a particular pollutant in the specified region. Geostatistical methods including the assessment of variogram are usually used to characterize this variability and Kriging offers an interesting opportunity to describe dependence structures for multivariate distribution (Dike, Ezealor & Oniye, 2004). Kriging method considers the spatial correlation between the sample points and is mostly used for mapping spatial variability (He, Bu, Xiong & Hu, 2013; Hengl, 2009). Kriging is distinguished from Inverse Distance Weighting (IDW) and other interpolation methods by taking into

consideration the variance of estimated parameters (Johnston, VerHoef, Krivoruchko & Lucas, 2001).

The results obtained through the mentioned tools are then used to adopt suitable remedial measures to protect the groundwater sources (Kumaresan & Riyazuddin, 2006). This assessment, on the whole, involves the evaluation of the physical, chemical and biological characteristics of water in relation to its natural quality, human effects and intended use which may impact human health and that of the aquatic system (UNESCO/WHO/UNEP, 1996) in Warri, Delta State of Nigeria.

Groundwater cannot be optimally used and sustained unless its quality is assessed. The region of active groundwater exploitation, to a large extent, coincides with the areas of industrial concentrations and residential areas within the study area. Therefore, understanding the spatial and temporal variation of groundwater quality is a crucial aspect for applying the optimal management of groundwater resources.

1.2 Problem Statement

Groundwater contamination has increased over the years as a result of anthropogenic activities and the geology of the study area (Puranik & Singh Mondal, Singh, 2010; Ogunlaja & Ogunlaja, 2007; Olobaniyi & Owoyemi, 2006; Olomukoro & Azubuike, 2009).These activities include but not limited to industrialization, urbanization, increase in population and agricultural activities. Hydrocarbon exploration, refining, oil spills, transportation and leakages of petroleum products, have also introduced chemical compounds and heavy metals into groundwater that have further deteriorated the quality of groundwater (Napacho & Manyele, 2010).The proliferation of on-site sewage disposal

systems emanating from urbanization and the failure of these onsite sewage systems have also resulted in contamination of groundwater by heavy metals due to the presence of permeable aquifers, high water levels, high hydraulic conductivity and porosity in the study area (Brown, Friedman, Kaufman & Yechieli, 2001; Francy, Helsel & Nally, 2000; Gardner & Vogel, 2005; Jin, Chen, Wang & Ogura, 2004; Landon, Clark, McMahon, McGuire & Turco, 2008; Panno, Hackley, Hwang, Greenberg,Krapa, Landsbergerand O'Kelly, 2006; Robertson, Cherry & Sudicky, Robertson, Cherry & Sudicky, 2000). Effluents from industries and saltwater intrusion in this coastal town are potential sources of groundwater contamination that have threatened the groundwater quality in the study area. Government's insensitivity and inability in fulfilling her constitutional responsibility of providing potable water to residents of the state have compelled millions of residents in the state to seek alternatives by drilling personal boreholes or hand dug wells without adherence to the standards of the supervising ministry or agencies thereby leading to compromised water quality. Groundwater is not static and the level of contamination is not uniform, so, the concentration of groundwater quality parameters varies in different locations.

Contamination of groundwater has become a severe problem for society and a major global concern as the water we drink daily cannot be assumed safe since over 50,000 people die daily as a result of water related diseases (Dike *et al.,* 2004). The contamination of groundwater has led to various health implications (Ogeleka & Uruejoma, 2018).These contaminants may be hazardous when consumed excessively. Studies have shown that high nitrate levels are associated with diseases such as methemoglobinemia (blue baby), gastric cancer, non-Hodgkin's lymphoma, typhoid, cholera, dysentery, diarrhea and other

water borne diseases (Mohamed Azwan, Mohd Kamil, Hazilia & Sahuni, 2010; WHO, 2004). Mortality in children under five years from water borne diseases annually is estimated to be about 4 million in developing countries and over 2.3 billon people worldwide have mortality and morbidity associated with water related ailments (Rank, 2011; WHO, 2004). Heavy metals in soils and water resources have led to carcinogenic and neurotoxic effects that have severe impact on plant and animal ecosystem including man (Singh & Chandra, 2014). In addition to health risks, other problems such as environmental issues, noticeable aesthetic problems, poor crop production, inferior and high cost of production of goods and products and high economic waste. WHO (2012) has reported that inadequate hygiene, poor sanitation and unsafe drinking water is the cause of over one million global annual deaths and about eighty percent of all ailments in developing nations. Several scholars have presented results on the health and environmental implications of heavy metals in soils and water resources in Warri area (Ayenimo, Adeeyinwo & Amoo, 2005; Emoyan, Ogban, & Akarah, 2006; Mode, Onokwai, Onwuka, Ekwe & Oha, 2010). Inadequate access to potable water and unavailability of reliable information on water quality are major contributors to frequent outbreak of pathogenic diseases in the Niger Delta of which Delta State is part (Owamah, 2019).

1.3 Objectives of Study

The main objective of this study is to model the spatial and temporal distribution of groundwater quality parameters in Warri, Delta State, Nigeria.

The specific objectives are:

i. To investigate the dry and wet seasons (temporal) physico-chemical and bacteriological characteristics (quality) of groundwater.

ii. To evaluate the water quality index (WQI) of groundwater in the study area and its fitness for human consumption.

iii. To develop regression models for predicting the concentration of selected water quality parameters of the water samples.

iv. To generate the spatial distribution maps (prediction maps) of groundwater quality parameters of the study area.

1.4 Significance of Study

The groundwater quality maps produced will give an insight into the spatial distribution of groundwater quality in the study area and would ensure better water resource management in Warri and its immediate environs. The study will give stakeholders in the water industry a broad knowledge of the spatial distribution of groundwater quality parameters in Warri and will serve as a decision support system to drill new boreholes or selecting existing wells to supply potable water.The results from this study will be useful for decision makers to adopt suitable remedial measures to protect the quality of groundwater sources. It will also help government in monitoring groundwater quality and will use same in her efforts to provide potable water to the residents of Warri and caution on any potential water related health problem. The spatial variability mapping of groundwater quality parameters in Warri will inform stakeholders on types of treatments groundwater should be subjected to at different locations as against the current prototype adopted by some individuals and government. This will ameliorate the outbreak of water borne diseases and any other associated health problem. By identifying areas and mechanisms by which pollutants enter

groundwater flow systems, this study will form a basis for minimizing the impact of existing or proposed industrial, agricultural or municipal activities on groundwater quality.

1.5 Scope of Work

The reach of this study entailed the digitization of layout map of Warri and its environs to display locations where groundwater samples were collected from existing boreholes. Water samples were analyzed in the field and or laboratory to determine their physico-chemical and bacteriological characteristics and compared same with WHO drinking water standards. The groundwater quality parameters were statistically evaluated, their seasonal variation investigated and developed empirical prediction models of concentration of some water quality parameters from insitu measured parameters. Water Quality Index (WQI) was evaluation to estimate the suitability of groundwater quality for drinking. Geo-data was acquired using a variety of digital forms/technologies from a variety of sources. The data was processed using the GIS techniques and applications of the geostatistical models to explore the spatial variation of groundwater quality in Warri.

1.6 Limitations of the Study

The greatest difficulties encountered in this study are:

i. High cost of laboratory analysis of the 50 borehole water samples for both dry and wet seasons.

ii. Indifference of most borehole owners to grant access to their boreholes for this research work, amongst others, are some constraints in collecting water samples from suitable locations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Groundwater

The earth is made up of about 70% of water (Patil, Sawant & Deshmukh, 2012) occurring naturally as surface or groundwater. 97% of this water is saltwater (Balakrishnan *et al.*, 2011) which is not useful for domestic use. The remaining 3% which is fresh water exists in lakes, rivers, groundwater and the atmosphere, with only 1% of it being available for consumption (El-Hoz, Mohsen & Laaly, 2013). Groundwater makes about 20% of the world's freshwater supply for various uses (Lathamani *et al.*, 2015). 70% of Nigerians rural and urban habitats are known to derive their agricultural, domestic and industrial water from groundwater (Ahianba, Damuna & Okogun, 2008; FOS, 2001; Saleem, Dandigi, Vijaykumar& Balakrishnan, 2012) as a result of its quality.

Groundwater is an extensive, concealed and relatively inaccessible resource that saturates the tiny spaces between alluvial materials (gravel, sand, silt and clay) or the crevices of fractures in rocks and sediments on the earth surface (GTZ, 2007). Groundwater scientists typically restrict the use of the term "groundwater" to underground water that can flow freely into a well, tunnel, spring etc. (Moench & Stapleton, 2007). This definition excludes underground water in the unsaturated zone. The origin of groundwater is primarily derived from rainfall and infiltration within the normal hydrological cycle, Plate 2.1 (Burns, Morgan, Peavler& Kahle, 2011; Kaponda, 2012). The hydrological cycle is the most fundamental principle of groundwater hydrology. The driving force of the circulation is derived from the radiant energy received from the sun. Two principal features of groundwater bodies distinguish them from surface water bodies: the groundwater residence

time and the considerable degree of physicochemical and chemical interdependence between the water and the containing material (Subramani, *et al.*, 2012). Water bodies can be fully characterized by the three major components: hydrology, physico-chemistry and biology (Todd, 2000).

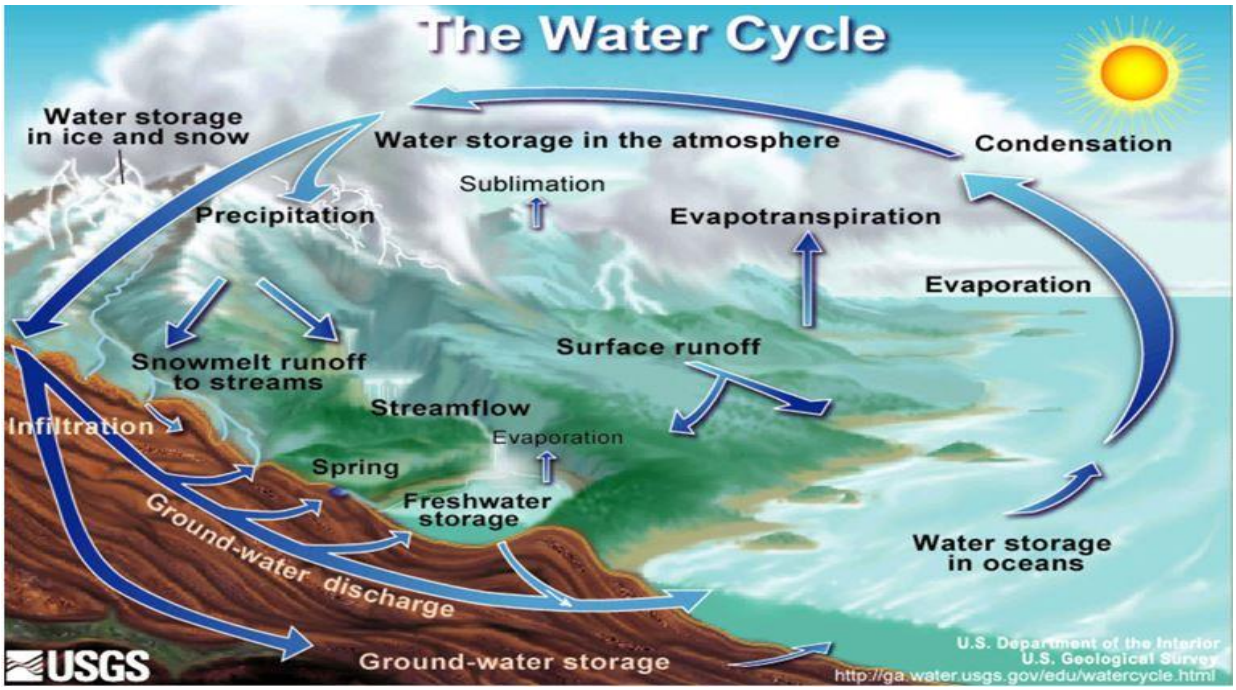


Plate 2.1. Schematic representation of the hydrological cycle.(Burns *et al.*, 2011).

Heath, (1998) states that:

1. Groundwater makes up about 1% of the water on the Earth (most water is in oceans)
2. But groundwater makes up to 35 times the amount of water in lakes and streams.
3. Groundwater occurs everywhere beneath the earth's surface, but is usually restricted to depth less than about 750 meters.
4. The volume of groundwater is equivalent to a 55metres thick layer spread out over the entire surface of the Earth.

2.1.1 Uses of groundwater

Groundwater is one of humans' major and most valuable natural resources that is vital for his existence and it plays a vital role in almost every facet of people's lives (Nas & Berktay, 2010; Sener & Davraz, 2013).Groundwater resources account for the greater percentage of domestic and industrial water requirements especially in developing countries (Okoro, Egboka, Anike &Enekwechi, 2010). It is also exploited for agricultural (livestock and irrigation) and septic systems since the earliest times (Moench & Stapleton, 2007; Nas & Berktay, 2010; Sadat-Noori *et al.*, 2014; Sener & Davraz, 2013; UNDP, 2006; UNESCO, 2006) due to long retention time and natural filtration capacity of the aquifer (Ehirim & Nwankwo, 2010). Groundwater is also used to cool nuclear reactors that generate electricity, civil engineering works, and in the manufacture of millions of consumer products. It provides a reasonably constant supply that is not likely to dry up under natural conditions.

2.1.2 Occurrence and sources of groundwater

The major sources of water include surface water, rain water, groundwater amongst others (Aremu, Olawuyi, Metshitsuka, Sridhar& Oluwande, 2002; Edema, Omemu& Fapetu, 2001; Efe, 2005; Panno *et al.*, 2006). Plate 2.2 shows the record of the different types of water on the earth.

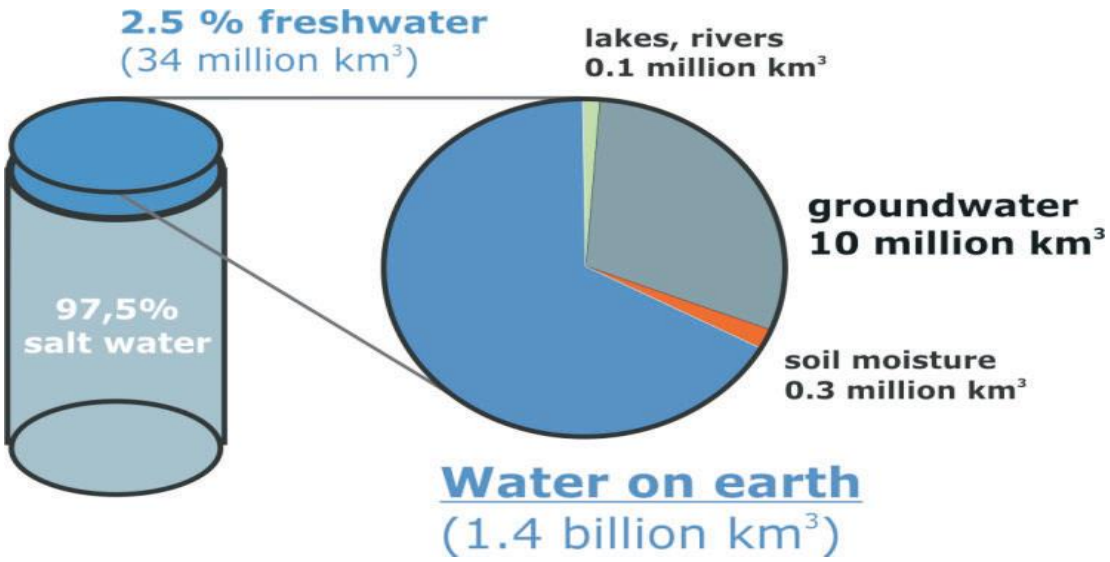


Plate 2.2. Water data on the earth (U. S. Environmental Protection Agency, 1996).

The occurrence and movement of groundwater are related to physical forces acting in the subsurface and the geologic environment in which they occur (Fetter, 1994). Groundwater makes up about 1% of the water on the Earth (most water is in oceans) and it makes up to 35 times the amount of water in lakes and streams (Balakrishnan *et al.*, 2011). Groundwater occurs in many different geological formations (Hassan, 2008; Michael, 2006; Tucker, 2011). The volume of water contained in the rock depends on the porosity of the rock. A layer of rock that is sufficiently porous to store water and permeable enough to transmit water in quantities that can be economically exploited is called an aquifer. Groundwater flow may take place through the spaces between the grains or through fissures, or by a combination of the two (Edmunds, 2000). Most groundwater is replenished by precipitationthroughrecharging during the rainy season in tropical climates or during winter in temperate regions.

Groundwater is constantly in motion and is moving very slowly back towards the sea. Most of the time, rivers and streams act as groundwater drains. This is the principle

involved in borehole construction (Naseh, Noori, Berndtsson, Adamowski & Sadatipour, 2018). It's actual rate of movement is dependent on the transmissivity and storage capacity of the aquifer. The subsurface occurrence of groundwater may be divided into zones of aeration (unsaturation) and saturation, Plate2.3 (Freeze & Cherry, 1979; Harter, 2003). Water occurring in the zone of saturation is commonly referred to simply as groundwater. A simple hydro chemical classification divides groundwaters into meteoric, connate and juvenile (Suthar, Bishnoi, Singh, Mutiyar, Nema& Patil, 2009; Hudak, 2001).

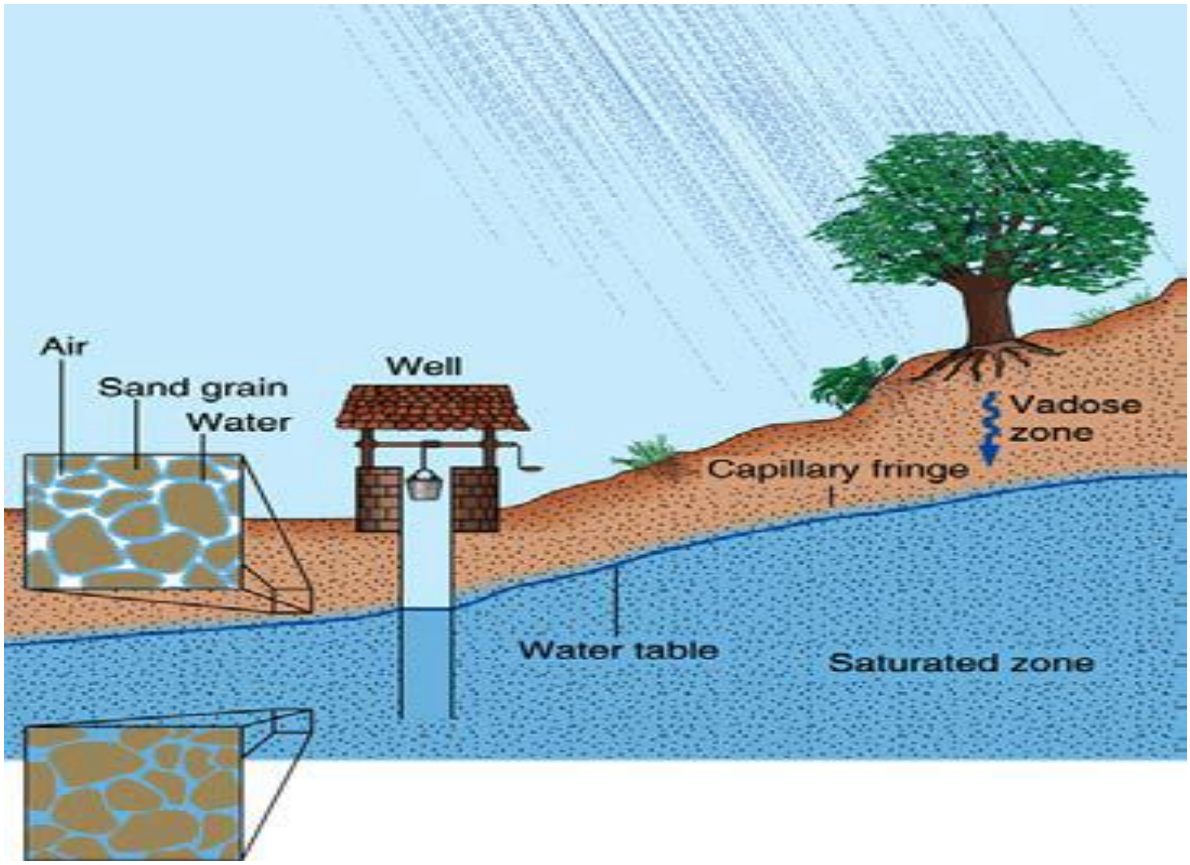


Plate 2.3. Water table showing saturated and vadose zones (Freeze and Cherry, 1979).

2.2 Quality of Groundwater

The term water quality is applied universally to the water status that meets the universal standards set for legitimate and vital use at any scale i.e., local, regional and international levels (WHO, 2002). Water contains different types of floating, dissolved, suspended and microbiological as well as bacteriological impurities. The natural chemical quality of groundwater is generally good, but elevated concentrations of a number of constituents can cause problems for water use (Sener &Davraz, 2013). Highly impure water has various effects on human beings, domestic purpose as well as industrial use. Human beings get affected/infected due to presence of different bacteria and heavy metals present in water. It may affect the different body organs andcause physiological disorder. Hard water is not suitable for domestic use such as washing, bathing, cooking as well as other purpose. Hard water is also not suitable for industrial and agricultural use. It damages the delicate machineries and affects the quality, stability and glossiness of the final product. High iron levels in groundwater are widely reported from developing countries, where they are often an important water quality issue. Provision of quality water to the various sectors such as domestic, irrigation, sanitation, environment and industry is the primary goal of any water resources project. The ratio of world population and water withdrawals during the twentieth century is found to be 3:7 (Mehrjardi, Jahromi, Mahmodi & Heidar, 2008). So, the protection of groundwater is necessary from its socio-economic point of view. A complete assessment of water quality is based on appropriate monitoring of three major components: hydrology, physico-chemistry, and biology components. In recent years, groundwater quality analysis gained importance to understand the processes contributing to pollution (Cronin, Barth, Elliot & Kalin, 2005).

Water quality is measured in terms of its physical, chemical and biological characteristics, usually with respect to its suitability for a specific purpose such as drinking or irrigation. (Sargaonkar and Deshpande, 2003; Ketata-Rokbani, Gueddari & Bouhlila, 2011) and it is important to ascertain its quality before it is used (Khan, Paterson& Khan, 2003, Sargaonkar & Deshpande, 2003). The availability of good quality water is an indispensable feature for preventing diseases and improving quality of life. Natural water contains different types of impurities that are introduced into it by different ways such as weathering of rocks and leaching of soils, dissolution of aerosol particles from the atmosphere and from several human activities, including mining, processing, the use of metal-based materials and lots of anthropogenic activities (Adeyeye & Abulude, 2004; Asaolu, Ipinmoroti, Adeyinowo & Olaofe, 1997; Ipinmoroti, Amoo & Adebisi, 2007). The increased use of metal-based fertilizer in agricultural revolution of the government could result in continued rise in concentration of metal pollutants in fresh water reservoir due to the water runoff. Also, faecal pollution of drinking water causes water born disease which has led to the death of millions of people (Adefemi & Awokunmi, 2010). Industrial waste and the municipal solid waste have emerged as one of the leading causes of pollution of surface and ground water. In many parts of the country, available water is rendered nonpotable because of the presence of heavy metals in excess. The situation gets worsened during the rainy season due to water scarcity and rain water discharge (Adefemi & Awokunmi, 2010). Contamination of water resources available for household and drinking purposes with heavy elements, metal ions and harmful microorganisms is one of the serious major health problems.

The quality of groundwater depends on various chemical constituents and their concentration, which are mostly derived from the geological data of the particular region (Adefemi & Awokunmi, 2010). Water in its pure form is H_2O. By reason of its good solvent attribute, this composition is modified as it passes through the atmosphere and percolates the ground dissolving soluble materials of varying compositions along its flow path, (Olobaniyi & Owoyemi, 2006). Chebotarev (1955) has shown that bearing local variations, which may result from an abnormal concentration of certain constituents in the soil, the composition of groundwater varies from bicarbonate at outcrops to sulphate water at intermediate depths to chloride waters at greater depths of continuous flow. These changes reflect the signatures of one or some of such factors as soil/rock composition, prevailing climatic condition, pH, the resident time of water within the formation and topography (Davis & De Wiest, 1966; Raji & Alagbe, 1997; Todd, 2000). In coastal environments the influence of saltwater intrusion is often significant. The overall implication of this is that the hydrochemical facies of groundwater changes in response to its flow path history.

In view of the complexity of factors determining water quality, and the large choice of variables used to describe the status of water bodies in quantitative terms, it is difficult to provide a simple definition of water quality. Furthermore, our understanding of water quality has evolved over the past century with the expansion of water use requirements and the ability to measure and interpret water characteristics. The physical and chemical quality of pristine waters would normally be as occurred in pre-human times, i.e., with no signs of anthropogenic impacts. The natural concentrationscould, nevertheless, vary by one or more orders of magnitude between different drainage basins. In practice, pristine waters

are very difficult to find as a result of atmospheric transport of contaminants and their subsequent deposition in locations far distant from their origin.

2.2.1 Factors Affecting Groundwater Quality and their Impact.

The quality of groundwater within a region is governed by both natural processes such as precipitation rate, weathering processes and soil erosion, hydrological processes, (Khalil &Ouarda, 2009;Pejman, Nabi-Bidhendi, Karbassi, Mehrdadi& Esmaeili-Bidhendi, 2009) and anthropogenic effects such as urbanization, industrialization and agricultural activities and the human exploitation of water resources, (Nouri, Karbassi & Mirkia, 2008, Noori, Sabahi, Karbassi, Baghvand & Taati,2010). The recent research in Haryana (India) concluded that it is the high rate of exploration than its recharging, inappropriate dumping of solid and liquid wastes, lack of strict enforcement of law and loose governance are the causes of deterioration of ground water quality (Guaya,Valderrama, Farran, Armijos & Cortina, 2015). Two prominent factors that affect groundwater quality considered in this study are river discharge (natural process) and land use (anthropogenic). According to Kang, Lee, Cho, Ki, Cha, and Kim, (2010), anthropogenic activities are directly reflected in land use characteristics: agriculture, forested and urban land use all reflect human activities. Understanding the relationship between land use and water quality is helpful for identifying primary threats to water quality, and the relationships are meaningful for effective water quality management because they can be used to target critical land use areas and to institute relevant measures to minimize pollutant loadings (Abler, Shortle, Carmichael & Horan, 2002).

Precipitation is a hydrological factor that affects groundwater quality (Nitasha & Tyagi, 2015). With the advent of industrialization and increasing populations, the range of requirements for water has increased together with greater demands for higher quality water. Experience has shown, however, that the resulting long-term environmental degradation often outweighs these benefits. Pollution and water quality degradation interfere with vital and legitimate water uses at any scale, i.e., local, regional or international (Meybeck, Chapman &and Helmer, 1989). Water quality criteria, standards and the related legislation are used as the main administrative means to manage water quality inorder to achieve user requirements. The most common national requirement is for drinking water of suitable quality, and many countries base their own standards on the World Health Organization (WHO) guidelines for drinking water quality (WHO, 1984, 1993; WHO/UNICEF, 2010).

2.2.2 Quality Parameters (Characteristics) of Water.

The quality of water is determined by its physical, chemical and bacteriological characteristics.Each freshwater body has an individual pattern of physical and chemical characteristics which are determined largely by the climatic, geomorphological and geochemical conditions prevailing in the drainage basin and the underlying aquifer.

2.2.2.1 Physico-chemical characteristics of groundwater.

Since groundwater often occurs in association with geological materials containing soluble minerals, higher concentrations of dissolved salts are normally expected in groundwater relative to surface water. Chemical quality describes all soluble or dissolved substances in the water. These include but not limited to dissolved cations and anions, toxic metals, organic and inorganic compounds, Biochemicaloxygen demand (BOD), Chemical oxygen

demand (COD) etc. (Huat *et al.*, 2011). The type and concentration of salts depends on the geological environment and the source and movement of the water (Ahn & Chon, 1999). Summary characteristics, such as total dissolved solids, conductivity and redox potential; provide a general classification of water bodies of a similar nature. Mineral content, determined by the total dissolved solids present, is an essential feature of the quality of any water body resulting from the balance between dissolution and precipitation. Oxygen content is another vital feature of any water body because it greatly influences the solubility of metals and is essential for all forms of biological life.The chemical quality of the aquatic environment varies according to local geology, the climate, the distance from the ocean and the amount of soil cover, etc.

The physical and chemical parameters are usually treated in combination as physico-chemical parameters of water and it gives a reflection of the chemical quality of water (Younger, 2007). It is very essential and important to test the water before it is used for drinking, domestic, agricultural or industrial purpose. Water must be tested with different physico-chemical parameters. Selection of parameters for testing of water solely depends upon what purpose we going to use that water and what extent we need its quality and purity (Chidanand, Shreekant & Arjun, 2013). Some physical test should be performed for testing of its physical appearance such as temperature, color, odour, pH, turbidity, TDS etc., while chemical tests should be performed for its BOD, COD, dissolved oxygen, alkalinity, hardness,trace metal, heavy metal contents and organic i.e. pesticide residue and other characters. It is obvious that drinking water should pass these entire tests and it should contain required amount of mineral level. Physico-chemical parameters are tested regularly for monitoring quality of water inorderto obtain exact idea about the quality of

water and the results (values) compared to standard values (Igboekwe & Akankpo, 2012). Major physico-chemical parameters include but not limited to the followings water quality parameters: Colour, Taste, Temperature, pH, Electrical Conductivity (EC), Carbon dioxide, Dissolved Oxygen (DO), Bicarbonate(HCO_3), Biochemical Oxygen demand (BOD), Chemical Oxygen demand (COD), Sulphate (SO_4), Ammonia, Calcium, Magnesium, Chloride, etc.

i. Turbidity: Turbid water is cloudy and prevents visibility (Agunwamba, 2000). It results from vegetable fibres and erosion of some colloidal materials such as; clay, silt, rock fragments, finely divided organic matter, finely divided plankton and other microscopic organisms, etc. The colloidal materials associated with turbidity provide adsorption sites for chemicals and biological organisms that may be harmful and cause undesirable tastes and odour (Wilkes University Center, 2009). The measurement of turbidity is based on the comparison of the intensity of light scattered by a sample as compared to light scattered by a reference suspension under the same condition (American Public Health Association, 1989). The colloidal matter will scatter or absorb light and thus prevent its transmission (Metcalf & Eddy, 1991). Turbidity is measured with an instrument called neophelometer. It measures the intensity of scattered light by turbid particles at right angles to the incident beam of light in comparison with the intensity of light passing through the sample. Scattering of light is a function of Tyndall effect exhibited by colloidal suspended particles (Chidanand, 2013). It is commonly recorded in nephelometer turbidity units (NTUs).

ii. Temperature: The temperature of water is a very important parameter because of its effect on chemical reactions and reaction rates, aquatic life, and the suitability of the

water for beneficial uses (Subramani *et al.,* 2012). Potable water should not be too hot or too cool. Information about the temperature of water is essential, because it affects the properties of water such as viscosity, density and surface tension. The solubility of chemicals and bacteriological activity are also affected by temperature. In an established system the water temperature controls the rate of all chemical reactions.

iii. pH: pH is one of the most operational water quality parameters which determines the suitability of water for various purposes with the optimum pH ranging from 6.5 – 8.5. pH is most important in determining the corrosive nature of water. The lower the pH value the higher is the corrosive nature of water. pH is positively correlated with electrical conductance and total alkalinity (Guaya *et al.,* 2015). The reduced rate of photosynthetic activity, the assimilation of carbon dioxide and bicarbonates which are ultimately responsible for increase in pH, the low oxygen values coincided with high temperature during the summer month. Various factors bring about changes of the pH of water. Higher pH values suggest that carbon dioxide, carbonate-bicarbonate equilibrium is affected more due to change in physicochemical condition (Karanth, 1987). Pure distilled water is neutral with a pH of 7.

iv. Hardness: When water is heated, they break down and precipitate out of solution, forming scale. Water with hardness above 200mg/l will cause scales in distribution systems, scum deposits in boilers and irrigation pipes (Ishaku, Ahmed &Abubakar, 2011; Ketata-Rokbani *et al.,* 2011,). Hardness above 300mg/l is considered to be very hard and may cause heart disease and kidney problems (Ramesh & Elango, 2006; WHO, 2008). Water hardness limits its use for domestic, industrial and agricultural activities. Another possible disadvantage of hardness in water, arise from the association

of magnesium with sulphate ion resulting in water possessing laxative properties. The salts if present in sufficient quantity will cause taste in water. Water should have Total Dissolved solids (TDS) of not more than 500mg/l if the effect of hardness is to be checked. Hardness is expressed as $CaCO_3$mg/l of water. Hard water requires considerable amounts of soap to produce foam or lather. Total hardness is now defined as the sum of calcium and magnesium concentrations in water, expressed as calcium carbonate equivalents in milligrams per litre (APHA, 2017). Table 2.1 gives the hardness classification of water.

Table 2.1: *Classification of Water in Terms of Hardness*

Degree of Hardness	Hardness of $CaC0_3$ mg/l
Soft	0 – 55
Slightly Hard	56 – 100
Moderately Hard	101 – 200
Very Hard	201 – 500

Source: APHA, 2017.

v. Electrical Conductivity (EC): Electrical conductivity is the ability of any medium, water in this case, to carry an electric current. The presence of dissolved solids such as calcium, chloride, and magnesium in water samples carries the electric current through water. it is the capacity (measure of the ability) of electrical current to pass through the water.It is the conductanceof electric current by water and it is directly related to concentration of ionized substances in water, that is, it depends upon the number of ions or charged particles in the water, and is measured by passing a current between two electrodes (a known distance apart) that are placed into a sample of water (Singh & Khan, 2011).

The salt concentration is measured generally by determining the EC of water (Ramesh & Elango, 2006). EC is a good measure of salinity hazard to crops (Ishaku et al., 2011), excess of it reduces the osmotic activity of plants and therefore interferes with the water absorption and nutrients from the soil. Conductivity shows significant correlation with other parameters such as temperature, pH value, alkalinity, total hardness, calcium, total solids, total dissolved solids, chemical oxygen demand, chloride and iron concentration of water. Electrical conductivity is affected by water temperature, the warmer the water, the higher would be the EC (Mrunmayee, 2014). The groundwater drinking quality management of study areas can be checked effectively by controlling conductivity of water (Kumar, Bharti, Singh & Singh, 2009). It is measured with the help of EC meter which measures the resistance offered by the water between two platinized electrodes. The instrument is standardized with known values of conductance observed with standard KCl solution. The unit of measurement for electrical conductivity is expressed in either microsiemens per centimeter ($\mu S/cm$) or millisiemens per centimetre (mS/cm).

vi. Carbon Dioxide: Carbon dioxide is the end product of organic carbon degradation in almost all aquatic environments and its variation is often a measure of net ecosystem metabolism (Hopkinson, 1985; Smith 1993). Excess carbon dioxide in water is disadvantageous because it can make water acidic and corrosive to materials. It is present in water in the form of carbonates, bicarbonates or free carbon dioxide. It can also make water hard. Therefore, in aquatic biogeochemical studies, it is desirable to measure parameters that define the carbon dioxide system. CO_2 is also the most important greenhouse gas on earth. Its fluxes across the air-water or sediment-water

interface. There are various readily measurable parameters of aquatic carbon dioxide system, such as pH (pCO_2), total dissolved inorganic carbon (DIC) and total alkalinity (TA). Surface water pCO_2 can be measured by photometric method (DeGrandpre, 1993; Wang, 2001) and DIC CO_2 is measured by coulometer or by an infrared CO_2 analyzer (Dickson&Goyet, 1994). Total Alkalinity CO_2 is determined by HCl titration of the water sample to the CO_2 equivalence point (Gran, 1952).

vii. Alkalinity: It is composed primarily of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-), alkalinity acts as a stabilizer for pH. Alkalinity of water may be due to the presence of one or more of a number of ions. These include: hydroxides, carbonates and bicarbonates. It is expressed commonly as mg/l ofcalcium carbonate. Excessive alkalinity may cause eye irritation in human and chlorosisin plants (Sisodia & Moundiotiya, 2006). The standard desirable limit of alkalinity of potable water is 120mg/l. The measurement of alkalinity and pH is needed to determine the corrosiveness of water (Nicholas, 2007). Alkalinity, pH and hardness affect the toxicity of many substances in the water. It is determined by simple dilute HCl titration in presence of phenolphthalein and methyl orange indicators.

viii. Dissolved Oxygen (DO): Surface water is usually saturated with dissolved oxygen but the discharge of waste water into rivers depletes the oxygen content. Groundwater drawn from great depths may be deficient of dissolved oxygen. The amount of O_2 that it can hold is small and it is inversely proportional to temperature (Kataria, Quershi, Iqbal & Shandilya, 1996; Morrissette&Mavinic, 1978; Moss, 1972; Krishnamurthy, 1990).DO is one of the most important water quality parameters. Its correlation with water body gives direct and indirect information e.g., bacterial activity,

photosynthesis, availability of nutrients, stratification etc. (Premlata, 2009). DO in sample is measured titrimetrically by Winkler's method after 5 days incubation at 293K. The difference in initial and final DO give the amount of oxygen consumed by the bacteria during this period. It is usually expressed as a concentration of oxygen in a volume of water (milligrams of oxygen per litre of water i.e. mg/l). Natural water has DO of 8mg/l to 10mg/l depending on the temperature. Dissolved oxygen makes the water taste good (Apeh & Ezugwu, 2017).

ix. Carbonate: Whenever the pH touches 8.3, the presence of carbonates is indicated (Patil, *et al.*, 2012). It is measured by titration with standardized hydrochloric acid using phenolphthalein as indicator. Below pH 8.3, the carbonates are converted into equivalent number of bicarbonates. The titration can also be done pH metrically or potentiometrically.

x. Bicarbonate: It is also measured by titration with standardized hydrochloric acid using methyl orange as indicator. Methyl orange turns yellow below pH 4.0. At this pH, the carbonic acid decomposes to give carbon dioxide and water.

xi. Biochemical Oxygen Demand (BOD): BOD is a measure of the amount of oxygen used by biological and chemical processes in a stream of water over a five day. It is a measure of organic material contamination in water, specified in mg/l. It is the amount of dissolved oxygen required for the biochemical decomposition of organic compounds and the oxidation of certain inorganic materials (e.g., iron, sulphites). Typically, the test for BOD is conducted over a five-day period. BOD measures the amount of oxygen that microorganisms consume while decomposing organic matter. BOD directly affects the dissolved oxygen, the greater the BOD the more rapidly

oxygen is depleted (APHA, 1998). BOD can be used to determine the pollution of waste water, the degree of pollution of water resources, self-purification capacity of sources, designing of treatment facilities and the efficiency of wastewater treatment methods.

xii. Chemical Oxygen Demand (COD): COD is another measure of organic material contamination in water specified in mg/l. COD is the amount of dissolved oxygen required to cause chemical oxidation of the organic material in water. Both BOD and COD are key indicators of the environmental health of a surface water supply. They are commonly used in waste water treatment but rarely in general water treatment. COD can be related empirically, to BOD, organic carbon or organic matter. COD is an index of organic content of water because the most common substance oxidized by dissolved oxygen in water is organic matter having a biological origin that is, dead plant and animal waste (Mrunmayee, 2014).

xiii. Total Organic Carbon: The total organic carbon (TOC) concentration represents all the carbon covalently bonded in organic molecules and so is not filtered. It is also the amount of carbon found in an organic compound. Often used as a non-specific indicator of water quality of cleanliness of pharmaceutical manufacturing equipment.

xiv. Volatile Suspended Solids (VSS): Volatile suspended solids (VSS) are defined as the portion of total suspended solids (TSS) that are lost on ignition (heating to 550℃). This information is useful to the treatment plant operator as it gives an approximation of the amount of organic matter present in the solid fraction of wastewater, activated sludge or industrial waste. It is sometimes referred to as Loss on Ignition (Khondakar, Sayed&Lovegrove, 2015).

xv. Cations and Anions: The cations which are present in the greatest concentration in most groundwater are Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^{+}) and Potassium (K^{+}). Modest concentrations of all the four elements are introduced to aquifers by rainwater (Younger, 2007). Dissolved calcium and magnesium in water are the two most common minerals that make water hard (Ramesh & Elango, 2013; Singh & Khan, 2011). Calcium occurs in water mainly due to the presence of limestone, gypsum and dolomite minerals (Karthekeyan *et al.,* 2013). Sodium salts (e.g., sodium chloride) are used in all food and are found in drinking water. It should be noted that some water softeners can add significantly to the sodium content of drinking water (WHO, 2008). Potassium is an essential element in both plant and human nutrition, and occurs in groundwater as a result of mineral dissolution, from decomposition, from decomposing plant material, and from agricultural runoff (APHA, 1999).

The major anions which are present in the greatest concentration in most groundwater are bicarbonate (HCO_3^{-}), sulphate (SO_2^{-4}), chloride (Cl^{-}) and nitrate (NO_3^{-}) and they are also introduced to aquifers through rainwater (Younger, 2007). As water travels through the earth surface, sulphates are picked up and dissolved in groundwater during infiltration of rainfall and groundwater recharge (Singh & Khan, 2011). It is beneficial in irrigation practices especially in the presence of calcium (Nas, 2009). High concentration of chloride indicates high degree of pollution (Singh & Khan, 2011; Yogendra &Puttaiah, 2008). It originates from natural sources, sewage and industrial effluents, it gives a salty taste to water and beverages at high concentration may cause physiological damages and can be toxic to crops and unsuitable for irrigation and industrial uses (Balakrishnan et al., 2011).

The main source of nitrate in water is from the atmosphere, legumes, plant debris, animal excreta and intensive use of fertilizers for agricultural purposes and higher concentration of it causes illness known as infant methemoglobin (Balakrishnan et al., 2011; Nas, 2009). Some of these anions and cations are briefly discussed.

a) Sulphate: It is measured by nephelometric method in which the concentration of turbidity is measured against the known concentration of synthetically prepared sulphate solution. Barium chloride is used for producing turbidity due to barium sulphate and a mixture of organic substance (Glycerol or Gum acetia) and sodium chloride is used to prevent the settling of turbidity. Water containing high levels of sulphates, particularlymagnesium sulphate (Epsom salts) and sodium sulphate (Glauber's salt) may have a laxative effect on persons used to the water.

b) Ammonia (Nitrogen): It is measured spectroscopically at 425nm radiation by making a colour complex with Nessler's reagent. The conditions of reaction are alkaline and cause severe interference from hardness in water.

c) Calcium: It is measured by complexometric titration with standard solution of ETDA using Patton's and Reeder's indicator under the pH conditions of more than 12.0. These conditions are achieved by adding a fixed volume of 4N Sodium Hydroxide. The volume of titre (EDTA solution) against the known volume of sample gives the concentration of calcium in the sample.

d) Magnesium and Iron: They occur together. They impart a bitter and unpleasant taste and colour to water. They are usually present as sulphates. Iron causes reddish particles in water while magnesium gives rise to brown water. It is measured by complexometric titration with standard solution of EDTA using Eriochrome black

T as indicator under the buffer conditions of pH 10.0. The buffer solution is made from Ammonium Chloride and Ammonium Hydroxide. The solution resists the pH variations during titration. A metallic taste may be present and it may affect the taste of beverages made from the water. High concentrations of iron and manganese do not appear to present a health hazard.

e) Sodium: It is measured with the help of flame photometer. The instrument is standardized with the known concentration of sodium ion (1 to 100 mg/litre). The samples having higher concentration are suitably diluted with distilled water and the dilution factor is applied to the observed values.

f) Potassium: It is also measured with the help of flame photometer. The instrument is standardized with known concentration of potassium solution, in the range of 1 mg to 5 mg/litre. The sample having higher concentration is suitably diluted with distilled water and the dilution factor is applied to the observed values.

g) Phosphorus: Sources of phosphorus enrichment are detergents, fertilizers (in both rural and urban areas), animal faeces (e.g., from farms and feed lots), sewage and some industrial wastes. High levels of phosphorus and other key nutrients may lead to related problems such as nuisance or toxic algal blooms, although some waterways are naturally eutrophic (nutrient enriched).

h) Chloride: Chloride is one of most important parameters in assessing the water quality. There are several potential human related sources of chloride and sulphate to aquifers. These include agriculture, household sewage, landfill leachate, industrial effluent and road salting (Hudak, 2000; Fetter, 1999). It is measured by titrating a known volume of sample with standardized silver nitrate solution using

potassium chromate solution in water or eosin/fluorescein solution in alcohol as indicator. The latter indicator is an adsorption indicator while the former makes a red colored compound with silver as soon as the chlorides are precipitated from solution. Excess chlorides in water impart an undesirable taste. The concentration of chloride in water should not exceed 250mg/l. NaCl is the most common chloride in water. It gets into water supplies as water flows through deposits in mines or when there is salt water intrusion. It could also result from sewage mixing with water.

i) Hydrogen Sulphide: Its presence in water produces bad taste and odour. Hydrogen sulphide is found in ground water due to contact with particular type of geological strata. The reduction process of organic and inorganic substances may also produce Hydrogen sulphide (H_2S). It can be removed by aeration or a combination of aeration and pH adjustment.

j) Silicates and Phosphate: These are also measured spectroscopically. Yellow colour is developed from the action of phosphates and silicates on molybdate ion under strong acidic conditions. The intensity of colour is directly proportional to the concentration of phosphate and silicates in the sample.

k) Nitrate (NO_3) and Nitrite (NO_2): Nitrite and nitrate are sources of nitrogen (N), an important nutrient for plants and algae. As ammonia (NH_3) is broken down by bacterial action, nitrite is formed and is then converted to the more stable, much less toxic nitrate through a process called “nitrification”. Fertilizers, animal wastes, sewage, etc. are major sources of nitrogen enrichment.

l) Heavy Metals: Metals are pollutant residues detectable in water. They are introduced in aquatic systems as a result of the weathering of soils and rocks, from volcanic eruptions and from a variety of anthropogenic activities involving mining, processing or use of metals and/or substances that contain metal pollutants (Ogunlaja&Ogunlaja, 2007). They are toxic to aquatic animals and can go through food chains with negative effects on human health. Metals commonly determined include:Aluminum (Al), silver (Ag), arsenic (As), Boron (B), Barium (Ba), Beryllium (Be), Calcium (Ca), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Iron (Fe), Mercury (Hg), Potassium (K), Lithium (Li), Magnesium (Mg), Manganese (Mn), Molybdenum (Mo), Sodium (Na), Nickel (Ni), Lead (Pb), Antimony (Sb), Selenium (Se), Tin (Sn), Titanium (Ti), Uranium (U), Vanadium (V) and Zinc (Zn).

Heavy metals are metallic chemical elements that have relatively high densities and are toxic or poisonous at low concentrations. When the pH in water falls, metals solubility increases and the metal particles become more mobile. This is why metals are more toxic in soft waters. Unlike some organic pesticides, metals cannot be broken down into less harmful components in the environment.Metals in water may be present in any or all of the following forms, each of which may require determination:

(a) Dissolved (filterable) metals: Those metals which pass through a 0.45μm membrane filter.

(b) Suspended (non-filterable) metals: Those metals which are retained by a 0.45μm membrane filter.

(c) Total metals: The concentration of metals in solution after vigorous digestion of an unfiltered sample, or the sum of the concentrations of metals in both the dissolved and suspended fractions.

(d) Acid-extractable metals: The concentration of metals in solution after treatment of an unfiltered sample with hot dilute mineral acid.Most metals present in water in the dissolved state, as well as those in the other three forms, after suitable treatment to bring them into the dissolved state, can conveniently be determined by means of atomic absorption spectrophotometry (AAS). Atomic Absorption Spectrometry (AAS) is a very common and reliable technique for detecting metals and metalloids in environmental samples (Baron, Legret & Astruc, 1990). Table 2.2 is a list of some heavy metals and some cations with their wavelengths and lamp current.

Table 2.2: Some heavy metals and cations with their corresponding wavelengths andlamp current.

Element	Wavelength (nm)	Lamp Current (mA)
Cadmium (Cd)	228.8	8
Chromium (Cr)	357.8	10
Copper (Cu)	324.8	5
Iron (Fe)	248.3	15
Lead (Pb)	217.0	10
Manganese (Mn)	279.5	12
Nikel (Ni)	232.0	15
Zinc (Zn)	213.9	10
Calcium (Ca)	422.7	10
Potassium (K)	766.5	8
Sodium (Na)	589.0	8
Magnesium (Mg)	285.2	4
Arsenic	219.0	12

Source: Smith1983.

2.2.2.2 Biological characteristics of groundwater

Biological quality, including the chemical analysis of biota, has a much longer time dimension than the chemical quality of the water since biota can be affected by chemical, and/or hydrological events that may have lasted only a few days, some months or even years before the monitoring was carried out.

From the public health standpoint, the bacteriological quality of water is as important as the chemical quality. A number of diseases can be transmitted by water. Among them are: typhoid and cholera. Bacteriological impurities are most important and perhaps most dangerous. They are microscopic and lethal (Ezomo, Biose & Ajieh, 2013; Ezugwu, 2010). The best way to measure bacteriological quality of water lies in the concept of indicator organisms. The indictor organism most often used is a group of microbes of the Escherichia coli (often called coliform bacteria or E. coli), which are present in large numbers in the human intestine. Therefore, the presence of coliform organisms in water indicates faecal contamination.The following attributes make their use as universal indicators justifiable (Metcalf & Eddy, 1991).

i. They are plentiful, hence not difficult to find.

ii. They are easily detected with simple tests.

iii. They are generally harmless except in universal circumstances.

iv. Their die off rate is very low thus they survive longer than most known pathogens.

v. They are enteric and thus suggestive of faecal pollution.

The major coliform bacteriae found in water are:

i. Faecal Coliform Bacteria: Like total coliform, faecal coli – forms (FC) are the sources of pathogens or disease-causing bacteria and viruses. The disease-causing

organisms are accompanied by other common types of non-pathogenic bacteria found in animal intestines which include; coli-form bacteria, Escherichia coli (E. coli) bacteria and enterococci bacteria.

ii. Escherichia coli: These bacteria are of definite faecal origin (human and animals) and they are excreted in vast numbers (EPA, 2001). Their presence in a water supply is proof that faecal contamination has occurred and it is therefore a definite indication of the risk that pathogens maybe present. They can cause serious infections such as urinary tract infections, bacteraemia, diarrhea and meningitis. The unit for reporting faecal bacteria is "colony – forming units" per 100 millimetres of water (CFU/100ml).

iii. Total Coliforms: The term 'total coliforms' refers to a large group of gram-negative, rod-shaped bacteria that share several characteristics. The group includes thermotolerant coliforms and bacteria of faecal origin, as well as some bacteria that maybe isolated from environmental sources. Thus, the presence of total coliforms may not indicate faecal contamination. In extreme cases, a high count for total coliform group maybe associated with a low or even zero, count for thermotolerant coliforms. Such a result would not necessarily indicate the presence of faecal contamination. It might be caused by entry of soil or organic matter into the water or by conditions suitable for the growth of other types of coliforms. Mostly found in sewage and natural waters some of these bacteria are also found in the faeces of humans and animals. They are provisionally identified by the production of acid and gas from the fermentation of lactose (Bartram & Pedley, 1996).

Micro-organisms do not affect the direction of reactions governed by the thermodynamic constraints of the system, but they do affect their rate. Sulphides, for instance, can be

oxidized without microbial help, but microbial processes can greatly speed up oxidation to the extent that, under optimum moisture and temperature conditions, they become dominant over physical and chemical factors. For an organism to grow and multiply, nutrients must be supplied in an appropriate mix, which satisfies carbon, energy, nitrogen and mineral requirements (Ehrlich, 1990). Most micro-organisms grow on solid surfaces and, therefore, coat the grains of the soil or aquifer. Up to 95 per cent of the bacterial population may be attached in this way rather than being in the groundwater itself (Jha, Chowdary & Chowdhury, 2010).The depth to which such activity is possible is determined by the nutrient supply and, in addition pH, EC, salt content, groundwater temperature and the permeability of the aquifer (Kaya & Kahraman, 2011). Nitrogen compounds are affected by both nitrifying and denitrifying bacteria. Reduction of nitrate by denitrifying bacteria occurs in the presence of organic material in anaerobic conditions, leading to the production of nitrite which is then broken down further to elemental nitrogen (Yimit, Eziz, Mamat, & Tohti, 2011). A principal microbiological concern in groundwater is the health hazard posed by faecal contamination. Feacal coliform counts and total coliform counts are some of the microbiological parameters that cause groundwater contamination (Olaoye & Onilude, 2009).

Of the four types of pathogens contained in human excreta, only bacteria and viruses are likely to be small enough to be transmitted through the soil and aquifer matrix to groundwater bodies (Lewis, Southwick, Ouellet-Hellstrom, Rench& Calderon, 1999). Bacteriological contamination of groundwater remains a major concern, especially where many dispersed, shallow dug wells or boreholes provide protected but untreated domestic water supplies. In summary, microbiological processes may influence groundwater quality

both positively and negatively. The former includes reducing nitrate and sulphate contents of groundwater, and removal of organic pollutants. The latter include the production of hydrogen sulphide and soluble metals, production of gas and biofilm fouling of well screens and distribution pipes (Hudak &Sanmanee, 2003). Common impurities found in water and their effects are highlighted in the Table 2.3.

Table 2.3: *Common Impurities in Water and Their Effects*

Micro-Organisms	Potential Health Effects	Sources of contaminants in Drinking Water
Cryptosporidium	Gastrointestinal illness	Human and animal fecal waste.
Guardia lambia	Gastrointestinal illness	Human and animal fecal waste.
Legionella	Ligionaire'sDisease (Pneumonia)	Found naturally in water, multiplies in heating systems.
Total Coliforms	Used as indicator that other potentially harmful bacteria may be present	E. coliand faecal coliforms come from human and animal waste.
Turbidity	Higher turbidity levels may have disease-causing micro-organism	Soil runoff
Viruses	Diarrhea, vomiting, cramps.	Human and animal faecal waste
	INORGANIC CHEMICALS	
Antimony	Increase in bloodcholesterol, decrease in blood sugar	Discharge from petroleum refineries, fire retardants, and ceramics.
Arsenic	Skin damage, increased risk of cancer and circulatory system problems	Erosion of natural deposits; runoff from glass and electronics production wastes.
Asbestos	Increased risk of developing benign intestinal polyps.	Decay of asbestos cement in water mains, erosion of natural deposits.
Cadmium	Kidney damage	Corrosion of galvanized pipes, runoff from waste batteries and paints.
Copper	Short term exposureGastro-intestinal distress long term exposure; liver or kidney damage	
Lead	Infants and Children Delays in physical and mental development. Adults Kidney problems, high blood pressure	Corrosion of household plumbing systems; erosion of natural deposit.
Nitrate/Nitrites	"Blue baby syndrome" in infants under six months	Run off from fertilizer use; leaching from septic tanks; sewerage.
	ORGANIC CHEMICALS	
Benzene	Anaemia increased risk of cancer	Discharge from factories leaching from gas storage tanks and landfills.
Benzo (a) pyrene (PAH'S)	Reproductive difficulties; carcinogenic	Leaching from liming of water storage tanks and distribution lines
Di (2-ethy hexyl) adipate	General toxic effects or reproductive difficulties	Leaching from PVC Plumbing systems discharge from chemical factories.

Source:Hudak and Sanmanee, 2003.

2.2.2.3 Spatial and temporal distribution of water quality parameters

To manage and preserve groundwater, it is necessary to evaluate the status and variability of groundwater quality.The quality of groundwater varies with space and time. By spatial distribution of groundwater quality parameters is meant existing or occurring in space while temporal distribution implies variation with time or season. If water quality changes significantly with time at a given area, temporal variation of water quality processes can be revealed by comparing the chemical characteristics of the clusters to which that area belong (Srivastava, Han, Gupta & Mukherjee, 2012). Factors controlling the spatial distribution and temporal trend of groundwater quality at a national scale are important to investigate for sustaining livelihood and ecological balance.

2.3 Water Quality Index (WQI)

To address the health hazards associated with using contaminated water, guidelines that set out the maximum acceptable concentrations of these substances in drinking water were developed.The Guidelines for Canadian Drinking Water Quality and the Guideline Technical Documents gave rise to what is today referred to as Water Quality Index (WQI). The guidelines set out the basic parameters that every water system should strive to achieve inorder to provide the cleanest, safest and most reliable drinking water possible. The Guidelines for Drinking Water Quality deal with microbiological, chemical and radiological contaminants. This approach looks at each drinking water system from the source all the way to the consumer's tap to make sure all known and potential hazards are identified and addressed so water remains free of contaminants.

A Water Quality Index (WQI) is a means by which water quality data is summarized for reporting to the public in a consistent manner (Tyagi *et al.*, 2013). It is a valuable and

unique rating to depict the overall water quality status in a single term that is helpful for the selection of appropriate treatment technique to meet the concerned issues. It provides a single number that usses the overall water quality status of a particular location (Yogendra & Puttaiah, 2008). The drinking water guidelines can be used as markers to make sure the barriers are working and the treated drinking water is safe. They also address concerns with physical characteristics of water, such as taste and odour. It describes the suitability of water sources for human consumption and it is one of the most effective policies formulated by various environmental monitoring agencies for in determining the quality of water. The use of individual water quality variable in order to describe the water quality for the common public is not easily understandable (Akoteyon *et al.*, 2011; Bharti & Katyal, 2011). Hence, WQI has the capability to reduce the bulk of the information into a single value to express the data in a simplified and logical form (Babaei, 2011). It takes information from a number of sources and combines them to develop an overall status of a watersystem (Chowdhury, Muntasir & Hossain, 2012; Jagadeeswari & Ramesh, 2012; Karbassi, 2011; Srivastava & Kumar, 2013),thereby increasing the understanding ability of highlighted water quality issues by the policy makers as well as for the general public as users of the water resource (Nasirian, 2007).

The WQI which was first developed by Horton in United States in the early 1970s is basically a mathematical means of calculating a single value from multiple test results (Miller & Ullman, 2004; Yogendra & Puttaiah, 2008) which attempts to provide a mechanism for presenting a cumulatively derived, numerical expression defining a certain level of water quality (Asuquo, 2012). Ten (10) most commonly used water quality variables like dissolved oxygen (DO), pH, coliforms, specific conductance, alkalinity and

chloride etc. are selected and applied in determining WQI of water and has been accepted in European, African and Asian countries (Horton, 1965). Weights are assigned to groundwater quality parameters based on their health effects. The assigned weight reflected significance of a parameter for a particular use and has considerable impact on the index. The index result represents the level of water quality in a given water basin, such as lake, river or stream. Furthermore, a new WQI similar to Horton's index was developed by the group of Brown in 2001 (Brown, 2001) which was based on weights to individual parameter. Recently, many modifications have been considered for WQI concept through various scientists and experts (Bhargave, 1983; Dwivedi, Tiwari & Bhargava, 1997, Yogendra & Puttaiah, 2008) and have developed WQI based on rating of different water quality parameters (Miller and Ullman, 2004).

WQI is a unitless number ranging from 1 to 100 and it allows good and bad water quality to be quantified. WQI does not negate the comparison of water quality parameter with the recommended limits (Singh & Khan, 2011) but in addition uses its tool to communicate the information on the overall quality of water (Asadi, Vuppala & Reddy, 2007; Ketata – Rokbani et al., 2011; Pradhan, Patnaik & Rout, 2001). It improves understanding of water quality issues by integrating complex data and generating a score that describes water quality status and trend (Saeedi, Abessi, Sharifi & Meraji, 2010). Avvannavar & Shrihari (2008) utilized water quality index to determine the suitability of River Netravathi, Mangaore and South India for drinking purposes. However, WQI depicts the composite influence of different water quality parameters and communicates water quality information to the public and legislative decision makers. In spite of absence of a globally

accepted composite index of water quality, some countries have used and are using aggregated water quality data in the development of water quality indices.

Attempts have been made to review the WQI criteria for the appropriateness of drinking water sources. Besides, a Water Quality Index that is globally accepted has been developed in a simplified format, which may be used at large and could represent the reliable picture of water quality. The way one can tell if water is healthy is to calculate its water quality index (Brown et al., 2001; Mitchell & Stapp, 2000). It gives the public a general idea the possible problems with the water in the region. It is similar to the UV index or an air quality index, and it tells us, in simple terms, what the quality of drinking water is from a drinking water supply. Essentially the WQI is a statistically tool used to transform large quantities of water quality data into a single cumulatively derived number which resembles the degree of pollution (Agbaire, Akporido & Akporhonor, 2014) and it is calculated by comparing the water quality data to "Guidelines for Canadian Drinking Water Quality".

In this study, WQI will be calculated by using weighted index method utilized by Vasanthavigar, Srinivasamoorthy, Ganthi, Vijayaraghavan and Subrahmanya, 2010; Ketata-Rokbani *et al.*, 2011; Al-Hadithi, 2012; Jagadeeswariand Ramesh 2012. Their methods assigned a weight (w_1) on groundwater quality parameters based on their health effects as shown in Table 2.5. The maximum weight of 5 is assigned to parameters like TDS, Cl^-, sulphate and nitrate due to their major importance in water quality assessment. Bicarbonate is given the minimum of one (1) as it plays an insignificant role in the water quality assessment. For this study, the mean assigned weight value will be utilized to calculate WQI value for each sample as given in Table 2.4 (Vasanthavigar *et al.,* 2012).

Table 2.4: *Water Quality Parameters with Assigned Weights.*

Water quality parameter	Weightassigned (1)	Weightassigned (2)	Weight assigned (3)	Weight assigned (4)	Mean value
pH	-	3	4	2	3.7
TDS (mg/l)	5	5	4	1	4.5
Cl^- (mg/l)	5	3	3	2	3.5
SO_4^{2-} (mg/l)	5	3	4	1	4
NO_3^- (mg/l)	5	5	5	1	5
HCO_3^- (mg/l)	1	2	3	2	2.3
Na^+ (mg/l)	4	3	2	1	2.8
Ca^+ (mg/l)	3	2	2	1	2.3
Mg^+ (mg/l)	3	2	2	1	2.3
					$\sum W_i = 30.4$

Source: Vasanthavigar et al., 2012; Ketata – Rokbani et al., 2011; Al – hadithi, 2012; Jagadeeswari and Ramesh, 2012.

2.3.1 Evaluation of Water Quality Index

A general WQI approach is based on the most common factors, which are described in the following three steps (Fernandez et al., 2012):

i. Parameter selection: This is carried out by judgment of professional experts, agencies or government institutions that is determined in the legislative area. The selection of the variables from the 5 (five) classes namely oxygen level, eutrophication, health aspects, physical characteristics and dissolved substances, which have the considerable impact on water quality, are recommended (Dunnette, 1979).

ii. Determination of quality function (curve) for each parameter considered as the sub-index:Sub-indices transform to non-dimensional scale values from the variables of its different units (ppm, saturation percentage, counts/volume etc.).

iii. Sub-Indices aggregation with mathematical expression: This is frequently utilized through arithmetic or geometric averages.However, a huge number of water quality indices viz. Weighted Arithmetic Water Quality Index (WAWQI), National Sanitation Foundation

Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), Oregon Water Quality Index (OWQI) etc. have been formulated by several national and international organizations. These WQI have been applied for evaluation of water quality in a particular area (Chaturvediand Bassin, 2012; Lumb, Halliwell & Sharma, 2002). Moreover, these indices are often based on the varying number and types of water quality parameters as compared with respective standards of a particular region. Water quality indices are accredited to demonstrate annual cycles, spatial and temporal variations in water quality and trends in water quality even at low concentrations in an efficient and timely manner (Bordalo, Teixeira & Wiebe, 2006). Continuous periodical monitoring of water quality is necessary so that appropriate steps may be taken for water resource management practices (Etim, Odoh, Itodo, Umoh & Lawal, 2013). The rating of water quality as according to different WQI methods are given in Table 2.5 and Table 2.6.

Table 2.5: *Water Quality Rating as Per Weighted Arithmetic Water Quality Index Method*

Water quality index level	Water quality status	Grading
0-25	Excellent water quality	A
26-50	Good water quality	B
51-75	Poor water quality	C
76-100	Very poor water quality	D
> 100	Unsuitable for drinking	E

Source: Chatterjee et al., 2009.

Table 2.6**:** *Water Quality Rating as Per Different Water Quality Index Methods.*

National Sanitation Foundation Water Quality Index (NSFWQI)	
WQI Value	Rating of Water Quality
91-100	Excellent water quality
71-90	Good water quality
51-70	Medium water quality
26-50	Bad water quality
0-25	Very bad water quality
Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI)	
95-100	Excellent water quality
80-94	Good water quality
60-79	Fair water quality
45-59	Marginal water quality
0-44	Poor water quality
Oregon Water Quality Index (OWQI)	
90-100	Excellent water quality
85-89	Good water quality
80-84	Fair water quality
60-79	Poor water quality
0-59	Very poor water quality

Source: Chatterjee et al., 2009; Tyagi et al., 2013.

2.3.1.1 Evaluation of WQI using the weighted arithmetic index method:

The Weighted Arithmetic Index method of water quality index computation utilizes ten to thirteen chosen important parameters and drinking water quality standards recommended by the WHO, EU and NSDWQ. The mean assigned weight value is utilized in calculating WQI value for each sample as given in the weight assigned column of the Table 2.5 (Vasanthavigar et al., 2012). Further, quality rating or sub index are calculated using the following expression (Equation 2.5).

$$q_n = 100\,\frac{[V_n - V_{i0}]}{[S_n - V_{i0}]} \qquad (2.5)$$

(Let there be nwater quality parameters and quality rating (q_n) corresponding to nth parameter is a number reflecting relative value of this parameter in the polluted water with respect to its standard permissible value)

q_n = Quality rating for the n^{th} Water quality parameter

V_n = Estimated value of the n^{th} parameter at a given water sampling station

S_n= Standard permissible value of the n^{th} parameter

V_{i0} = Ideal value of n^{th} parameter in pure water (i.e., 0 for all other parameters except the parameters pH and Dissolve oxygen (7.0 and 14.6 mg/l respectively).

The unit weight will be calculated by a value inversely proportional to the recommended standard value S_n of the corresponding parameter,

$$W_n = \frac{k}{S_n} \qquad (2.6)$$

Where: W_n= unit weight for nth parameter

S_n= standard permissible value for nth parameter

k = proportionality constant.

The overall WQI will be calculated by aggregating the quality rating with the unit weight linearly from Equation 2.6 and its status compared to Table 2.5 to give the Equations 2.7, 2.8, 2.9, 2.10 and 2.11.

$$WQI = \frac{\sum q_n W_n}{\sum W_n} \qquad (2.7)$$

Alternatively, WQI could also be calculated as follows:

$$\text{Relative weight } (W_i) = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad (2.8)$$

$$\text{Quality rating scale } (q_i) = \frac{c_i}{s_i} \times 100 \qquad (2.9)$$

$$Sl_i = W_i \times q_i \qquad (2.10)$$

$$WQI = \sum Sl_i \qquad (2.11)$$

where;

w_i = weight of each parameter

n = number of parameters

c_i = concentration of each parameter in each water sample in mg/l

$SI_i = \text{sub} - \text{index of ith parameter}$
$q_i = \text{rating based on concentration of ith parameter}$
$S_i = \text{standard value}$

2.4 Water Quality Standards

High quality, safe and sufficient drinking water is essential for our daily life, for drinking and food preparation, washing, cleaning, hygiene or watering our plants. The quality of water generally is defined in terms of its physical, chemical and biological parameters (Ketata-Rokbani *et al.*, 2011). Ascertaining the quality is crucial before its use for various purposes (Khan et al., 2003; Sargaonkar & Deshpande, 2003).Water quality standards serve as a basis for appraisal of the results of chemical analyses of water in terms of suitability of the water for various intended uses and it is judged by regulatory standards set by Environmental Protection Agency (EPA) to control the nation's drinking water for human safety. Drinking water quality standards describes the quality parameters set for drinking water. It ensures the safety of the drinking water supplies and the protection of public health. The safe drinking water act (SDWA) of the USA was the first federal law mandating drinking water standards for all public systems which still remains the cornerstone of her drinking water standard (Linsley, Franzini, Freybery&Tchobanoglous, 1992; Singh, Kumar, Thakural & Galkate, 2009). The World Health Organization has set a benchmark for drinking water standards for developing nations and each country uses that in providing her drinking water standard (Ruth, 2003). The EU standards are more recent (2014), complete and strict than the WHO standards (1993). The WHO, EU and the Nigerian Standard for Drinking Water Quality (NSDWQ) recommended limits will be used in this study. Many developed countries specify standards to be applied in their own country. In Europe, this includes the European Drinking Water Directive (EU, 2014) and

in the United States, the United States Environmental Protection Agency (EPA) establishes standards as required by the Safe Drinking Water Act. For countries without a legislative or administrative framework for such standards, the World Health Organization publishes guidelines on the standards that should be achieved (WHO, 2011). Where drinking water quality standards do exist, most are expressed as guidelines or targets rather than requirements, and very few water standards have any legal basis or, are subject to enforcement (WHO, 2011). The recommended limits for concentrations of inorganic constituents in drinking water have existed for many years. Limits for organic constituents such as pesticide residues are a recent addition. The standard limit established by WHO (2011), EU (2014) and NSDWQ (2007) and stringent values (least permissible concentrations of the three standards) for drinking and public health is as contained in Table 2.7.

Table 2.7: *Standard Water Quality Parameter Limits.*

S/N	Physiochemical parameters	WHO	EU	NSDWQ	Stringent value
1	Temperature (^{0}C)	25	-	-	25
2	pH	6.5 – 8.5	6.5 – 9.5	6.5 – 8.5	6.5 – 8.5
3	EC ($\mu S/cm$)	400	2500	1000	400
4	Turbidity (NTU)	5	-	5	5
5	Colour unit	15	-	15	15
6	T. S. S	-	-	-	-
7	T. D. S	500	-	500	500
8	DO (Dissolved Oxygen)	6	-	-	6
9	BODs	10	-	-	10
10	COD	10 - 20	-	-	10
11	HCO_3	125- 350	-	-	125
12	Sodium (Na)	40	200	200	40
13	Potassium (K)	20	-	-	20
14	Ammonium (NH_4)	< 1.5	0.5	-	0.5
15	Calcium (Ca)	75 - 200	-	-	75
16	Magnesium (Mg)	30	-	0.2	0.2
17	Chlorine (Cl)	5	250	250	250
18	Phosphate (P)	0.3	-	-	0.3
19	Nitrate (NO_3)	50	50	50	50
20	Nitrite (NO_2)	-	0.5	0.2	0.2
21	Sulphate (SO_4)	250	250	100	100
22	Iron (Fe)	0.3	0.2	0.3	0.2
23	Manganese (Mn)	0.05	0.05	0.2	0.05
24	Zinc (Zn)	5	-	3	3
25	Arsenic (As)	-	0.01	0.01	0.01
26	Copper (Cu)	2	2.0	1	1
27	Chromium (Cr)	0.05	0.05	0.05	0.05
28	Cadmium (Cd)	0.003	0.005	0.003	0.003
29	Nickel (Ni)	-	0.02	-	0.02
30	Lead (Pb)	0.09	0.01	0.01	0.01
		MICROBIOLOGICAL PARAMETERS			
1	Total Coliform (cfu/ml)			10	10
2	E-coli (cfu/100ml)		0	0	0

Source: EU, 2014; NSDWQ, 2007; WHO, 2011.

2.5 Groundwater Contamination

Water in nature is never pure. It picks up bits and pieces of everything it comes into contact with, including minerals, silt, vegetation, fertilizers, and agricultural run-off (Yimit, et al., 2011). While most of these substances are harmless, some may pose a health risk. Availability of safe and reliable source of water is an essential prerequisite for sustainable development and a basic need for good health. Fresh water quality and availability remain one of the most critical environmental and sustainability issues of the twenty first century (UNEP, 2012). Most of the fresh water bodies all over the world are

getting polluted, thus decreasing the potability of water (Wagner, 2004). Water is said to be polluted when it is impaired by anthropogenic and natural pollutants and either does not support human use, like serving as drinking water, or undergoes a marked shift in its ability to support its constituent biotic communities, such as fish and other aquatic animals. It is any chemical, physical or biological change in water quality that is harmful or hazardous when in contact or consumed (Huat et al., 2011). Pollutants such as bacteria, viruses, heavy metals, nitrate and salt pollute water sources as a result of inadequate treatment and disposal of waste from humans, livestock and industrial discharges (Singh and Mosley, 2005). Groundwater once was thought to be of unlimited quantity and naturally protected by the soils above it. It is, however, significantly vulnerable to contamination due to overuse, improper use and disposal of chemicals at the land surface (Chandra, Rawat, Garg & Singh, 2012). The excessive demand on water resources by increasing population of most developing economies exacerbated by the impact of climate change results in the drying up of surface water and depletion of groundwater (Ekenta, Okoro&Ezeabasili, 2015). Also, been a universal solvent, it dissolves numerous chemicals and thus carries a lot of impurities along its path that can be injurious to health when it exceeds WHO, tolerable limits (Oyem, Oyem & Ezenweali, 2014; Amanipoor, Ghafoori & Lashkaripour, 2013) and the quality varies from one geological formation to another.

Contamination of water bodies has gradually been on the increase and availability and quality of water either surface or ground, have been deteriorating due to some important factors like increasing population, industrialization, urbanization, poor sanitation, land use for commercial and agricultural activities and other factors responsible for environmental degradation, etc. and has therefore become issue of serious environmental

concerns (Akaninwor, Anosike & Egwim, 2007; Egila & Terhemeren, 2004; Hodges, 1980; Michele, Richard& Byron, 2003; Pink, 2006). Also, in the Niger Delta region where oil exploration and exploitation are most rampant, flared gas and other petroleum refining activities contribute solid, liquid and gaseous waste to the environment, and once introduced into the environment, they pollute the environment as well as the surface and groundwater sources (Dami, Ayuba &Amukali, 2012; Ezenwaji, Okoye & Otti, 2013).

Potable water is water that is safe for drinking, pleasant in taste and suitable for domestic purposes and does not contain any physical, chemical and biological impurity.Increase in human population has exerted an enormous pressure on the provision of safe drinking water especially in developing countries (Umeh, Okorie & Emesiani, 2005), unsafe water is a global public health threat, placing persons at risk for a host of diarrheal and other diseases as well as chemical intoxication (Hughes and Koplan, 2005; Ogodo, Agwaranze, Chioma & Agyo, 2017). The use of contaminated drinking water has caused harm to people in form of detrimental health problems and deadly diseases in the short term, long term or both (Ohwoghere, 2012; UNEP, 2007; Idoko, 2010). Contaminated drinking water and poor sanitation rank third in the list of the 20 leading death risk factors in developing nations (Olaoye &Onilude, 2009; WHO, 2003). Quality of water from local wells are unsafe (Machdar, Van Der Steen, Rashid – Sally & Lens, 2013) and 94% of diarrhea cases in developing countries are as a result of contaminating water which are preventable through better sanitation and access to safe water (Onabolu, Jimoh, Igboro, Sridhar, Onyilo, Gege & Ilya, 2011).

Groundwater contamination occurs from both natural and anthropogenic sources (UNDESA, 2013). The activities that result in groundwater being contaminated include but are not limited to: unsewered domestic sanitation, acid deposition, land disposal of solid wastes, sewage disposal on land, agricultural activities (cultivation, use of urban waste water for irrigation), petroleum leakage, spills and uncontrolled location and leakage of storage tanks in filling stations, disposal of radioactive wastes, accidents and leaks, mining activities, poorly constructed septic tanks, graveyards, indiscriminate citing and poorly engineered dumpsites, improper disposal of condemned engine oil from mechanic shops, abandoned borrow pits, effluents discharged from industries, dredging activities, leachate from unengineered waste disposal open dumps and buried pipelines etc. (Akudo et al., 2010; Lamastra et al., 2016; Trevisan et al., 2000) as depicted in Plate 2.4.

Groundwater contamination is also a function of time, types of waste, topography, soil, underlying geology, surface water ingression, season of the year and direction of groundwater flow (Afolayan & Ogundele, 2012; Efe, 2005). These have increasingly threatened directly and indirectly both groundwater and surface water qualities negatively (Hamblin and Christiansen, 2004; Nas&Becktay, 2010; Niemi *et al.*, 1990) making them unsafe for use without appropriate treatment (Kang et al., 2010).

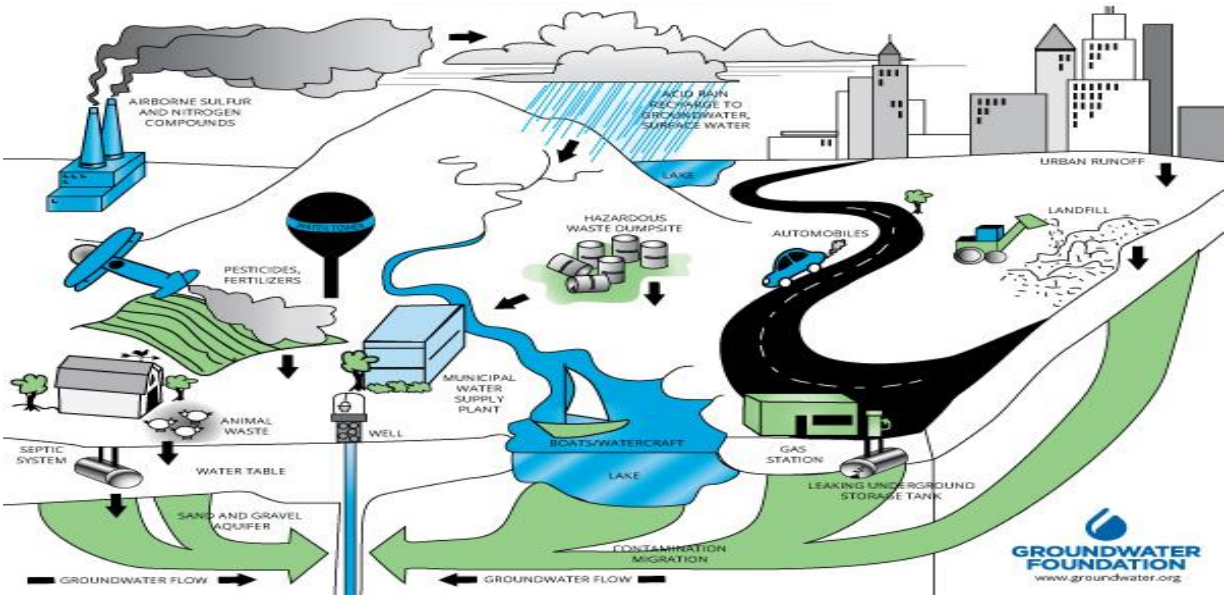


Plate 2.4. Potential sources of groundwater contamination

Source: The Groundwater Foundation, National Groundwater Association, USA, 2018.

Pollution may result from point sources or diffuse sources (non-point sources). There is no clear-cut distinction between the two, because a diffuse source on a regional or even local scale may result from a large number of individual point sources, such as automobile exhausts (Akudo, Ozulu & Osugbua, 2010). An important difference between a point and a diffuse source is that a point source may be collected, treated or controlled (diffuse sources consisting of many point sources may also be controlled provided all point sources can be identified). The major point sources of pollution to freshwaters originate from the collection and discharge of domestic wastewaters, industrial wastes or certain agricultural activities, such as animal husbandry. Most other agricultural activities, such as pesticide spraying or fertilizer application, are considered as diffuse sources. The atmospheric fall-out of pollutants also leads to diffuse pollution of the aquatic environment. While the relative abundance of dissolved constituents in groundwater have been summarized in

Table 2.3, the potential sources of groundwater contaminants as given by Simmons and Cole, (1985) are presented further in Table 2.8.

Table 2.8: *Potential Sources of Groundwater Contamination*

Potential	Source Contaminant
Salting practices and storage	Chlorides
Snow dumping	Chlorides
Agricultural fertilizers	Nitrates
Manure handling	Nitrates, pathogens
Urban landscapes	Hydrocarbons, pesticides, nitrates
Agricultural feedlots	Nitrates, pathogens
Solid waste landfills	Hazardous materials
Industrial uses RCRA 'C'	Hazardous materials
Industrial uses RCRA 'D'	Hazardous materials
Small quantity generators	Hazardous materials
Households	Hazardous materials
Gas stations	Hydrocarbons
Auto repair shops	Hydrocarbons
Recycling facilities	Hydrocarbons
Auto salvage yards	Hydrocarbons
Underground storage tanks	Hydrocarbons
Industrial floor drains	Hydrocarbons
Injection wells	Hydrocarbons
Junkyards	Hydrocarbons

Source: The Groundwater Foundation, 2018

Once the contaminant source has been controlled or removed, the contaminated ground water can be treated in one of several ways:

i. Containing the contaminant to prevent migration.

ii. Pumping the water, treating it, and returning it to the aquifer.

iii. Leaving the ground water in place and treating either the water or the contaminant.

iv. Allowing the contaminant to attenuate (reduce) naturally (with monitoring), following the implementation of an appropriate source control.

2.5.1 Effects of groundwater contamination. The use of contaminated groundwater has negative impacts on our health, economy and environment as listed below:

2.5.1.1 Health.

Health effects are some of the greatest risks associated with groundwater pollution. Geogenic contaminants (the overstepping of certain thresholds e.g. drinking water guidelines without direct or indirect anthropogenic influence) affect the health of hundreds of millions of people worldwide, it is estimated that around 200 million people worldwide are affected by arsenic and fluoride contamination alone, roughly 5 per cent of all those who use groundwater for drinking (Amini et al., 2009). The health implications of the ingestion of arsenic contaminated drinking water include dermal lesions such as hyperpigmentation and hypopigmentation, peripheral neuropathy, skin cancer, bladder, lung and kidney cancers and peripheral vascular diseases (Amini, Johnson, Abbaspour & Mueller, 2009; IPCC, 2001; WHO, 2011). The ingestion of elevated concentrations of fluoride leads to dental and skeletal fluorosis (Edmunds & Smedley, 2005; IPCC, 2008; WHO, 2011). Some other health issues include: hepatitis, dysentery, typhoid, poisoning etc.

2.5.1.2 Economy.

When groundwater becomes contaminated, the economy can also easily suffer. Potential economic problems associated with groundwater pollution amongst others are:

depreciating value of land and less stable industry, high cost of softening hard water or desalination, etc.

2.5.1.3 Environment.

The environment can be seriously altered when groundwater is polluted. Included here are: nutrient pollution and toxic water in ecosystems

2.6 Groundwater Quality Assessment and Monitoring

Water levels rise in wet periods and decline in dry periods, independently of rate of pumping. These two extreme conditions have given the U.S. Geological Survey the major responsibility to assess the quantity and quality of the nation's water supplies (Wallace & Lowe, 2009). To locate ground water accurately and to determine the depth, the prediction of the quantity (capacity) of the groundwater resource for long-term pumpage, the effects of that pumpage, and evaluation of water quality conditions are among the principal aims of modern-day hydrologic practice in achieving proper planning and management of ground water resources (Annapoorna & Janardhana, 2015). To achieve the above, several techniques must be used, and a target area must be thoroughly tested and studied to identify hydrologic and geologic features important to the planning and management of the resource (Oki & Akana, 2016).

The landscape may offer clues to the engineer about the occurrence of shallow ground water. Areas where water is at the surface as springs, seeps, swamps, or lakes reflect the presence of ground water, although not necessarily in large quantities or of usable quality and rocks are the most valuable clues of all. Engineers employ the following steps in a typical assessment endeavour of groundwater quality:

(i) Preparation of geologic maps and cross sections

(ii) Obtaining information on the wells in the target area

(iii) Chemical analysis of water

WHO, (2004) states that the principal objective of groundwater assessment, monitoring and evaluationis aimed at:

a. To provide water quality assessments to governments, the scientific community and the public on the quality of freshwater.

b. To define the status of water quality.

c. To identify and quantify trends in water quality.

d. To define the cause of observed conditions and trends.

e. To identify water quality problems that occurs in specific geographical areas.

f. To provide the accumulated information and assessments in a form that resource management and regulatory agencies can use to evaluate alternatives and make necessary decisions.

Groundwater quality assessment is therefore invariably directed towards factors which may lessen the suitability of pumped groundwater with respect to its potability and use in agriculture and industry. The overall goal of a groundwater quality assessment programme, is to obtain a comprehensive picture of the spatial distribution of groundwater quality and of the changes in time that occur, either naturally, or under the influence of man (Wilkinson & Edworthy, 1981). The benefits of well-designed and executed programmes are that timely water quality management, or pollution control measures, can be taken which are based on comprehensive and appropriate water quality information. Each specific assessment programme is designed to meet a specific objective, or several

objectives, which are related in each case to relevant water quality issues and water uses. Water Quality Assessment or Analysis is therefore the overall process of evaluation of the physical, chemical and biological nature of water (Subramani, et al., 2012).

Monitoring is the collection of relevant information. As groundwater is a natural source of drinking water, it needs to be monitored regularly and people should be made aware of its quality. Management of ground water is very important to meet the increasing demand of water and its deterioration is receiving increased attention (Eslami, Dastorani, Javadi & Chamheidar, 2013). Monitoring of groundwater quality is an essential tool for observation endeavours as per water resources development and provision of background information needed to determine the suitability of water resources for human consumption (Ayeni, Balogun & Soneye, 2010; Oyem et al., 2014; UNEP, 2007). As a result, the quality of groundwater has become equally important as its quantity, as the use of contaminated groundwater has negative impacts on our health, economy and environment.

2.7 Scientific Models

These are models of a representation of a particular phenomenon in the world using something else to represent it thereby making it easier to understand. It could be empirical, computer (mathematical) or visual.

i. Empirical (statistical): This is a generic term for activities that creat models by obsevations and experiments. It is statistical research in the form of primary data which is usually collected in the form of survey, questionnaire or interviews. It relies on observations rather than theory. Some of its advantages include:
    a. It contributes to existing knowledge and adds high value to the research.

b. The method is flexible by changing sample sizes, data collectionmethods and analysis methods as necessary.

c. Fewer rules are to be followed as they are flexible to incorporate.

d. It saves a lot of time.

While its disadvantages include

a. Experimental data arealways needed and in most cases are applicable only for modeled experimentunder a particular condition.

b. Presentation of data could be tricky.

c. Results can be unpredictable.

d. They are lengthy, depending on the number of variables and the data analysis used.

In this study empirical model is used in the prediction of the concentration of some water quality parameters, while a computer model is used in the spatial distribution of groundwater quality parameters.

2.7.1 Statistical Analysis.

Groundwater quality parameters are usually analyzed statisticallyin order to evaluate the relationship between the various water quality parameters. The statistics could be inferential (i.e., probabilities for values make predictions) or descriptive (i.e., describe the data). Some statistical tools adopted in groundwater study include but not limited to:

2.7.2 Measure of Central Tendency

In either of these statistical methods, the mean (used to derive the central tendency of a dataset), median (middle value in a list of data after arranging them from the smallest to the biggest value), standard deviation (a measure of the dispersion of a dataset relative to

its mean and is calculated as the square root of the variance), normal distribution (a symmetric distribution where most of the observations cluster around the central peak and the probabilities for values further away from the mean tapper off equally in both directions), skewness (a measure of the degree of asymmetry of the probability distribution of a real-valued random variable about its mean), variance (average of the squared differences from the mean, it is a measure of how much a random variable differs from the expected value) and kurtosis (the degree of peakedness of a distribution, usually taken relative to the normal distribution) are very vital.

2.7.3 Correlation and Regression.

The most commonly used techniques for investigating or representing the linearrelationship between two quantitative variables are correlation and linear regression analysis. Correlation and regression are used for interpreting groundwater quality data and relating them to specific hydrogeological processes. These tools are quite useful in characterizing and obtaining firsthand information of the groundwater system than actually going through complex methods and procedures.

2.7.3.1 Correlation.

Correlation is a measure that quantifies the strength of the linear relationship between a pair of variables and correlation coefficient indicates the extent to which two variables move together. The value of a correlation coefficient can vary from minus one to plus one. A minus one indicates a perfect negative correlation, while a plus one indicates a perfect positive correlation. A correlation of zero means there is no relationship between the two variables. When there is a negative correlation between two variables, it implies that as the value of one variable increases, the value of the other variable decreases, and vice versa.

The standard error of a correlation coefficient is used to determine the confidence intervals around a true correlation of zero. If your correlation coefficient falls outside of this range, then it is significantly different from zero. The standard error can be calculated for interval or ratio-type data (i.e., only for Pearson's product-moment correlation). The significance (probability) of the correlation coefficient is determined from the t-statistic. The probability of the t-statistic indicates whether the observed correlation coefficient occurred by chance if the true correlation is zero. In other words, it asks if the correlation is significantly different than zero. When the t-statistic is calculated for Spearman's rank-difference correlation coefficient, there must be at least 30 cases before the t-distribution can be used to determine the probability. If there are fewer than 30 cases, you must refer to a special table to find the probability of the correlation coefficient.

2.7.3.1.1 Types of correlation

The various types of correlation are:

a. Positive Correlation: When the value of one variable increases with respect to another.
b. Negative Correlation: When the value of one variable decreases with respect to another.
c. No Correlation: When there is no linear dependence or no relation between the two variables.

2.7.3.2 Regression

Regression indicates the impact of a unit change in the known variable (x) on the estimated variable (y). It expresses the relationship in the form of an equation. Regression analysis is used in statistics to generate an equation to describe the statistical relationship if any, that

exists between sets of data (between one or more predictor variables and the response variable). Simple regression is used to examine the relationship between one dependent and one independent variable. After performing an analysis, the regression statistics can be used to predict the dependent variable when the independent variable is known. The regression line (known as the least squares line) is a plot of the expected value of the dependent variable for all values of the independent variable. In general, a model fits the data well if the differences between the observed values and the model's predicted values are small and unbiased.

Residual = Observed value - Fitted value

Using the regression equation, the dependent variable may be predicted from the independent variable. The slope of the regression line (b) is defined as the rise divided by the run. The y intercept (a) is the point on the y axis where the regression line would intercept the y axis. The slope and y intercept are incorporated into the regression equation. The intercept is usually called the constant, and the slope is referred to as the coefficient. Since the regression model is usually not a perfect predictor, there is also an error term in the equation. In the regression equation, y is always the dependent variable and x is always the independent variable. Here is a way to mathematically describe a linear regression model expressed in Equation 2.12:

$$y = a + bx + c \qquad (2.12)$$

The significance of the slope of the regression line is determined from the t-statistic.The t-statistic is equal to the estimated coefficient divided by its standard error. Two important factors in the regrssion analysis are:

i. The coefficient of determination (R^2) is the square of the correlation coefficient. Its value may vary from zero to one. It has the advantage over the correlation coefficient in that it may be interpreted directly as the proportion of variance in the dependent variable that can be accounted for by the regression equation. The standard error of the estimate for regression measures the amount of variability in the points around the regression line. It is the standard deviation of the data points as they are distributed around the regression line. The standard error of the estimate can be used to develop confidence intervals around a prediction. R^2 is a statistical measure of how close the data are to the fitted regression line. It is also known as the coefficient of multiple determination for multiple regression. The definition of R^2 is fairly straight-forward, it is the percentage of the response variable variation that is explained by a linear model given in Equation 2.13,

$$R^2 = \frac{Explained\ variation}{Total\ variation} \tag{2.13}$$

R^2 is always between 0 and 1 (0 and 100%):

a. 0% indicates that the model explains none of the variability of the response data around its mean.
b. 100% indicates that the model explains all the variability of the response data around its mean.

In general, the higher the R^2, the better the model fits your data. However, there are important conditions for this guideline. R^2 is not the bottom line. All it measures is the percentage reduction in mean-squared-error that the regression model achieves relative to the naive model "Y= constant", which may or may not be the appropriate naive model for purposes of comparison.

ii. Adjusted R^2: Adjusted R-squared compares the correlation of the data to several measured models. This is R-squared (the fraction by which the variance of the errors is less than the variance of the dependent variable) adjusted for the number of coefficients in the model relative to the sample size in order to correct it for bias (the same adjustment used in computing the standard error of the regression). That is, adjusted R-squared is the fraction by which the square of the standard error of the regression is less than the variance of the dependent variable. It is the most over-used and abused of all statistics - don't get obsessed with it. The adjusted R-squared compensates for the addition of variables and only increases if the new predictor enhances the model above what would be obtained by probability. Conversely, it will decrease when a predictor improves the model less than what is predicted by chance. The adjusted R-squared is a modified version of R^2 for the number of predictors in a model. The adjusted R-squared can be negative but isn't always. While an R-squared value between 0 and 100 and shows the linear relationship in the sample of data even when there is no basic relationship, the adjusted R-squared gives the best estimate of the degree of relationship in the basic population. To show the correlation of models with R-squared, pick the model with the highest limit. However, the best, and easiest, way to compare models is to select one with the smaller adjusted R-squared. Adjusted R-squared is not a typical model for comparing nonlinear models but, instead, shows multiple linear regressions.

2.7.3.2.1 Types of regression

Some of the regression types include:

a. Linear Regression. It is the simplest form of regression.

b. Polynomial Regression. It is a technique to fit a nonlinear equation by taking polynomial functions of independent variable.
c. Logistic Regression.
d. Quantile Regression.
e. Ridge Regression.
f. Lasso Regression.
g. Elastic Net Regression.
h. Principal Components Regression (PCR)

2.7.4 Student t-test

A t-test is a type of inferential statistic used to determine if there is a significant difference between the means of two groups, which may be related in certain features. It is used to determine whether two samples are likely to have come from the same two underlying populations that have the same mean. A t-test is used as a hypothesis testing tool, which allows testing of an assumption applicable to a population. A t-test looks at the t-statistic, the t-distribution values, and the degrees of freedom to determine the statistical significance. To conduct a test with three or more means, one must use an analysis of variance (ANOVA).

Mathematically, the t-test takes a sample from each of the two sets and establishes the problem statement by assuming a null hypothesis that the two means are equal. Based on the applicable formulas, certain values are calculated and compared against the standard values, and the assumed null hypothesis is accepted or rejected accordingly.If the null hypothesis qualifies to be rejected, it indicates that data readings are strong and are probably not due to chance. The t-test produces two values as its output: t-value and degrees of freedom. The t-value is a ratio of the difference between the mean of the two sample sets and the variation that exists within the sample sets. Degrees of freedom refer to

the values in a study that has the freedom to vary and are essential for assessing the importance and the validity of the null hypothesis. One type of t-test is the paired t-test and will be adopted in this study. The correlated (paired) t-test is performed when the samples typically consist of matched pairs of similar units, or when there are cases of repeated measures. Correlated or paired t-tests are of a dependent type, as these involve cases where the two sets of samples are related.

A p-value is used in hypothesis testing to help support or reject the null hypothesis. The p-value is the evidence against a null hypothesis. The smaller the p-value, the stronger the evidence that you should reject the null hypothesis.P-values are expressed as decimals although it may be easier to understand what they are if you convert them to a percentage.A small p (≤ 0.05), reject the null hypothesis. This is strong evidence that the null hypothesis is invalid. A large p (> 0.05) means the alternate hypothesis is weak, so you do not reject the null.

2.8 Geographic Information System (GIS)

Most natural phenomena are variable both in space and time. The variability is a result of natural processes, thus deterministic (Roseanne & Ariel, 2005). As most of these processes are sensitive and the conditions under which they take place are not fully known, it is not possible to describe them based on physical and chemical laws completely and therefore resulting in some practical variability consequences such as:

i. Field and laboratory measurements are necessary

ii. Up scaling is non trivial

iii. There is always a limited degree of explanation one can achieve

It is not uncommon to use probabilistic and statistical methods for describing partly known (sampled) natural parameters. Reliance on laboratory results only provides limited coverage for measurement and analysis, hence the incorporation of GIS for better results (Bardossy, 2011; Roseanne & Ariel, 2005). The GIS is a powerful configuration and organized integrated computer hardware, software, geographic data, and personnel designed to efficiently enter, compile, manage, store, update, manipulate, analyze, integrate, modify and display all forms of spatial and geographically referenced (locations with their coordinates) information, (Balakrishnan *et al.*, 2011; Busch, Ingraham & Smith, 1992; Chang, 2008; Narshima *et al.*, 2013; Subramani *et al.*, 2012; Walski, Chase, Savic, Grayman, Beckwith & Koelle, 2003), with data acquisition, pre-processing, data management, data manipulation and analysis and product generation as its basic elements (Otto & Rolf, 2009). GIS is a powerful and effective computer system capable of capturing, managing, storing, analyzing, displaying and mapping all types of spatial information/data that are geographically referenced (Karthekeyan et al., 2013; Nwankwoala, Eludoyin& Obafemi, 2012; Singh & Khan, 2011). GIS provides accurate and reliable estimation at unsampled locations from results obtained at locations sampled on spatially distributed parameters (Jeihouni, Toomanian, Shahabi & Alavipanah, 2014; Kumar, 2007). It is capable of developing information in different thematic layers and integrating them with sufficient accuracy within a short period of time. GIS applications that are of particular importance to groundwater industry are: mapping, monitoring, modeling and maintenance (Shamsi, 2005). GIS has grown to become an effective tool for managing huge amount of geographical data to solve various spatial problems (Rangarajan, Mondal, Singh & Singh, 2009). GIS is applicable in many fields including

environment, urban planning, natural hazard management, agriculture (precision farming), archaeology, water quality, air pollution, health care, river discharges, geology and for making spatial distribution maps of various hydro-chemical parameters of constituents (Narshima et al. 2013; Chang, 2008; Roseanne & Ariel, 2005; Subramani *et al.,* 2012). It is a powerful tool that addresses and manages geographical information in holistic manner without loosing the spatio-temporal variability which are often critical in assessment and decision making (Environmental Sciences and Research Institute, 2004; Mtetwa *et al.*, 2013).

GPS technology is also a very useful tool for enhancing the spatial accuracy of the data integrated in the GIS (Ramesh & Elango, 2006). Spatial analysis extension of GIS allows its use for investigating groundwater quality information by interpolation of the water quality parameter at unknown locations from known values inorder to create a continuous surface (Singh & Khan, 2011) which will help to understand the trend of water quality parameters of the study area. Singh and Khan, (2011) stated that advancement of GIS and spatial analysis help to integrate the laboratory analysis data with the geographic data and to model the spatial distribution of water quality parameters most robustly and accurately. GIS is usually stored as coordinates and topology and its data can be mapped. Geospatial data is often accessed, manipulated or analyzed through GIS. Geostatistical approach of GIS is very helpful to analyze the spatial variation of groundwater quality.

2.9 Geostatistics

Time series analysis is one of the first fields where variability has been considered and described with stochastic methods. These methods were extended and further developed to

analyze spatial variability (Mendes & Ribeiro, 2010). These spatial methods form the discipline called geostatistics. It is used with two different meanings:

i. As a collection of all statistical and probabilistic methods applied in geosciences

ii. As another name for the theory of regionalized variables

Geostatistics is the generic name for a family of techniques which are used for estimation of values at unsampled locations from limited sample areas (Webster & Oliver, 2007).The word geostatistics is used to mean a collection of all statistical and probabilistic methods applied in geosciences, and is the other name for the theory of regionalized variables (Bardossy, 2011). It is a branch of statistics that focuses on spatial or spatiotemporal dataset (Isaaks & Srivastava, 1989; Jeihouni et al., 2014; Xie, Chen, Lei, Yang, Guo, Song & Zhou, 2011). Geostatistics is a spatial statistical technique that can be used to assess and represent the distribution of concentration over space and time (Otto & Rolf, 2009; Yeh, Chang, Hsu & Lee, 2007). It provides a set of statistical tools for the analysis of data distributed in space and time domain (Goovaerts, 2014). This technique predicts the estimated values based on the relationship between the sample points and estimates the uncertainty of that prediction (Caridad-Cancela, Vazquez, Vieira, Abreu & Gonzalez, 2005; ESRI, 2003; Piccini, Marchetti, Farina & Francviglia, 2012).

Geostatistics science provides a number of methods based on random functions theory, which are frequently used to estimate the value of a spatially measured variable at the unsampled places. The main subject regarding any geostatistical method is the evaluation of spatial correlations, through parametric classes of covariance and variogram functions, which present the spatial regression among a dataset based on the spatial variability of

couple of points at the specific spatial distances (lags) (Barca, Porcu, Bruno& Passarella,2017). In the previous decades, the accuracy of interpolation methods for predicting groundwater properties has been investigated in several studies (Karami, Madani, Katibeh & Marj, 2018). Geostatistics follow the basic assumption that the properties of earth have some spatial continuity up to a certain lag distance (Gorai & Kumar, 2013). Geostatistics could therefore be defined as the modeling of regional data or variables.

Important advantage of Kriging is that, it identifies the error of predictions reflected in the semivariogram model (Huat et al., 2011). It has the capability to predict and understand the geochemical concentration pattern as an alternative to DRASTIC model which is unable to provide the measurable information of geochemical characteristics (Bruce, Friedman, Kaufman & Yechieli, 2001). It is also a useful tool to eliminate errors and increase calculation accuracies (Seyedmohammadi, Esmaeelnejad & Shabanpour, 2016).

The spatial distribution of water quality parameters shows some heterogeneity and it is not feasible to collect the data of every possible location in the specified area (Pradeep, Ritu & Punia, 2015). This infeasibility is also due to the time, accessibility and the cost involved in data collection analysis hence the need for employing geostatistical methods of interpolation.Geostatistics was developed originally to predict probability distributions of ore grades for mining operations (Armstrong and Campigny, 1988). It was proposed by a South African Engineering geologist D.G. Krige in 1951 and developed by a French geologist G. Matheron in 1962 (Bohling, 2005). Geostatistics has the variogram (or semivariogram) as its central model (Lark, 2000), and therefore, uses this technique of variogram to measure the spatial variability of a regionalized variable and provides the

input parameters for the spatial interpolation of Kriging model (Jiachum, Haizhen, Jianjun, Xingmei & Haiping, 2007). Variogram analysis consists of the experimental variogram calculated from the data and the variogram model fitted to the data. The variogram model is chosen from a set of mathematical functions that describe spatial relationshps. The appropriate model is chosen by matching the shape of the curve of the experimental variogram to the shape of the curve of the mathematical function. Once geostatistics is used to produce predictions for the unsampled locations, kriging identifies the error of prediction reflected in the variogram model (Ketata-Rokbani et al., 2011). Flow chart of the steps followed for the geostatistical analysis using the ArcGIS is shown in Figure 2.1.

2.9.1 Applications of Geostatistcs

Applications of geostatistics can be found in very different disciplines of science and engineering of spatially distributed data ranging from the classical fields geography, mining and geology to soil science, hydrology, oceanography, biotechnology, geophysics, hydrography, groundwater pollution, meteorology, environmental sciences, agriculture, even structural engineering and so on (Arslan, 2012; Bardossy, 2011; Cemek, Güler, Kılıç, Demir & Arslan, 2007; Delgado, Pacheco, Cabrea, Baltlori, Orellana & Baustista, 2010; Gokalp, Basaran, Uzun & Serin, 2010; Nas & Berktay, 2010). Geostatistical is also used for:

i. Spatial data modeling
ii. Characterizing the spatial variation
iii. Spatial interpolation
iv. Simulation
v. Optimization of sampling
vi. Characterizing the uncertainty.

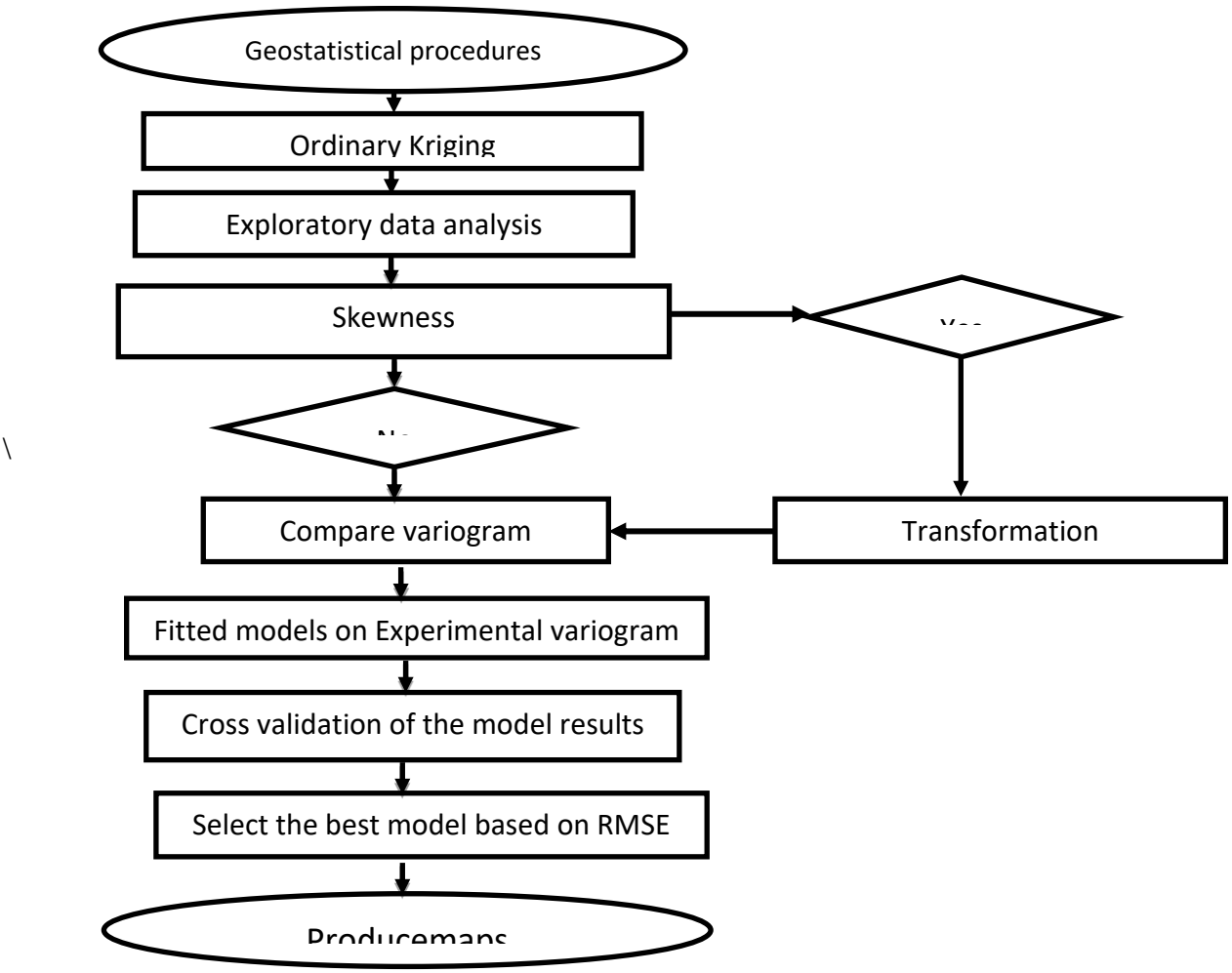


Figure 2.1. Flow chart of the steps for the geostatistical analysis (Marko el al., 2013).

2.10 Spatial Statistical Modeling

Spatial interpolation is the process of using a set of point data to create surface data. A point data set has data values only for certain locations, such as field work locations, within the study area. Surface data divides the study area into cells, with a data value for each cell. Spatial interpolation has been widely and commonly used in many studies to create surface data based on a set of sampled points, such as soil properties, temperature, groundwater and precipitation.Currently, there are many commercial Geographic

Information System (GIS) or statistics software offering spatial interpolation functions, such as inverse distance weighted (IDW), kriging, spline, and others.Groundwater quality modeling involves the prediction of water pollution using mathematical simulation techniques. Spatial Statistical Modeling accounts for the spatial location at which a response is collected. This means that the model that is fitted to the data represents the spatial effects. This may be to account for any effects due to location in the model or to predict values of the response at other locations via some form of interpolation that characterize both other predictor variables or the spatial location. There might be spatial effects depending on the response variable and the application area. It is possible that geographical features are predictors for our response or is a surrogate for other factors. Many factors can be linked to location e. g. weather, deprivation, altitude, pollution or wealth which might influence the response, thus to improve the model.

2.10.1 Types of Spatial Data

There are many forms of spatial data but we can broadly divide these into three types (Cressie, 1993):

i. Geostatistical Data:Here measurements are taken at a fixed number of chosen locations in a geographical area. Methods such as variograms and spatial interpolation are used to analyze such data. Such data however, is not ideally suited to standard random effect modeling.

ii. Lattice Data: Here measurements are taken at on a regular lattice and at each point on this lattice a measurement is collected. Although a map is not regular, we can construct a lattice from a map by identifying neighbouring regions and linking neighbouring regions to form a lattice.

iii. Point process data:In this case, each observation is the location of a response and its co-ordinates are also recorded.This data is also commonly found in disease mapping although may be used in many applications where cases of an event are seen at particular locations. Each item of data consists of the locations of events, the response (type of event) and potentially predictor variables for the event.

2.11 Spatial Interpolation Techniques

Interpolation is a method of estimation that constructs the data points within a range of descrete set of known data points. It uses known data values to estimate unknown data values. A point data set has data values only for certain locations, such as field work locations, within the study area. Surface data divides the study area into cells, with a data value for each cell. With surface data, there is often a data value for every location inside the study area, whether it was sampled or not. Though a set of point data is more manageable in terms of labor, budget, and time; surface data are more useful and practical in many disciplines, such as precision agriculture, particularly with variable rate applications (Adamchuk, Morgan, & Loewenberg, Deboer, 2004; Brase, 2006). Spatial Interpolation or spatial prediction is the process of using points with known values from sampled locations to estimate values of other unsampled points (Chang, 2008; Manisha, 2016; Sining & Jun, 2017). It is the process of manipulating spatial information to extract new information and meaning from the original data. It is sometimes referred to as surface interpolation which is a procedure for estimating the values of characteristics at unsampled sites within an area covered by existing observations.In most cases, the input data is a network of points, while the output is a surface that divides the study area into small cells with a data value for each cell. There are two basic assumptions for spatial interpolation.

First is spatial autocorrelation, which is best explained by Tobler's first law of geography "everything is related to everything else, but near things are more related than distant things" (Tobler, 1970). The second assumption is that values are smooth and continuous over space. Though there are different techniques in carrying out interpolation, to date, there is no "rule of thumb" on the most appropriate spatial interpolation techniques for certain situations, though general suggestions have been published (Wu, 2013; Yi-Hwa & Ming-Chih, 2016). There are many spatial interpolation algorithms available in both in literature, as well as in commercial GIS or statistics software (ESRI, 2008; Longley, Goodchild, Maguire& Rhind, 2005,). Each algorithm typically requires different parameters. Even with the same algorithm and same input data points, these different parameters can create different surfaces. Many studies rely on quantitative assessment to determine the performance of spatial interpolation techniques. For estimation to be effective, known points should be well distributed within the study area involved (Chang, 2008). Usually, spatial analysis is carried out with a Geographic Information System (GIS). Geostatistical methods provide:

a. How to deal with the limitations of deterministic interpolation
b. The prediction of attribute values at unvisited points is optimal
c. BLUE (Best Linear Unbiased Estimate)

Commercial GIS or statistical software provides several spatial interpolation functions, such as inverse distance weighted (IDW), kriging, spline, etc. These interpolations could be deterministic or stochastic as are techniques employed to yield models from assessed data for errors andvariances. Spatial interpolation methods could be categorized as in

Figure 2.2 and Table 2.9



*Figure 2.2.*Spatial interpolation methods

Table 2.9: *A Classification of Spatial Interpolation Method.*

Global		Local	
Deterministic	Stochastic	Deterministic	Stochastic
Trend surface (inexact)	Regression (inexact)	Thiessen (exact), Density estimation (inexact), Inverse distance weighted (exact), Spline (exact).	Kriging (exact)

Source: Chang et al., 1998.

i. Global Polynomial Interpolation (GP): Global Polynomial Interpolation (GP) fits a smooth surface that is defined by a mathematical function (a polynomial) to the input sample points. It is a single mathematical function applied to all points that tends to produce smooth surfaces. This method uses every known point available to estimate an unknown value. It is designed to capture the general trend of the surface. The GP surface changes gradually capture coarse-scale patterns in the data. Conceptually, GP

interpolation is like taking a piece of paper and fitting it between the raised points (raised to the height of value). The result from GP interpolation is a smooth surface that represents gradual trends in the surface over the area of interest. Global methods include trend surface models and regression models.

ii. Local Polynomial (Exact) Interpolation (LP): While GP interpolation fits a polynomial to the entire surface; LP interpolation fits many polynomials, each within specified overlapping neighbourhoods. It honours all data points such that the resulting surface passes exactly through all data points, appropriate for use with accurate data. LP is a single mathematical function applied repeatedly to subsets of the total observed points, links regional surfaces into composite surface. LP interpolation, fits the specified-order (zero, first, second, third and so on) polynomial using points only within the defined neighbourhood. The neighbourhoods overlap, and the value used for each prediction is the value of the fitted polynomial at the centre of the neighbourhood. LP uses a sample of known points to estimate an unknown value within a short range and it is more efficient than the global interpolation. It is also preferred because it requires less computation. The search neighbourhood can be defined by using the size and shape, number of neighbours, and sector configuration.

iii. Inexact Interpolation: Otherwise known as approximate method predicts a value at the point location that differs from its known value. It does not honour all data points, it is more appropriate when there is high degree of uncertainty about data points. Trend surface model, Regression model, Density estimation models are all examples of inexact interpolation.

iv. Deterministic Interpolation: The interpolation provides no assessment of errors with predicted values. They include: Trend surface model, Theissen, Density estimation model, Inverse Distance Weighting (IDW) and Spline.

v. Stochastic Interpolation: This considers the presence of some randomness in its variable and offers assessment of prediction errors with estimated variances. They are Regression models and Kriging models.

2.11.1 Criteria for Selection of Interpolation Method

It is important to remember that there is no single interpolation method that can be applied to all situations. Some are more exact and useful than others but take longer to calculate. They all have advantages and disadvantages. In practice, selection of a particular interpolation method should depend upon the sample data, the type of surfaces to be generated and tolerance of estimation errors. Generally, a three-step procedure is recommended:

i. Evaluate the sample data.

ii. Apply an interpolation method which is most suitable to both the sample data and the study objectives.

iii. Compare the results and find the best result and the most suitable method.

2.11.2 Interpolation Techniques Employed in Geostatistical Analysis

As geographic information systems (GIS) and modeling techniques are becoming powerful tools in natural resource management and biological conservation, spatial continuous data of environmental variables are increasingly required (Collins & Bolstad, 1996; Hartkamp, Kirsten, Stein&White, 1999). Thus, the values of an attribute at unsampled points need to

be estimated, meaning that spatial interpolation from point data to spatial continuous data is necessary. It is also necessary when:

i. The discretized surface has a different level of resolution, cell size or orientation from that required.
ii. A continuous surface is represented by a data model that is different from that required.
iii. The data we have do not cover the domain of interest completely (Burrough & McDonnell, 1998).

In the instance of (iii) above, spatial interpolation methods provide tools to fulfill such task by estimating the values of an environmental variable at unsampled sites using data from point observations within the same region. Predicting the values of a variable at points outside the region covered by existing observations is called extrapolation (Burrough & McDonnell, 1998). This is necessary, because, the true value is not known. Therefore, some measured points have to be selected as reference points for testing the accuracy of the interpolation method. Current methods of interpolation are deterministic and indeterminate (geostatistical), phenomenal changes in space and time (Deutsch, 2002).

2.12 Geographical Information System (GIS) and Geostatistics

Since it is not feasible to collect data from all the locations in a study area, the geostatistical analyst extension of ArcGIS is used to generate the spatial distribution maps of the water quality parameters using the data collected (Pradeep et al., 2015). ArcGIS geostatistical analyst is an extension of ArcGIS desktop that provides a powerful suite of tools for the spatial exploration and surface generation. ArcGIS geostatistical analyst

effectively bridges the gap between geostatistics and GIS analysis by enabling us to model spatial phenomenal, interpolate and predict values within the study area (Kumar et al., 2007; Nas, 2009). It is a useful technique that has been employed in various fields (Jeihouni et al., 2014), presenting a collection of tools aimed at understanding and modeling spatial variability (Davis & De Wiest, 1966). By considering how the correlation of data values varies with distance and direction, it will be better to interpolate values at unsampled locations throughout the study area. Thus, with ArcGIS Geostatistical Analyst, we can create surfaces from data measurements taken over areas where collecting information for every location would be impossible or cost prohibitive. We can examine sample data, evaluate uncertainties, and create customized interpolation surfaces for more informed decision making (Otto and Rolf, 2009). This accurate and reliable scientific database will give an overview of the current water quality situations resulting from different management strategies informing management of future system states and potential anomalies. Information on spatial continuity of groundwater concentrations using ArcGIS will help in identifying the magnitude of contamination.

2.13 Geostatistical Modeling

In geostatistical modeling using Kriging interpolation technique, the following steps are usually adopted:

i. Evaluation of normality test and data transformation
ii. Identifying global trend
iii. Semivariogram/Variogram models fittings
iv. Cross validation
v. Spatial dependency determination

vi. Kriging modeling and interpolation

vii. Creation of groundwater quality distribution maps

2.13.1 Normality Test and data transformation (Check for normality)

It is often observed that, environmental variables are skewed. Skewness characterizes the degree of symmetry of a distribution around its mean. Data can be distributed or spread out in different ways either to the left (skewed left) or to the right (skewed right) or randomly. Positive skewness indicates a long right tail, and the negative one indicates a long-left tail, while zero skewness indicates symmetry around the mean. The normal distribution (Gaussian distribution) Figure 2.3. has a skewness nearly of zero value and has a bell shape and kurtosis (measure of whether the data are peaked or flat relative to a normal distribution) of 3 (Jeihouni et al., 2014).

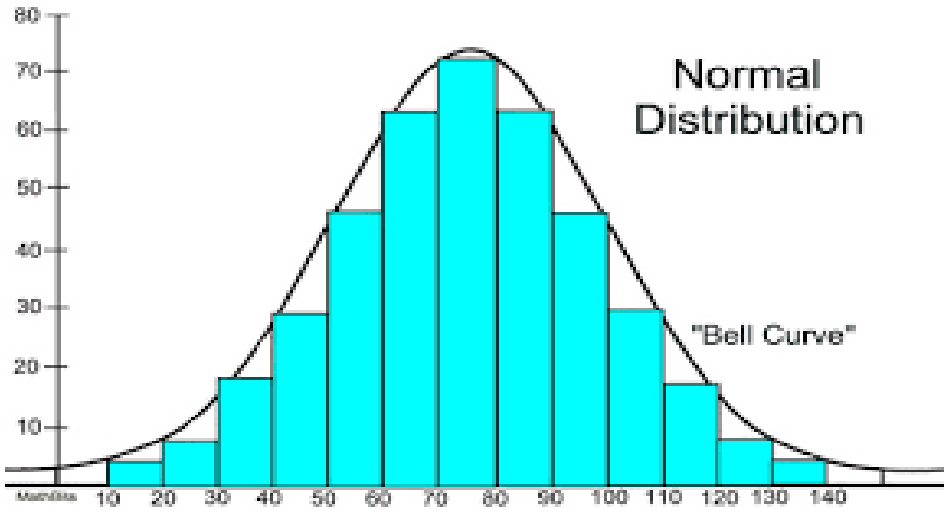


Figure 2.3. A normal distribution curve (Isaaks and Srivastava, 1989)

Geostatistical methods are optimal when data are normally distributed, and deviation from normality can cause problems as such data can impair the variogram structure and the Kriging results (Bohling, 2005). Normality test is as such done to determine the normality

of the dataset using the histogram plot or the quartile-quartile (Q-Q) plot. The histogram is an effective graphical technique for showing normality of dataset. The quartile-quartile (Q-Q) plot provides another measure for checking normality in data. The closer the points are to straight line in a graph, the closer the sample data follows a normal distribution (ESRI, 2010; Yimit *et al.,* 2011). When the data is skewed, they are transformed. Data transformation converts the raw data to normal distribution in case of non-normality by simple mathematics, and it is necessary to normalize the data set that falls short of normality.Transformations is to ensure that data distribution did not deviate too severely from normality (Bohling, 2005) by making the data more symmetric, more linear and more constant in variance (Helsel & Hirsch, 2002). Also, spatial modeling works better when data are normally distributed (Bohling, 2005) hence the need for normality check. Transformation is done using any of the following: TheBox-Cox, arcsine and logarithm or the kolomonous plot. Logarithmic transformation is widely applied in order to normalize positively skewed dataset. However, it is observed that datasets in environmental sciences do not always follow lognormal distribution. In such cases, a power transformation is needed and the Box-Cox transformation is one of the most frequently used. However, it is recommended to apply all transformation tools and the transformation which converts the data most efficiently to normality or that gives the best transformation is adopted.

Through the use of exploratory spatial data analysis (ESDA) tool in ArcGIS, data is explored to check the data distribution and remove the outliers and trend in dataset before creating prediction surfaces. The values which are very high or low as compared to the surrounding values in the dataset are known as outliers. These outliers put negative effect on the geostatistical analysis, therefore their presence is very necessary to know and should

be removed from the dataset.From a collected dataset the average value could be known. An average is a value that is typical, or representative of a set of data. Since such typical values tend to lie centrally within a set of data arranged according to magnitude, averages are also called ‘measure of central tendency’. Several types of averages can be defined, the most common being the arithmetic mean, the median, the mode, the geometric mean, and the harmonic mean. Each has advantages and disadvantages, depending on the data and the intended purpose (ESRI, 2010).

2.13.2 Identifying Global Trends in the Dataset

Trend analysis tries to predict trend. It helps to estimate the quantities of current or previous events and their variability or uncertainties in different time points. It is also the foundation for prediction and prediction after analyzing the significance of time and relationship with other predictors. It summarizes patterns over time to show the direction of change. Trends are systematic changes in data across an entire study area. It is a pattern of gradual change in a condition, output, or process or an average or general tendency of a series of data point to move in a certain direction over time, represented by a line or curve on a graph. Trend analysis is part of the exploratory data tool in Geostatistical Analyst software used to identify the presence or absence of trends in the input dataset and which order of polynomial fits the trend best. Each vertical stick in the trend analysis plot represents the location and value (height) of each water quality parameter measurement. The projected points are automatically drawn showing trends in specific directions. If the lines are flat, there is no trend. If trend exists in a data, it is a non-randomcomponent of a surface and will produce a surface that is too smooth to accurately depict the phenomenon (ESRI, 2010). We can check the trend analysis with the ESDA tool. The green line shows

the trend in the east-west direction, and the blue line depicts the trend in the north-south direction. Green line shows trend in the east – west direction and the blue line depicts trend in the north – south direction.

2.13.3 Semivariogram Models (Variography)

Semivariogram quantifies autocorrelation because it graphs out the variance of all pairs of according to distance. Kriging relies on the semi-variogramas it calculates the estimative variance and the Kriging equation also contains the variogram value. In simple terms, semivariograms quantify the spatial autocorrelationbetween measured samples at different sampling locations (Shahid, Chen & Hazarika, 2006) because it graphs out the variance of all pairs of data according to distance (Bardossy, 2011). A variogram (sometimes called a "semivariogram") is a visual depiction of the covariance exhibited between each pair of points in the sampled data. It is a graph of how semivariance changes as the distance between observations changes, that is, it is used to measure the degree of dissimilarity between observations as a function of distance (ESRI, 2010). For each pair of points in the sampled data, the gamma-value or "semi-variance" (a measure of the half mean-squared difference between their values) is plotted against the distance, or "lag", between them. It measures dissimilarity, or increasing variance between points (decreasing correlation) as a function of distance. The Variogram provide a way to study the influence of other factors which may affect whether the spatial correlation varies only with distance (the isotropic case) or with direction and distance (the anisotropic case) (Zheng, Chen & He, 2008). Semivariance is directly proportional to distance between two locations. Semivariance grows until at some point the locations are considered independent of each other and at this point semivariance no longer increases. Chances are that closer things are more related and

have small semi-variance. While far things are less related and have a high semi-variance. But at a certain distance (range), autocorrelation becomes independent. Where that variation levels off is called sill. This means there is no longer any spatial autocorrelation or relationship between the closeness of your data points.

Semivariogram is commonly represented as a graph that shows the variance in measure with distance between all pairs of sampled locations (Zheng et al., 2008). In the semivariogram figure, the nearest points (on the far left on the x-axis) have low semivariogram (low values on the y-axis). As the length among the pairs of points increases (moving right on the x-axis), the semivariogram increase (move up on the y-axis). Some points near to each other (near zero on the x-axis) have a higher semivariogram (high on the y-axis) than expected.Such a graph is helpful to build a mathematical model that describes the variability of the measure with location. Modeling of relationship among sample locations to indicate the variability of the measure with distance of separation is called semivariogram modeling. It is applied to applications involving estimating the value of a measure at a new location. The variogram could be the "experimental" variogram or the "theoretical" or "model" variogram.

Variogram models are drawn from a limited number of "authorized" functions, including linear, spherical, exponential, and power models. Variogram map provides a visual picture of semi variance in every compass direction. If there is anisotropy, this allows one to easily find the appropriate principal axis for defining the anisotropic variogram model (Nourani and Ejlali, 2012). The semivariogram is a means to explore this relationship. Pairs that are close in distance should have a smaller measurement difference than those farther away from one another. The extent to which this assumption is true can be examined in the

empirical semivariogram (Johnston et al., 2001). Semi variance (g) of Z between two data points is an important concept in geostatistics and is defined asbelow in Equation 2.17:

$$\gamma(x_i, x_0) = \gamma(h)\frac{1}{2}var[Z](x_i) - Z(x_0) \qquad (2.17)$$

Where h is the distance between points x_i and x_0 and $\gamma(h)$is the semivariogram, commonly referred to as variogram (Webster & Oliver, 2001). The formula involves calculating half the difference squared between the values of the paired locations. Variogram modeling and estimation is extremely important for structural analysis and spatial interpolation (Burrough & McDonnell, 1998).

The experimental semi-variogram is a graphical representation of the mean square variability between two neighboring points of distance h.The variogram can be defined as one-half the variance of the difference between the attribute values at all points separated by h as shown in Eqn. (2.18).

$$\gamma(h) = \frac{1}{2N(h)}\sum_{i=1}^{N(h)}[Z(x_i) - Z(x_i + h)]^2 \qquad (2.18)$$

Where:

γ(h) is the estimated or "experimental" semi-variance value for all pairs at a lag distance h.

N(h) is the number of experimental pairs separated by vector h;

$Z(x_i)$ is the water quality value at point i,

Z(x) and $Z(x_i + h)$ are values of the variable Z at the point x_i and at a point of distance h from the point x_i.

At the experimental semi-variogram, a theoretical one is adjusted whose equation is derived based on the principle that kriging re-evaluates correctly the measurements at the

observation points (Journel & Zhu, 1990). A semi variogram may be used alone as a measure of spatial autocorrelation in the data set, but to be used as an interpolator in Kriging, the the semivariogram must be fitted with a mathematical function or model (Chang, Scrimshaw, Emmerson & Lester, 1998). While the "theoretical" or "model" variogram is the distributional model that best fits the data. The variogram function has to be estimated on the basis of the available data. In the case of a finite data set, the estimation of the variogram can be made for a finite set of vectors only. At the experimental semi-variogram, a theoretical one is adjusted whose equation is derived based on the principle that Kriging re-evaluates correctly the measurements at the observation points (Journel& Zhu, 1990)

2.13.3.1 Variogram models

Models provide information about the spatial structure as well as the input parameters for the Kriging interpolation. The accuracy of a model usually depends on the values of mean square error (MSE) which should be close to zero. If the values of root mean square error (RMSE) and average standard error (ASE) are close to one another, the prediction error is much accurate. If root mean square error values are more than the average standard error, the prediction is overestimated (ESRI, 2003). On the other hand, if the values of root mean square error are smaller than average standard error values, the prediction is underestimated. Again, the values of root mean square standard error should be close to 1. If the values are over 1, the prediction is overestimated and if the root mean square standard error is less than 1, it is underestimated. The best model will then be selected after assessing all these statistics. The modeling of a semivariogram is similar to fitting a least square line in regression analysis. The empirical semivariogram is fitted by an analytical

function (model), the geostatistical analyst provides the following functions to choose from the model empirical semivariogram: Circular, Spherical, Tetraspherical, Pentaspherical, Exponential, Gaussian, Rational Quadratic, Hole Effect, K-Bessel, J-Bessel and Stable. The selected model influences the prediction of the unknown values, particularly when the shape of the curve near the origin differs significantly. The steeper the curve nears the origin, the more influence the closest neighbours will have on the prediction. As a result, the output surface will be less smooth. Each model is designed to fit different types of phenomena more accurately (Burrough and McDonnell, 1998; Denby, Walker, Horalek & Eben, 2005; Johnston *et al.,* 2001; Pebesma, 2004; Webster & Oliver 2001).

The basic goal is to calculate the variogram parameters (i.e. range, sill and nugget) of the curve to minimize the deviations from the points according to some criterion. When the fitted curve does not pass through the origin, it denotes the existence of the nugget effect (Johnston *et al.,* 2001). Variogram modeling and estimation is extremely important for structural analysis and spatial interpolation (Burrough & McDonnell, 1998). Thus, following normality and transformation of data, variography (i.e., variogram model fitting) is then carried out. Also, there is need for cross validation of model to choose the best that suits the data.

2.13.4 Semivariogram Model Fitting and Testing

Semivariograms can be fitted with many models which include; Circular, Spherical, Exponential, Gaussian, Power, Rational quadratic, Sine hole effect, k- Bessel, J- Bessel and Stable. Fitted semivariogram can be used for estimating the semi variance at any given distance and is usually characterized by three measures, the nugget, the range and the sill as shown in the Figure 2.4.

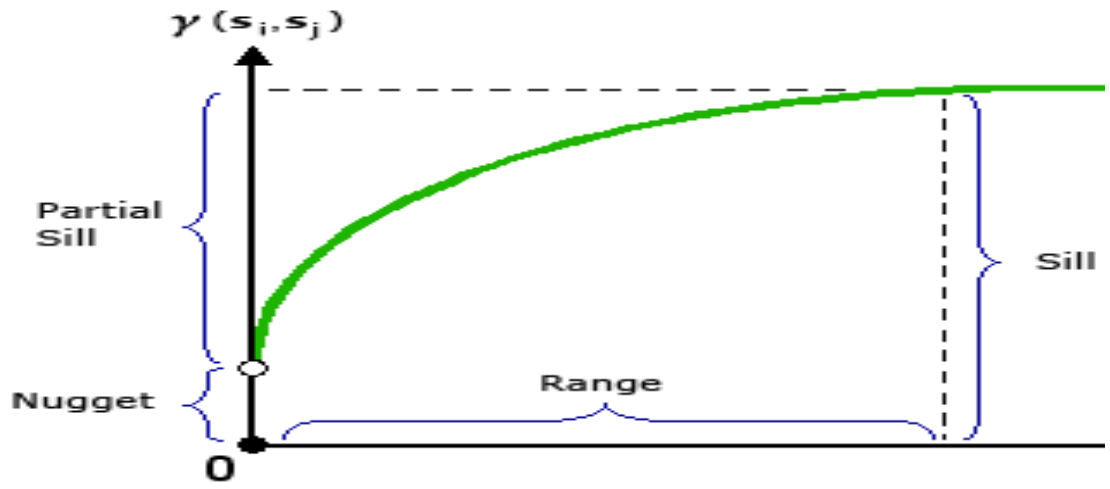


Figure 2.4. Semivariogram depicting range, sill and nugget effect (ESRI, 2010)

The basic parameters of variogram are nuggets (C_o), sill (C) and range (R) (Bardossy, 2011; Bohling, 2005). These parameters are the requisite criteria for the recognition of measurement error, determination of spatial dependency and the distance at which spatial dependency seized to exist. The distance where the mode first flattens out is known as the range. Sample locations separated by distance closer than the range are spatially autocorrected, whereas locations farther apart than the range are not. The value that the semivariogram model attains at the range is called the sill. The partial sill is the sill minus the nugget. Theoretically, at zero separation distance the semivariogram value is zero. However, at a small separation distance, the difference between measurements often does not tend to zero. This is called the nugget effect. The nugget effect can be attributed to measurement error or microstructures (Bardossy, 2011; Bohling, 2005). Using h to represent lag distance, C_n to represent nugget effect, α to represent range which is the distance at which the semivariogram reaches the sill, σ to represent partial sill and C to represent sill which consists of the nugget effect, if present and the partial sill, i.e. (Equation 2.21),

$$C = c_n + \sigma \quad (2.19)$$

Some of the mathematical models used in Kriging interpolation are:

i. Spherical: $\gamma(h) = \begin{cases} 0 & \text{if } h = 0 \\ c_n + \sigma\left(1.5\left(\frac{h}{a}\right) - 0.5\left(\frac{h}{a}\right)^3\right) & \text{if } h \leq a \\ c & \text{if } a > h \end{cases}$ (2.20)

ii. Circular: $\gamma(h) = \begin{cases} c_n + \sigma\left(1 - \frac{2}{\pi}\cos^{-1}\left(\frac{h}{a}\right) + \sqrt{1 - \frac{h^2}{a^2}}\right) & \text{if } h \leq a \\ c & \text{if } h > a \end{cases}$ (2.21)

iii. Exponential: $\gamma(h) = c_n + \sigma\left(1 - \exp\left(\frac{-h}{a}\right)\right)$ (2.22)

iv. Gaussian: $\gamma(h) = c_n + \sigma\left(1 - \exp\left(\frac{-h^2}{a^2}\right)\right)$ (2.23)

v. Sine holeeffect: $\gamma(h) = c_n + \sigma\left(1 - \frac{\sin\left(\frac{\pi h}{a}\right)}{\frac{\pi h}{a}}\right)$ (2.24)

vi. Power; $\gamma(h) = c_n + \sigma h^a$ with $0 < a < 2$ (2.25)

Where:

h = lag distance,

c_n= nugget effect,

a = range,

σ= partial sill,

c = nugget effect and partial sill, i.e. $c = c_n + \sigma$.

These models provide information about the spatial structure as well as the input parameters for the Kriging interpolation.

2.14 Spatial Dependency

Spatial dependence (spatial autocorrelation) is the tendency for nearby locations to influence each other and to possess similar attributes. That is, it is a statistical measure of

the similarity of attributes of point locations. Spatial autocorrelation is a metric that represents the property of spatial dependency and is measured by comparing different values of the same variable (i.e., "auto") at different points in space (Chamannejadian, Moezzi, Sayyad, Jahangirl & Jafarmejadi, 2011). Spatial autocorrelation is the calculated correlation coefficient between the semivariance and the geographic distance between all pairwise comparisons across all points. The semivariance is a measure of the squared difference between values for each pair of points. The spatial dependency and structure of a measured property is described by a variogram. Semivariograms quantify autocorrelation because it graphs out the variance of all pairs of data according to distance.

A fitted variogram has the nugget effect, the range, the sill and the partial sill. The ratio the nugget semi variance to the sill semi variance ($\frac{c_n}{c}$) is a measure of the degree of spatial dependency of the measured quality. The nugget/sill ratio in geostatistics is regarded as a criterion to classify the spatial dependency of attributes (Uyan&Cay, 2010). The ratio values of 25% (0.25) and 75% (0.75) are the two thresholds for the relative strength index of spatial auto-correlation (Chamannejadian et al., 2011). The ratio value less than 25% shows that the variable has strong spatial dependence, between 25% and 75%, the variable has moderate spatial dependence and greater than 75%, the variable has weak spatial dependence (Chang et al., 1998; Chien, Lee, Guo & Houng, 1997; Jiachum et al., 2007; Liu, Wang, Zhang, Song, Li, Xiaoyan & Li, 2006; Bohling, 2005). If spatial dependence does exist in a data set, known points that are close to each other are expected to have small semi variances, and known points that are farther apart are expected to have large semi variances. This is the propensity for nearby locations to influence each other and to possess similar attributes (Bardossy, 2011). In GIS it helps understand the degree to which

one object is similar to the other nearby objects. If autocorrelation exists in a map, then this violates the fact that observations are independent from one another. Spatial autocorrelation indicates if there is clustering or dispersion in a map.

2.15 Cross Validation

Cross validation process in ArcGIS gives an idea of how well the model predicts the values at the unknown locations, using referen

ce points (Liu et al., 2006). It is anestimation method applied as the goodness-of-fit by comparing and selecting the variogram model that gives the best expectation. Cross validation techniques can be used to detect outliers of the measurement values. One of the advantages of kriging is the fact that it calculates the mean square interpolation error. Cross validation process is a step undertaken prior to geostatistical estimation to ensure the validity of the variogram parameters. The proposed verification procedures do not aim to prove the correctness of the model, but to ensure the absence of systematic errors that could lead to biased estimations (Nas, 2009).To determine the accuracy and validity of the process, the cross-validation method is applied. To validate the models, some validation indicators (prediction errors), including mean error (ME), mean standardized error (MSE), root mean square error (RMSE), average standardized error (ASE) and root mean squared standardized error (RMSSE)are applied and evaluated. It compares the measured and predicted values and offers qualitative insights into how prediction method performs (Liu et al., 2006). The statistics calculated on the prediction errors serve as diagonistics that indicate whether the model is reasonable for decision making and map production. (Chang, 2008; ESRI, 2010 and Nas, 2009), stated that to judge if a model provides accurate predictions, we verify that:

i. The predictions are unbiased, shown by amean expectation error close to zero.

ii. The standard errors are accurate, shown by the root mean square standardized error which should be close to one (1).

iii. The expectations do not deviate much from the estimated points (i.e. the standard errors are accurate), shown by the root mean square error and average standard error which should be as small as possible and close to each other (Hassan, 2014)

Using the geostatistical wizard in ArcGIS 10.6, cross validation is performed automatically and the prediction error results are presented at the last step of the wizard. Since a linear regression model is not always appropriate for the data, the accuracy of the model should be evaluated by defining residuals (actual data-estimated data) and examining residual plots. If the histogram of the residuals shows normal distribution with mean of zero, the accuracy of variogram parameters will be approved statistically (Deutsch, 2002).

2.16 Kriging Interpolation

Kriging is a linear optimum unbiased stochasticgeostatisticcalinterpolation technique similar to IDW. it also uses a linear combination of weights at known locations to estimate the data value of an unknown locationwith a minimum mean interpolation error.It was first proposed by Krige to create probabilistic models of uncertainty relating to the values of the attributes that predicts the value in a geographic area given a set of measurements if your data meets certain criteria (Isaaks and Srivastava, 1989; Krige, 1978). The criteria are:

i. Your must have a normal distribution

ii. The data needs to be stationary, that is, local variation doesn't change in different areas of the map. The variance is fairly constant in different areas of the map. Kriging is not optimal for abrupt changes and break lines.

iii. Data cannot have any trends. Trends are systematic change in data across an entire study area.

Other major assumptions of Kriging models are the assumptions of spatial dependency (spatial autocorrelation) and stationarity (Krivoruchko, 2011). The assumption of stationarity is that the mean is constant between samples, and irrespective of location, the covariance and variance of the difference is the same between any two points that are at the same distance and direction apart no matter which two points you choose (Johnston et al., 2001). The resulting surface created from Kriging models are the best linear unbiased predictors and the uncertainty or accuracy of the predictions can also be ascertained.Kriging models are often the most widely used and statistically sound geostatistical interpolation techniques (Chun & Griffith, 2013, Johnston *et al.,* 2001).

Kriging modeling is therefore based on semivariogram and covariance functions (spatial autocorrelation) and prediction of unknown values uses the semi variance to measure the spatially correlated component, a component that is also called spatial dependence or spatial auto correction (Ma, Yuan, & Cai, 2006). Variogram is an important input in kriging interpolation. It is a measure of spatial correlation between two points. With known variograms, weights can change according to the spatial arrangement of the samples. Furthermore, it is known to be an exact estimator in the sense that observation points are correctly re-estimated.Kriging can be used when data are irregularly spaced and can be either a smooth or exact interpolator (Yankey, 2018). This method does not necessarily

require observation networks where data are normally distributed, and for the estimation of the structure of the regionalized variables, it considers only the neighboring points of estimation data (De Marsily, 1986). The procedure facilitates the estimation at unsampled locations. Kriging estimates are calculated as weighted sums of the adjacent sampled concentrations. That is, if data appears to be highly continuous in spatial domain, the values closer to those estimated receive higher weights than those farther away (Ersoy, Balkan, Gunay, Onag& Egemen, 2004). Major advantages of kriging are that, in addition to estimating the surface data from point data it also provides a measure of error or uncertainty of the estimated surface (Yi-Hwa & Ming-Chih 2016). It presents the interpolation error of the values of the regionalized variable where there are no initial measurements. This feature offers a measure of the estimation accuracy and reliability of the spatial distribution of the variable (Theodossiou & Latinopoulos, 2006). (Longley *et al.*, 2005). Bekele, Downer, Wolcott, Hudnall & Moore, H (2003) compared several spatial interpolation methods, including kriging and IDW. They found that kriging generally performed better than IDW. However, they concluded that a regression based autocorrelated error model was overall a more flexible method for interpolation. Laslett, Handcock, S., Merier, Nychka & Machler, (1994) compared kriging and spline spatial interpolation methods and found that kriging produced better and more accurate surface than spline. Gotway, Ferguson, Hergert & Peterson, (1996) compared kriging and IDW, and reported that kriging performed better than IDW and was relatively more stable because it was less dependent on spatial structure or soil sampling. Bishop and McBratney (2001) conducted a study to explore the effect of having secondary data (such as color aerial photos) in the interpolation process. They reported an improved kriging

performance. Its disadvantage is that it requires substantially more computing time and more input from users, compared to IDW and spline (Longley, et al., 2005).

In kriging, the weight depends on the semivariogram, the distance to the prediction location and the spatial relationships among the measured values around the prediction location. Some of the various types of Kriging used include: ordinary, universal, simple, indicator, disjunctive, block and cokriging ordinary kriging.The Kriging formula is given in equation (2.9) for estimating the z value at a point (Nas, 2009)

$$Z_0 = \sum_{i=1}^{s} Z_x W_x \quad (2.9)$$

Where,

Z_0 = estimated value (prediction value)

W_x= weight associated with point x

Z_x= known value at point x

s = number of sample points used in estimation

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

The materials that were used in this research work are presented in Table 3.1.

Table 3.1: *Materials/Equipment and Their Uses*

S/N	Materials	Uses
1	Plumb bulb and line	To measure depth of borehole
2	Atomic absorption spectrophotometer (AAS) (Thermo Scientific Spectronic 20D+)	To determine concentration of heavy metals in water samples
3	Geographical Positioning System (GARMIN GPSMAP 76CSx model)	To deterime the UTM coordinate of sampling locations
4	ArcGIS 10.6 software	Software that was used to analyze the geo-datasets
5	Stop watch	To time the period taken to complete some experiments
6	EDTA (Complexometric) titration	To measure calcium, potassiunm and total hardness
7	Digital turbidity meter (model ME 988N)	To measure the turbidity of water sample
8	Thermometer	To measure the temperature of water samples
9	pH meter (PHS-25)	To measure the pH (acidity)
10	Conductivity/TDS Meter (HI 2315, Hanna Instrument)	To measure EC and TDS concentration
11	DO meter (DO analyzer JPG 607)	To measure the DO of water samples
12	Computer (hp 360X)	To type, store and calculate imputed information
13	Oven	Used in the dryinf of samples
14	Reagents	Used in the chemical analysis of water samples
15	Pipettes, burettes, separating funnels, flasks.	Used in titration

3.1.1 Description of Study Area

Warri is located in the western end and coastal region of the Nigerian Niger Delta about some 40 kilometres away from the shores of the Atlantic Ocean in Delta State, in Southern Nigeria. It lies between latitude 5°54′00’’N and 5°35′00’’N of the Equator and longitude

5°42′00’’E and 5°54′00’’E of the Greenwich Meridian. It is one of the major commercial cities in southern Nigeria and it has a port, a refinery and several oil fields and flow stations.The study area includes the area that covers the metropolitan city of Warri and Effurun, Orhuwhoru, Jeddo, Ukuokoko in Warri South, Uvwie, Udu and Okpe Local Government Areas, respectively. The area is bounded on the north by Okpe, to the south by Burutu and Udu LGAs, to the west by Warri Southwest and to the east by Okpe and Uvwie LGAs as in Figure 3.1.

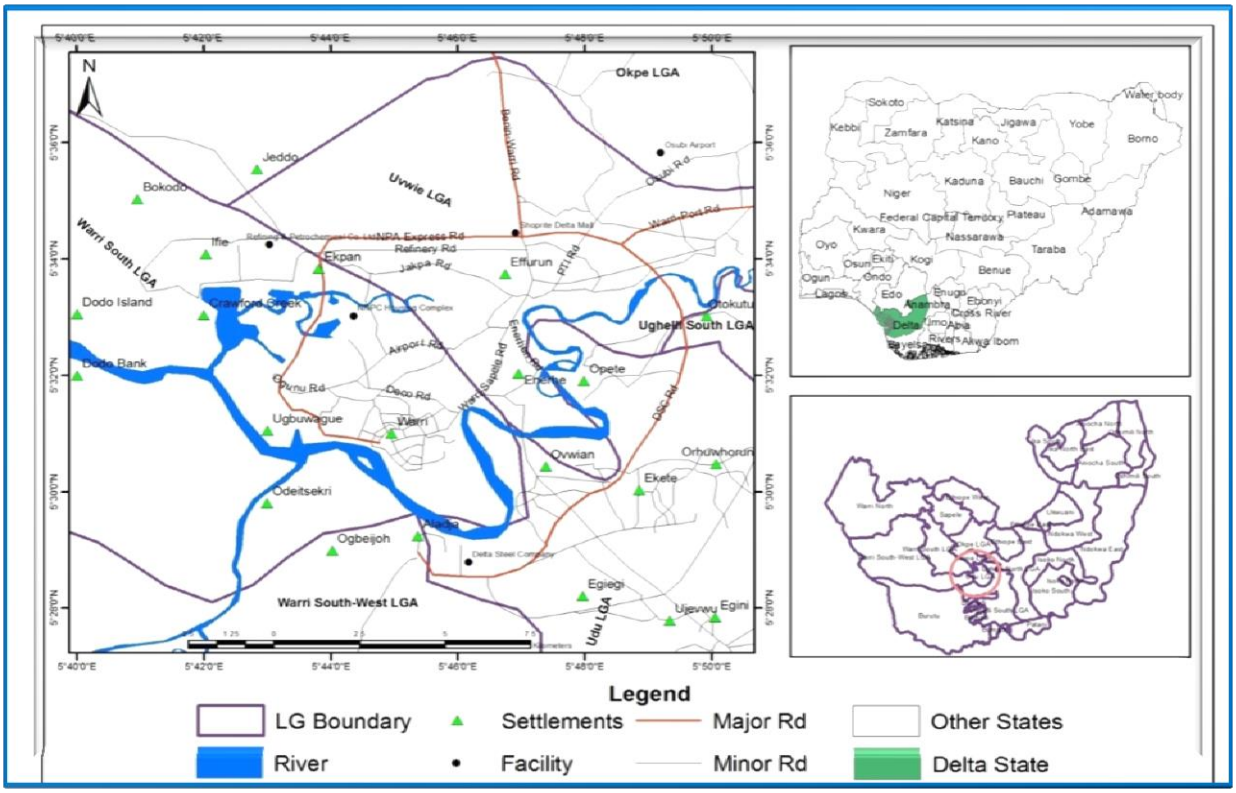


Figure 3.1. Map of Warri and its environs (Google Map, 2019)

The geological formation of the study area consists of more than 90% sands and about 10% shale/clays as shown in Figure 3.2. The sands range in size from fine-to-medium and coarse-grained unconsolidated sands, with occasional intercalations of gravelly beds that

are also poorly-sorted, sub-angular to well-rounded, and bear lignite streaks and wood fragments peat or lenses of plastic clay (Akpoborie, Nfor, Etobro&Odagwe, 2011; Fetter, 2007; Nwajide, 2006). The area overlies the three major subsurface lithostratigraphic units of the Niger Delta (from the oldest to the youngest, Akata, Agbada, and Benin) Formations (Frank & Cordry, 1967; Nwajide, 2006; Orji &Egboka, 2015; Short and Stauble, 1967). The continental Miocene-Recent Benin Formation conformably overlies the Agbada Formation. The Benin Formation is masked by the younger Holocene deposits of the Sombreiro-Warri Deltaic Plain, the Mangrove Swamp and Freshwater Swamp wetlands. The first aquifer (Benin formation which is less than 50m in thickness and is extremely vulnerable to pollution from surface sources especially due to the fact that groundwater could be encountered in this formation even at a depth of 4m or less (Akpoborie et al., 2011).

Hydraulic conductivities of the Quaternary sand vary from 3.82×10^{-3} to 9.0×10^{-2} cm/sec which indicates high aquifer potentials (Aweto, Akpoborie & Ohwoghere-Asuma, 2015), a potentially productive aquifer and specific capacities recorded from different areas within this formation vary from 6700lit/hr/m to 13,500lit/hr/m (Offodile, 1991). The water table is very close to the ground surface and varies from 0 to 4 metres. This limited groundwater level fluctuation reflects the high amount of precipitation recorded in Warri over the greater part of the year with annual average of about 3000mm (Adejuwon, 2012). This huge annual rainfall contributes largely in the recharging of the aquifer that has enriched the underground water source of the study area. The mean annual temperature of Warri urban is about 32.8°C and there are high temperatures of 36 and 37°C (Adejuwon, 2012).

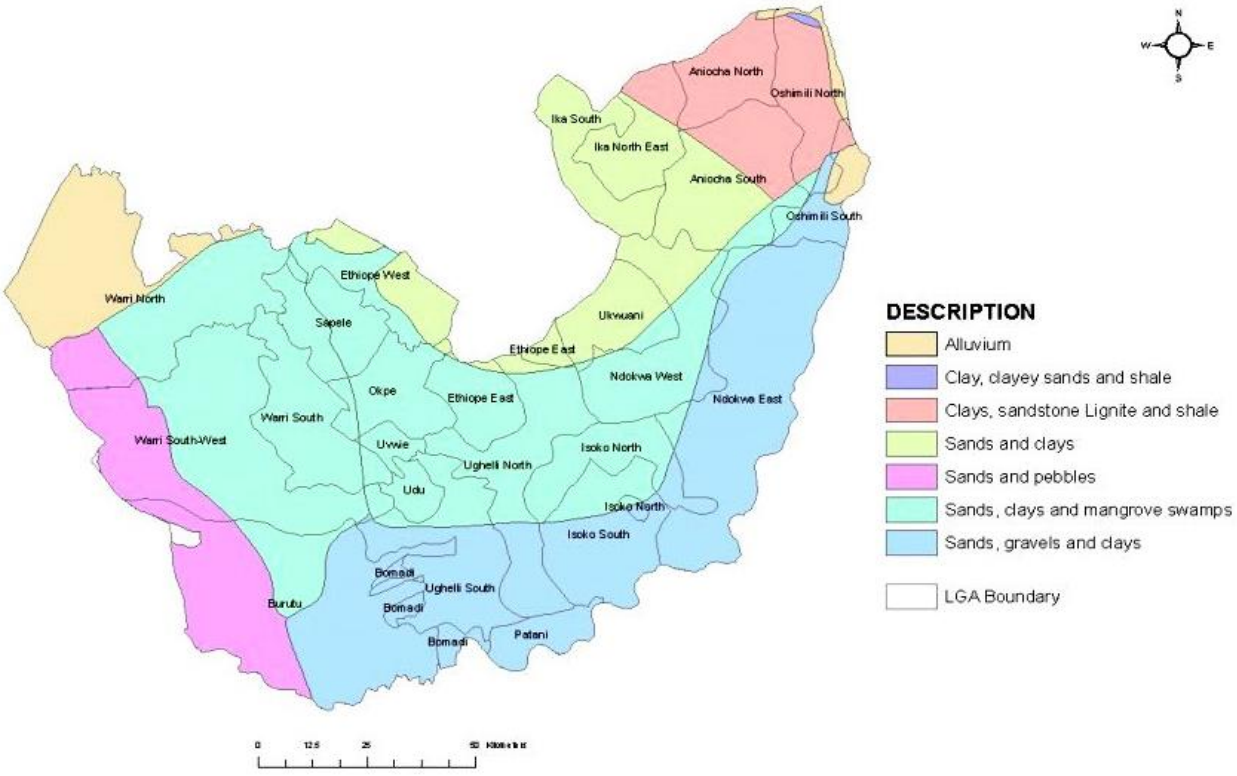


Figure 3.2. Geological map of Delta State by local governments (Akpoborie et al., 2011).

Physiographically, the land is gentle and rises from less than 6m above sea level in the lowlands that adjoin the sea to an average elevation of about 18m above the sea level (Olobaniyi & Efe, 2007). The flat and low-relief features of the area, often encourage flooding after rain. The area is traversed by numerous creeks with their dendritic drainage pattern with some tributaries emptying their waters into the Warri River. The River Warri which is a tributary of River Niger flows in an east-ward direction forming extensive swamp and finally draining into the Atlantic Ocean. The river is perennial and tide-influenced. As a result of the fresh water-salt water mixture, a brackish environment is created at the banks of the river and associated creeks (Akpoborie et al., 2011).

The climate of Warri and its environs is humid equatorial and it is influenced by two prevailing air masses; the south-west monsoon wind and the north-east trade wind. The monsoon wind prevails during the wet season and the trade winds during the dry season. The effects of the dry north-east trade winds are most noticeable from November to March when they usher in the dry, dusty haze and cool harmattan season and a long wet (rainy) season lasting from March to October that alternates with a shorter dry season that lasts from November to February, but it frequently rains even in the dry season. The rainfall regime is double-peak, the two periods of peak rainfall being June/July and September which are separated by a relatively dry period in August.

The natural vegetation of the study area along the banks is made up of mangrove plants of different species. Away from the banks, rainforest plants predominate. Tropical rainforest occurring in flat-floored valleys and adjoining low-lying areas with swamp forest that are seasonally or permanently waterlogged. The rain forest is floristically diverse and structurally complex, with several layers of trees. However, virtually all the rainforest in the area has been destroyed as a result of farming, especially shifting cultivation and the establishment of small-scale holdings of rubber tree, commercial lumbering and urbanization (Akpoborie et al., 2011). Today much of the country side is dominated by secondary regrowth vegetation with oil palms, rubber plantations and patches of swamp forest along water bodies (Ekeh, 2005). The population of the area is well over 700,000 in 2006 (Olobaniyi & Owoyemi, 2006).

Groundwater is the major source of water and it is extracted from large number of private bore wells. There is no record of the number of private bore wells within the study area.

Based on physical observation, it may be safely quoted that almost every house has one bore well.

3.2 Methods

The following steps were adopted in this research work and photographs while the work is in progress are presented in Appendix I.

3.2.1 Investigation of the temporal variation of the physico-chemical and biological characteristics (quality) of groundwater

The investigation of the groundwater quality of the study are was achieved through the following methods:

3.2.1.1 Sampling locations.

A satellite imagery of the study area was obtained using ArcMap 10.6. The built-up areas were digitized and gridded at 1km intervals to determine the sampling points, ensure adequate coverage and uniform spacing of sampling locations. Fifty (50) sampling locations at or close to the grid intersection points were selected and establishedbased on the areas of highand lowpopulation density, industrial or anthropogenic activities such as crude oil refining activities, open solid waste dump sites, density areas and river catchment areas.The sampling locations and their UTM coordinates were read with a hand-held GPS (GARMIN GPSMAP 76CSx model) and presented in 4.1 and the digitized map of the sampling locations with their codes are presented inFigure 4.2. The depths of some boreholes were also determined using a plumb bulb and line.

3.2.1.2 Samples collection

Water samples were collectedfrom the selected 50 existing boreholes during the dry season (December, 2019 – January, 2020) and the wet season (June, 2020 –August, 2020) from residential and commercial areas. Newhigh-density PET screw-capped containers of 1.5litres capacity were used to collect the water samples. The PET containers and stoppers were thoroughly washed with distilled water three times and once with the water to be sampled before collecting the actual samples. The bottles were filled, allowed to overflow and immediately corked, properly labeled to avoid mix up, placed in an ice block chest and transported to the laboratory within a prescribed period of not more than three hours after collection. Collection, preservation and transportation of the water samples to the laboratory(Jacio Environmental Limited, No. 3 ArubayiEstate, km 2, Refinary Road, Effurunfollowed the standard guidelines recommended by APHA, (2017). The water samples were preserved in refrigerators at $4^{o}C$ in the laboratory to keep the samples intact until analysis was carried out. As prescribed by APHA (2017), at each sampling location, samples were collected in triplicates. One bottle was filled with water having no acid for the analysis of the physico-chemical parameters. the second white bottle was filled and acidified by adding few drops of 5% nitric acid (HNO_3) to stop the activities of microorganismsand was for microbial analysis.The third container is black to prevent photosynthetic oxygen generation and was for the analysis of BOD after five days.

3.2.1.3 Characterization of water samples

The water samples were analyzed in the field and laboratory in order to obtain the concentration of the physico-chemical and biological water sample quality parameters. The samples were analyzed for twenty-six (26) physico-chemical and bacteriological

parameters after standard methods for the examination of water and wastewater quality, (APHA, 2017).

3.2.1.3.1 Field analysis

Non conservative (sensitive) parameters such as temperature, pH, electrical conductivity (EC), Total Dissolved Solids (TDS) and dissolved oxygen (DO) which change with storage time were measured in-situ with appropriate apparatus (Mercury thermometer, pH meter (PHS-25), Conductivity/TDS Meter (HI 2315, Hanna Instrument)and DO meter (DO analyzer JPG 607) respectively and recorded before other samples were transported to the laboratory for further physical, chemical and bacteriologicalanalysis.

3.2.1.3.2 Laboratory analysis of water quality parameters

The samples were analyzed to obtain the concentration of the physical, chemical and biological characteristics of the samplesin accordance to American Public Health Association, (APHA) 2017 standard methods of testing water and wastewater. The parameters analyzed in the laboratory are: turbidity, total hardness (TH), total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total coliform bacteria, sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), sulphate (SO_4), nitrate (NO_3), chloride (Cl^-), bicarbonate (HCO_3), ammonium (NH_4), phosphate (PO_4), iron (Fe), cadmium (Cd), chromium (Cr), copper (Cu), and lead (Pb).The specific tests method applied for each parameter are presented in Table 3.2. The heavy metals (Iron, Cadmium, Chromium Copper and Lead) examined were determined using Atomic Absorption Spectrophotometer (AAS) and the concentration of each parameter was read directly at their specific wavelength. Fe (248.3nm), Cd (228.8nm), Cr (357.9nm), Cu (324.8nm) and Pb (217nm).

Table: 3.2: *Methods Of Analysis For Different Water Quality Parameters.*

S/N	Parameter	Methods
1.	Turbidity	Nephelometric
2.	Total Hardness	EDTA Titrimetric
3	Total suspended solid	Gravimetric after filtration
4	Biochemical Oxygen Demand (BOD)	Bottle incubation for 3-days at 27^{o}C
5	Chemical Oxygen Demand (COD)	Open reflux
6	Total coliform bacteria-MPN	Total multiple tube fermentation
7	Sodium	Flame emission photometric
8	Potassium	EDTA Titration
9	Calcium	EDTA Titration
10	Magnesium	Calculation from TH and calcium
11	Sulphate	Nephelometry
12	Nitrate	UV Spectrophotometric
13	Chloride	Spectrophotometer
14	Bicarbonate	Calculation from pH and Alkalinity
15	Ammonium	Distillation titrimetric
16	Phosphate	Ascorbic acid spectrophotometric
17	Heavy metals (Fe, Cd, Cr, Cu, Pb)	Atomic Absorption Spectrophotometer (AAS)

Source: APHA, 2017.

3.2.1.4 Evaluation of the temporal variation of groundwater quality parameters

The results obtained from the field and laboratory analysis of water samples for dry and wetseasons are compared to determine the seasonal variation of the concentration of the parameters in both dry and wet seasons. The two tailed paired t-test of the Microsoft Excel data analyst tool was used to as a hypothesis testing tool to determine if there was a significant difference between the means of the water quality parameters in the dry season and wet season.

3.2.1.5 Comparison of laboratory results with world health organization (who) standards

The mean values of the concentration of water quality parameters obtained from both field and laboratory analysis of water samples were compared to WHO (2011) permissible limit

for drinking and public health. This was done to assess the water quality parameter of each sample in the study in order to determine parameters with concentrations above the stringentvalues and WHO permissible limits.

3.2.1.6 Evaluation of water quality index (WQI) of water samples

The suitability of groundwater in the study area for drinking purposes based on physico-chemical parameters was evaluated using the mathematical functions of the Microsoft excel and the weighted arithmetic method of calculating WQI. The values of WQI were computed and categorized using the procedure outlined in Section 2.3.1.

3.2.2 Development of Regression Models for Predicting Some Selected Groundwater Quality Parameters Samples

Empirical models were used in developing the regression models. To develop the prediction models, statistical analysis was conducted using the results of the concentration of the analyzed groundwater samples as input data. Correlation analysis was used to check the inter-relationships between the results obtain from the parameters analyzed insitu and some cations, anions and heavy metals if it existedand regression analysis was used to develop the regression model. The data analysis tool in Microsoft Excel was used to explore and study the interrelationship between some conservative parameters measured in the field (pH, EC, TDS, and DO) as independent variables and some cations, anions and heavy metals analysed in the laboratory (Na^{+}, Mg^{2+}, Ca^{2+}, HCO_3, SO_4^{2-},Cl^{-}, Fe^{2+}, Cd^{2+}, Cr^{3+}, $Cu^{2+}$and Pb^{2+}) as dependent variables. This was done to produce a regressionmodel that can be adopted to predict the concentration of these cations, anions and heavy metals before the rigorous laboratory analysis, to serve as a quick check for concentration of most disease-causing pollutants (Kumar et al., 2007) and to save time, money and resources,

especially the near absence of AAS for analyzing heavy metals in a good number of laboratories.According to Kumar *et al.,* (2007), cations and anions of groundwater are used to estimate the characteristics and origin of groundwater. The independent variables (pH, EC, TDS and DO) can be measured easily and inexpensively in the field by potable water quality checkers. On the other hand, the analysis of the dependent variables (Na, K, Ca, Mg, SO_4, NO_3, Cl, PO_4, HCO_3, Fe, Cd, Cr, Cu and Pb) are more difficult and expensive as they need more equipment and time (Rice, Baird & Eaton, 2017). However, cations, anions and heavy metals analysis are very important and principal because they can illustrate groundwater quality, particularly in understanding the quality status of water samples (Khaki, Yusoff & Ismalami, 2015). Hence, researchers have done various investigations to find out the precise mathematical correlation between these sets of parameters (Rice, et al., 2017). The statistical analysis performed were:

3.2.2.1 Measure of central tendency/dispersion

The minimum, maximum, mean and standard deviation of each parameter were evaluated.

3.2.2.2 Correlation and regression

Correlation and regression techniques of the Microsoft Excel tool was used to investigate the relationship between water quality parameters (variables).

3.2.2.2.1. Correlation analysis

Correlation matrix was performed to determine the strength of the linear relationship between insitu measured variables (pH, EC, TDS and DO) as independent variablesand cations, anions and heavy metals (Na, K, Ca, Mg, SO_4, NO_3, Cl, PO_4, HCO_3,Fe, Cd, Cr, Cu and Pb) as dependent variables and the correlation coefficient (R) was obtained. The

results of the correlation matrix for temperature arepresented in Table 4.8 and Appendix II for both dry and wet seasons.

3.2.2.2.2 Standard error.

In statistics, a sample mean deviates from the actual mean of the population, this deviation is the standard error of the mean and it is usually smaller than the standard deviation. This was carried out as well to aid in the determination of the significance level to which parameter values relate to each other in the dry and wet seasons. This enabled the seasonal variation of the water quality parameters to be subsequently established.

3.2.2.2.3 Regression analysis

To evaluate the relationship between a dependent variable and many independent variables if any exists between one or more predictor variables and the response variables.The multiple regression model was performed using Microsoft Excel data analysttool, resultsare presented in Tables 4.14a and 4.14b. Trend line tool in Microsoft Excel was used to develop the regression models. Equation 3.13 is the generalized regression model used for this study.

$$\text{Each ion} = a_0 + a_1\text{TDS} + a_2\text{pH} + a_3\text{DO} + a_4\text{EC} \quad (3.13)$$

Where,

$\text{Each ion} = \text{Predicted concentration of cations, anions and heavy metals}$

$a_0 = \text{Intercept of the graphs on the y} - \text{axis}$

$a_0 \text{ to } a_4 = \text{Cofficient value for each of the parameters (dependent variables)}$

$\text{EC, pH, TDS, and DO} = \text{insitu measured concentration of the parameters}$

3.2.2.2.4 Verification and validation of regression model.

The calibratedregression equations from the statistical modeling phase were verified and validated.This was achieved by analyzing water samples from four (4) different locations that were not originally sampled in both dry and wet seasons, concentrations of some water quality parameters were recorded and then inserting the field values of the independent variables into the regression equations to obtain values (concentrations) of the dependent variables.

3.2.3 Modeling the Spatial Distribution of Groundwater Quality Parameters

Spatial interpolation is a technique used to evaluate physical data in a continuous space domain. Computer models of eleven existing models already built into the Geostatistical Analyst Extension Tool of the ArcGIS 10.6 software was used in the modeling of the spatial distribution of groundwater quality parameters at unsampled locations based on Kriging interpolation method in standardtechnique as stipulated by ESRI, (2004). The results of laboratory analysis of water samples collected from knownsampling locations both for the dry and wet seasons were used as input data.The steps in the Geostatistical modeling using the ArcGIS 6.0 software included:

3.2.3.1 Evaluation of normality test and data transformation

The histogram was used to check for normality of the dataset. Where the dataset run short of normality, they were transformed using the log, arcsine or Box Cox transformation tools. This was done to justify the assumption of normality of datasets used in Kriging interpolation.

3.2.3.2 Identifying the global trend

The trend analysis tool of the geostatistical analyst tool was used as an experimental approach to determine and explain the changes in the study area over a period of time in statistical terms. This wasto justify the assumption of stationarity.

3.2.3.3 Semivariogram/variogram models fitting and testing

The normally distributed or transformed data were used to fit semivariogram models which are plots of semivariance against distance for water quality parameters between measured locations. Eleven (11) models (Circular, Exponential, Gaussian, Hole effect, J- Bessel, k-Bessel, Power, Rational quadratic, Spherical, Stable andTetraspherical) of the ArcGIS 10.6 were tested for each groundwater quality parameter using ordinary Krigininterpolation technique. The best model was then fitted using the least root mean square error (RMSE) criterion.

3.2.3.4 Spatial dependency determination

The spatial dependency or auto correlation was done using the nugget to sill ratio of the variogram model parameters.

3.2.3.5 Cross validation

Before Kriging interpolation/modeling, the models were cross validated. Cross valdation gave information of the best fitted semivariogram to adopt in consonance with cross validation technique as it is the most adequate for choosing the best or optimal semivariogram adjustment (Webster & Oliver, 2007). The least root mean square error criteria was used in adopting the best fitted variogram.

3.2.3.6 Creation of prediction maps

The interpolation of concentration of groundwater quality parameters at unsampled locations was achieved using the Kriging interpolation method which is based on the statistical analysis and applied in empirical modeling for approximating relationships impact factors of the measured and system response parameters at the unsampled locations created a continuous surface. The groundwater quality prediction maps for each groundwater quality parameter concentration were then produced using the Kriging interpolation method of ArcGIS 10.6.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Physico-Chemical and Biological Characteristics (Quality) of Groundwater

The reults obtained in establishing the water quality paramerters are in the sub sections below.

4.1.1.1 Sampling locations

The fifty (50) sampling locations, their codes, borehole depths and UTM coordinates arepresented in Table 4.1.The digitized map of Warri and its environs showing the sapling locations is presented in Figure 4.1. The average depth of the boreholes was 16m.

Table 4.1: *Sampling locations and their GPS in UTM coordinates*

S/N	Sample Location	Sample Location Code	Depth of borehole (m)	UTM Coordinates	
				Longitudes (E)	Latitudes (N)
1	Okuokoko	OKU	17.20	873764.26	617561.74
2	Effurun GRA	EFG	16.90	809311.71	616265.61
3	Army Barracks	ARB	Not available	806343.49	617014.43
4	Niger CAT	NCAT	15.00	803585.72	617216.33
5	Airport Road	APR	16.50	807682.28	613754.57
6	Jakpa Road	JKR	17.20	808039.86	614880.60
7	Shagholoh	SHA	18.50	802034.58	616405.78
8	Ekpan	EKP	19.45	803288.04	615763.82
9	Urhobo College Effurun	UCE	20.50	807932.75	612162,37
10	Effurun Market	EFM	14.80	808734.27	614759.96
11	Ogborode	OGD	15.75	796661.77	619874.80
12	Ughoton	UGT	14.85	795589.43	620671.69
13	Jeddo	JED	16.45	799838.04	618888.51
14	Ubeji 1	UBJ 1	17.00	799644.98	616528.51
15	Ubeji 2	UBJ 2	17.30	798928.54	616368.90
16	Osubi Market	OSM	14.50	810399.60	617088.74
17	Osubi Airport	OSA	Not available	812355.65	619128.23
18	Ogbuwangue	OGB	14.85	801383.19	611606.79
19	Warri Port	WAP	Not available	801978.92	611118.32
20	Ogunu	OGU	14.75	800441.59	612708.26

21	Edjebah	EDJ	15.65	803381.05	612880.96
22	Edjeba Housing Estate	EDHE	Not available	803354.16	614121.37
23	Federal Government College	FGC	16.00	801725.36	612241.99
24	Ajamimogha	AJA	17.20	803523.10	611447.95
25	Warri GRA	WAG	Not available	803089.34	610613.97
26	Okumagba Layout	OKL	16.20	805132.67	611876.84
27	Okere Road	OKR	15.00	804414.63	610867.87
28	Marine Quarters	MRQ	14.90	806349.18	611574.71
29	Essi Layout	ESL	13.60	806328.36	610275.72
30	Igbudu Market	IGM	14.75	805866.77	611039.40
31	Agbassa	AGS	16.20	805043.38	610226.30
32	Bowen Avenue	BOA	14.00	804792.89	609943.85
33	Iyara	IYA	14.00	805907.77	609616.93
34	Pessu Market	PEM	14.70	805373.32	609158.42
35	Orhunworun	ORH	17.40	814412.45	609039.09
36	Enerhen	ENE	16.25	809072.91	611100.90
37	Udu Road	UDR	17.00	812370.15	604744.47
38	Otokutu	OTO	16.85	814056.74	613752.53
39	Bendel Estate	BDE	18.00	806477.20	613425.55
40	Upper Erejuwah	UPE	16.45	804644.73	611059.84
41	Mammy Market	MAM	14.00	808310.16	617280.79
42	DSC Township	DST	18.00	812824.27	609360.84
43	Okumagba Estate	OKE	15,50	803923.81	612262.10
44	Mofor	MOF	14,90	811465.26	609295.86
45	FUPRE	FUP	Not available	810120.84	615008.04
46	Shoprite	SHP	Not available	808339.43	616442.94
47	Robbinson Plaza	ROP	18.20	805827.10	611528.83
48	Esisi Road	ESR	13.56	803801.62	610690.62
49	Robert Road	ROR	14.00	804203.17	610182.10
50	PTI Road	PTR	15,60	810142.35	616473.42

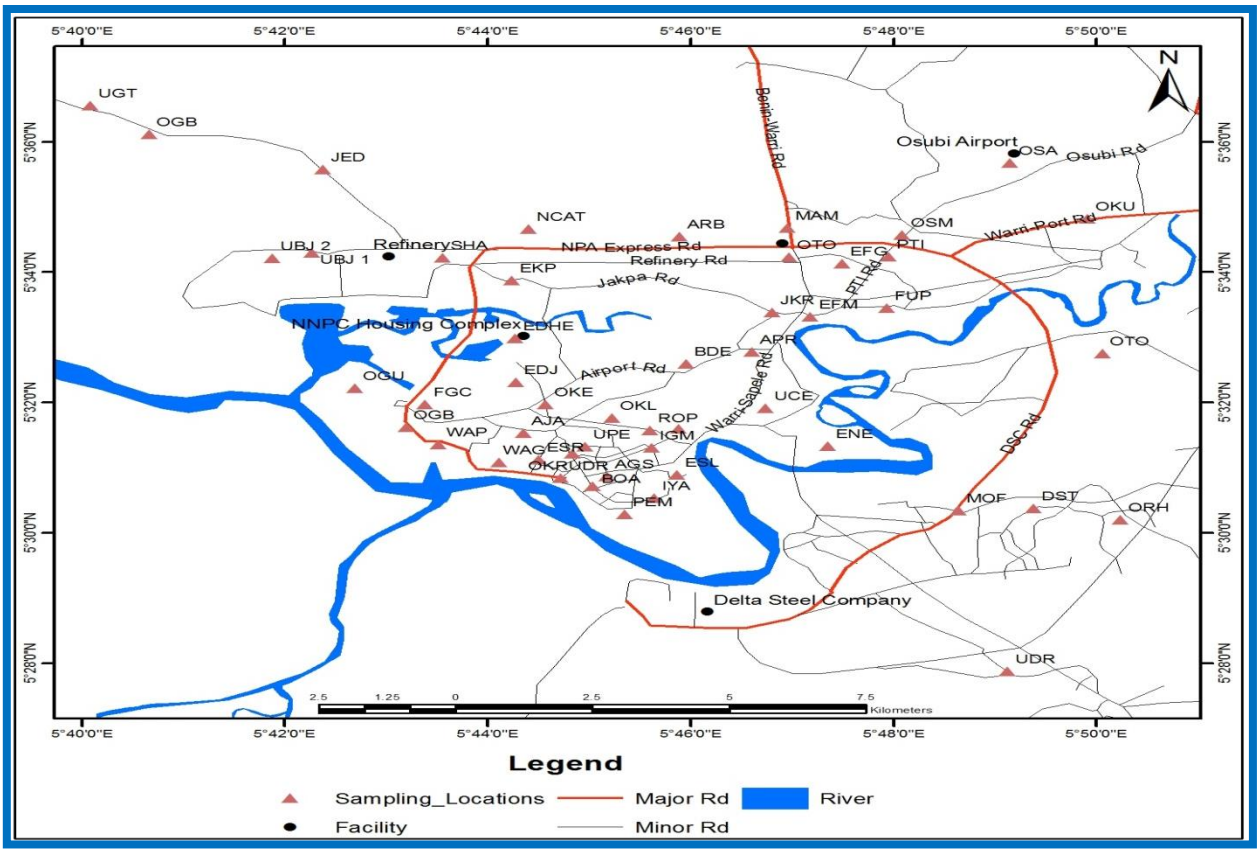


*Figure 4.1.*Digitized map of Warri and its environs (Study Area) showing sampling locations.

4.1.1.2 Temporal characteristics of groundwater quality in warri, delta state

The results of the twenty six (26) physico-chemical and bacteriological water quality parameters: temperature, pH, electrical conductivity (EC), turbidity, total hardness (TH), total suspended solids total dissolved solids (TDS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total coliform bacteria, sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), sulphate (SO_4), nitrate (NO_3), chloride (Cl^-), bicarbonate (HCO_3), ammonium (NH_4), phosphate (PO_4), iron (Fe), cadmium (Cd), chromium (Cr), copper (Cu), and lead (Pb) analyzed for each of the fifty (50) sampling locations in both the dry season and wet season are presented in AppendixII(a-b).Table 4.2. shows the minimum, maximum, mean and standard

deviation values of the concentration of the groundwater quality parameters. The range, mean, and standard deviation values revealed variations in the water samples with respect to their chemical composition.

Table 4.2: *Groundwater quality statistics of domestic boreholes samples analyzed during thedry and wet seasons (where, n = number of samples collected = 50).*

Parameter	Dry season (n = 50)				Wet season (n = 50)			
	Range				Range			
	min	max	Mean	SD	min	max	Mean	SD
Temperature (^oC)	23.21	32.20	27.27	2.40	22.20	32.20	27.47	2.52
pH	4.20	6.70	5.41	0.62	3.40	5.90	4.49	0.54
EC ($\mu S/cm$)	40.00	532.00	162.74	127.37	46.00	678.00	186.68	149.96
Turbidity (NTU)	0.00	37.53	5.69	7.84	0.00	35.77	6.27	7.53
TH (mg/l)	3.72	336.29	51.03	91.94	3.72	336.29	55.53	90.38
TSS (mg/l)	0.00	42.47	6.88	9.18	0.00	46.92	11.17	10.39
T.D.S (mg/l)	22.00	298.00	91.16	71.36	26.00	380.00	104.52	83.96
DO (mg/l)	1.00	7.70	3.22	1.66	1.90	9.60	4.29	2.42
BOD (mg/l)	0.30	1.40	0.07	0.36	0.70	2.50	0.70	0.48
COD (mg/l)	1.10	8.90	4.36	1.89	0.30	9.20	3.92	2.49
Total Coli (CFU's/100ml)	0.00	35.00	11.13	11.58	0.00	36.54	11.58	11.19
Na (mg/l)	1.50	27.30	9.30	6.98	1.50	30.50	10.34	7.62
K (mg/l)	0.10	3.90	1.30	0.91	0.10	4.20	1.74	1.22
Ca (mg/l)	4.00	69.00	18.54	16.15	4.10	90.20	21.42	19.68
Mg (mg/l)	0.10	1.90	0.47	0.38	0.11	2.40	0.59	0.45
SO_4 (mg/l)	0.12	5.92	1.00	1.14	0.14	8.08	1.20	1.51
NO_3 (mg/l)	0.02	3.27	0.83	0.81	0.01	4.12	1.06	1.08
Cl (mg/l)	10.30	117.00	34.89	26.69	12.30	147.10	39.41	30.40
HCO_3 (mg/l)	3.10	79.50	19.62	16.69	3.10	82.30	21.92	19.05
NH_4 (mg/l)	0.00	0.09	0.01	0.02	0.00	0.06	0.02	0.02
PO_4 (mg/l)	0.01	0.79	0.19	0.17	0.04	0.91	0.28	0.24
Fe (mg/l)	0.20	0.24	0.21	0.01	0.19	0.26	0.22	0.01
Cd (mg/l)	0.00	0.01	0.00	0.002	0.00	0.01	0.00	0.002
Cr (mg/l)	0.000	0.002	0.00	0.001	0.000	0.002	0.00	0.001
Cu (mg/l)	0.01	0.19	0.20	0.246	0.01	0.19	0.20	0.246
Pb (mg/l)	0.01	0.36	0.02	0.023	0.01	0.36	0.02	0.023

The graphical representation of the variation of temperature in both seasons is shown in Figure4.1bwhile those for other parameters in both seasons are in Appendix III(b).The Figures show the concentration values of each water quality parameter in both seasons.

Mean values were taken into consideration as characteristic in evaluating the differences during the two (2) different seasons.

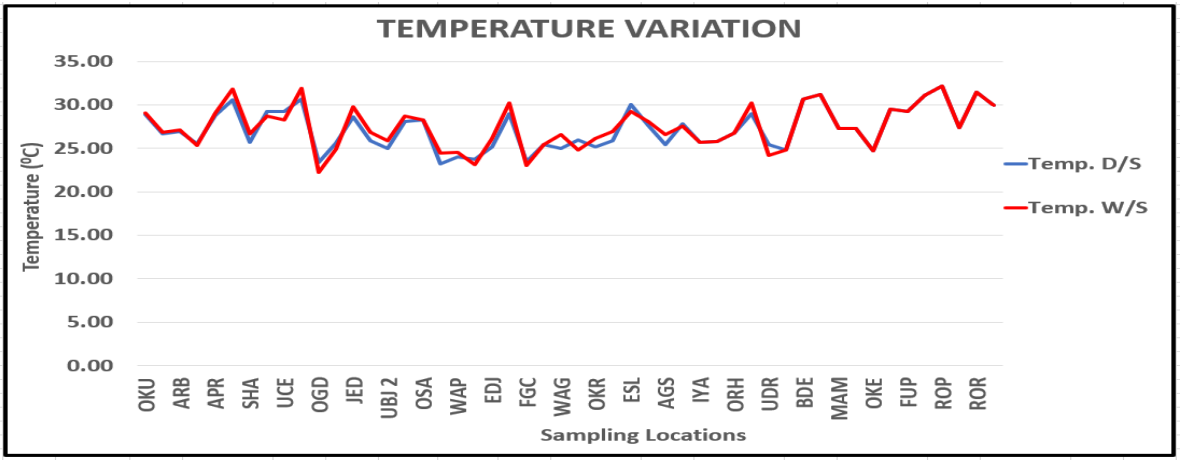


Figure 4.2. Seasonal variation of temperature in dry season (D/S) and wet season (W/S)

Results of the statistical deductions of the seasonal variation of groundwater temperature in the study area during the dry and wet seasons using the paired t-test in the Microsoft excel toolare presented in Table 4.3. Similarly, sample two tailed t-test results for difference in concentration of other groundwater quality parameters between dry and wet seasons are presented in Appendix III(c).

Table 4.3: *Two Tailed Paired T-Test for Temperature.*

Temperature	D	W
Mean	27.2684	27.467
Variance	5.7795	6.33263367
Observations	50	50
Pearson Correlation	0.96008	
Hypothesized Mean Difference	0	
df	49	
t Stat	-1.9947	
P(T<= t) $one-tail$	0.02583	
t Critical one - tail	1.67655	
P(T<= t) $two-tail$	**0.05166**	
t Critical two - tail	2.00958	

The results of the sample t-test for difference in concentration of other groundwater quality parameters in the dry season and wet season are presented in Table 4.4.

Table 4.4: *Sample T-Test for Difference In Concentration Between Dry and Wet Season Groundwater Parameters*

Parameter	Pair	Mean ± Std Error	N	Std. Dev.	d.f	t statistics	t critical	p-value	α	Remark
Temp.	D.S	27.27±0.340	50	2.40	49	-1.9947	2.0096	0.0516	0.05	NS (Accept)
	W.S	27.47 ± 0.356		2.52						
pH	D.S	5.41±0.088	50	0.62	49	9.9540	2.0096	2.3E-13	0.05	Sig. (Reject)
	W.S	4.49 ± 0.077		0.54						
EC	D.S	162.74±18.013	50	127.37	49	-6.3983	2.0096	5.79E-08	0.05	Sig. (Reject)
	W.S	186.68 ± 21.207		149.96						
Turbidity	D.S	5.69±1.108	50	7.84	49	-2.6838	2.0096	0.0099	0.05	Sig. (Reject)
	W.S	6.27 ± 1.065		7.53						
TH	D.S	51.03±13.003	50	91.94	49	-5.934	2.0096	2.96E-07	0.05	Sig. (Reject)
	W.S	55.53 ± 12.781		90.38						
TSS	D.S	6.88±1.280	50	9.18	49	-2.7054	2.0096	0.00936	0.05	Sig. (Reject)
	W.S	11.17 ± 1.469		10.39						
T.D.S	D.S	91.16±10.092	50	71.36	49	-6.3972	2.0096	5.7E-08	0.05	Sig. (Reject)
	W.S	104.52 ± 11.874		83.96						
DO	D.S	3.22±0.234	50	1.66	49	-7.5062	2.0096	1.1E-09	0.05	Sig. (Reject)
	W.S	4.29 ± 0.342		2.42						
BOD	D.S	0.07±0.030	50	0.36	49	-5.2529	2.0096	3.2E-06	0.05	Sig. (Reject)
	W.S	0.70 ± 0.121		0.48						
COD	D.S	4.36±0.267	50	1.89	49	-1.3891	2.0096	0.1711	0.05	NS (Accept)
	W.S	3.92 ± 0.353		2.49						
Total Coli	D.S	11.13 ± 1.637	50	11.58	49	-0.762	2.0096	0.44972	0.05	NS (Accept)
	W.S	11.58±1.582		11.19						
Na	D.S	9.30±0.987	50	6.98	49	-8.644	2.0096	2E-11	0.05	Sig. (Reject)
	W.S	10.34 ± 1.077		7.62						
K	D.S	1.30±0.129	50	0.91	49	-6.813	2.0096	1E-08	0.05	Sig. (Reject)
	W.S	1.74 ± 0.173		1.22						

Ca	D.S	18.54±2.285	50	16.15	49	-5.269	2.0096	3E-06	0.05	Sig. (Reject)
	W.S	21.42 ± 2.783		19.68						
Mg	D.S	0.47±0.054	50	0.38	49	-5.755	2.0096	6E-07	0.05	Sig. (Reject)
	W.S	0.59 ± 0.064		0.45						
SO_4	D.S	1.00±0.161	50	1.14	49	-3.164	2.0096	0.0027	0.05	Sig. (Reject)
	W.S	1.20 ± 0.213		1.51						
NO_3	D.S	0.83±0.114	50	0.81	49	-4.374	2.0096	6E-05	0.05	Sig. (Reject)
	W.S	1.06 ± 0.152		1.08						
Cl	D.S	34.89±3.774	50	26.69	49	-5.781	2.0096	5E-07	0.05	Sig. (Reject)
	W.S	39.41 ± 4.299		30.40						
HCO_3	D.S	19.62±2.360	50	16.69	49	-4.442	2.0096	5E-05	0.05	Sig. (Reject)
	W.S	21.92 ± 2.694		19.05						
NH_4	D.S	0.01±0.002	50	0.02	49	-3.677	2.0096	0.0006	0.05	Sig. (Reject)
	W.S	0.02±0.002		0.02						
PO_4	D.S	0.19±0.024	50	0.17	49	-6.432	2.0096	5E-08	0.05	Sig. (Reject)
	W.S	0.28 ± 0.034		0.24						
Fe	D.S	0.21±0.001	50	0.01	49	-14.79	2.0096	1E-19	0.05	Sig. (Reject)
	W.S	0.22±0.002		0.01						
Cd	D.S	0.00±0.000	50	0.002	49	1.66149	2.0096	0.103	0.05	NS (Reject)
	W.S	0.00±0.003		0.002						
Cr	D.S	0.00±0.000	50	0.001	49	4.3233	2.0096	8E-05	0.05	Sig. (Reject)
	W.S	0.00±0.000		0.001						
Cu	D.S	0.20±0.047	50	0.246	49	3.94952	2.0096	0.00025	0.05	Sig. (Reject)
	W.S	0.20±0.035		0.246						
Pb	D.S	0.02±0.077	50	0.023	49	-9.308	2.0096	2E-12	0.05	Sig. (Reject)
	W.S	0.02±0.088		0.023						

D.S = Dry season. W.S. = Wet season. Sig. = Significant. N.S. = Not significant.

4.1.1.3 Comparison of physico-chemical parameter results with WHO, EU and NSDWQ standard (stringent value)

The obtained results of measured concentrations of each water quality parameter in both dry and wet seasons were compared with the stringent standard values given in Table 4.5. Also, the numbers of boreholes within and above the recommended values are as presented.

Table 4.5: *Water Quality Parameter Values of Sampled Boreholes Within and Above Recommended*

S/N	PHYSICO-CHEMICAL PARAMETERS	STRINGENT VALUE	DRY SEASONS (DS) Number of boreholes		WET SEASONS (WS) Number of boreholes	
			Within limit	Above limit	Within limit	Above limit
1.	Temp.	25	8	42	10	40
2.	pH	6.5 – 8.5	1	49*	50	0*
3.	EC	400	46	4	44	6
4.	Turbidity	5	31	19	29	21
5.	TH	500	50	0	50	0
6.	TSS	-	NG	NG	NG	NG
7.	T.D.S	500	50	0	50	0
8.	DO	6	46	4	36	14
9.	BODs	10	50	0	50	0
10.	COD	10	50	0	50	0
11.	Total Coli	10	27	23	27	23
12.	Na	40	50	0	50	0
13.	K	20	50	0	50	0
14.	Ca	75	50	0	49	1
15.	Mg	0.2	7	43	39	11
16.	SO_4	100	50	0	50	0
17.	NO_3	50	50	0	50	0
18.	Cl	250	50	0	50	0
19.	HCO_3	125	50	0	50	0
20.	NH_4	0.5	50	0	50	0
21.	PO_4	0.3	40	10	36	14
22.	Fe	0.2	50	0	48	2
23.	Cd	0.003	19	31	13	37
24.	Cr	0.05	50	0	50	0
25.	Cu	1	50	0	50	0
26.	Pb	0.01	50	0	50	0

* = Below Specified range

Table 4.6 presents the descriptive statistics of each water quality parameter from each location compared to the WHO standard for both seasons in groundwater of the study area.

Table 4.6: *Comparisonof Water Quality Parameters with WHO Standards*

Parameter (mg/l)	Dry Season		Wet Season		WHO Permissible Standards (WHO, 2011)	Re-mark
	Mean Values	Std. deviation	Mean Values	Std. deviation		
Temp. (^{0}C)	27.27±0.340	2.40	27.47 ± 0.356	0.622	25	AL
pH	5.41±0.088	0.62	4.49 ± 0.077	1.061	6.5 – 8.5	BL
EC (µS/cm)	162.74±18.013	127.37	186.68 ± 21.207	20.506	400	WL
Turbidity(NTU)	5.69±1.108	7.84	6.27 ± 1.065	0.339	5	WL
TH (mg/l)	51.03±13.003	91.94	55.53 ± 12.781	16.327	500	WL
TSS (mg/l)	6.88±1.280	9.18	11.17 ± 1.469	8.726	No guideline	NL
TDS (mg/l)	91.16±10.092	71.36	104.52 ± 11.874	11.314	500	WL
DO (mg/l)	3.22±0.234	1.66	4.29 ± 0.342	1.556	6	AL
BOD_5 (mg/l)	0.07±0.030	0.36	0.70 ± 0.121	1.061	10	WL
COD (mg/l)	4.36±0.267	1.89	3.92 ± 0.353	2.263	10 - 20	WL
Total Coli.(CFU's/100l)	11.13 ± 1.637	11.58	11.58±1.582	17.847	10	AL
Na (mg/l)	9.30±0.987	6.98	10.34 ± 1.077	0.212	40	WL
K (mg/l)	1.30±0.129	0.91	1.74 ± 0.173	0.000	20	WL
Ca (mg/l)	18.54±2.285	16.15	21.42 ± 2.783	3.465	75 - 200	WL
Mg (mg/l)	0.47±0.054	0.38	0.59 ± 0.064	0.014	30	AL
SO_4 (mg/l)	1.00±0.161	1.14	1.20 ± 0.213	0.099	250	WL
NO_3 (mg/l)	0.83±0.114	0.81	1.06 ± 0.152	0.106	50	WL
Cl (mg/l)	34.89±3.774	26.69	39.41 ± 4.299	4.172	5	AL
HCO_3 (mg/l)	19.62±2.360	16.69	21.92 ± 2.694	2.758	125 – 350	WL
NH_4 (mg/l)	0.01±0.002	0.02	0.02±0.002	0.006	< 1.5	WL
PO_4 (mg/l)	0.19±0.024	0.17	0.28 ± 0.034	0.106	0.3	WL
Fe (mg/l)	0.21±0.001	0.01	0.22±0.002	0.01	0.3	WL
Cd (mg/l)	0.0001 ± 0.000	0.002	0.00±0.003	0.002	0.003	WL
Cr (mg/l)	0.00±0.000	0.001	0.00±0.000	0.001	0.05	WL
Cu (mg/l)	0.20±0.047	0.246	0.20±0.035	0.246	2	WL
Pb (mg/l)	0.02±0.077	0.023	0.02±0.088	0.023	0.01	AL

KEY: AL – Above Limit, WL – Within Limit, NL – No Limit, Perm.–Permissible, BL – Below Limit

4.1.1.4 Water quality index (WQI) of Warri

The result of the calculated WQI for sampling location Okuokoko (OKU) is presented in Table 4.7, while the WQIresult for other locations is provided in Appendix IV for dry and wet seasons respectively.

Table 4.7: *Wet Season Water Quality Index (WQI) For Location OKU*

Sample parameter	Weight (W_i)	Measured value (C_i)	Standard value (S_i)	Quality rating q_i) $q_i = \left(\frac{c_i}{s_i}\right) \times 100$	Relative weight (WI) $= \frac{w_i}{\sum w_i}$	Parameter index (SI) $SI = WI \times q_i$
pH	3.7	5.40	7.5	72.00	0.122	8.78
TDS	4.5	27.00	500	5.40	0.148	0.80
Cl	3.5	12.30	250	4.92	0.115	0.57
SO_4	4	0.15	100	0.15	0.132	0.02
HCO_3	5	3.10	100	3.10	0.164	0.51
NO_3	2.3	0.14	50	0.28	0.076	0.02
Ca	2.8	5.30	75	7.07	0.092	0.65
Mg	2.3	0.18	0.2	90.00	0.076	6.84
Na	2.3	3.40	200	1.70	0.076	0.13
$\sum w_i = 30.4$						**$WQI = \sum SI$ = 18.32**

Table 4.8 shows the WQI status of the sampled boreholes in the study area and the number/percentage of boreholes and their rating for both dry and wet seasons.

Table 4.8: *Number/Percentage of Boreholes Within Each WQI Index Range (Status)*

Water quality index range	Type of water quality	No/Percentage of boreholes during dry season within each range	No/Percentage of boreholes during wet season within each range
0 – 25	Excellent	17 (34%)	16 (32%)
26 – 50	Good	22 (44%)	20 (40%)
51 – 75	Poor	5 (10%)	6 (12%)
76 – 100	Very poor	5 (10%)	7 (14%)
> 100	Unsuitable	1 (2%)	1 (2%)
Total		50 (100%)	50 (100%)

The WQI distribution maps in the study area for both dry and wet seasons are presented in Figure 4.2a and Figure 4.2b.

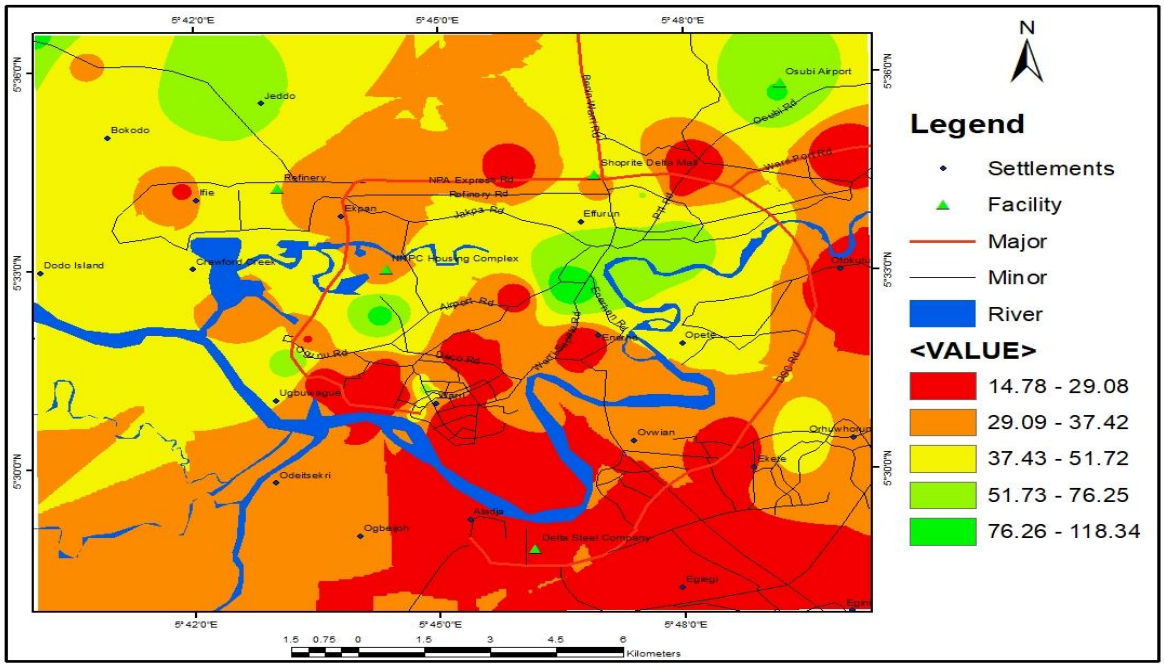


Figure 4.2a. Map showing water quality index distribution in the dry season

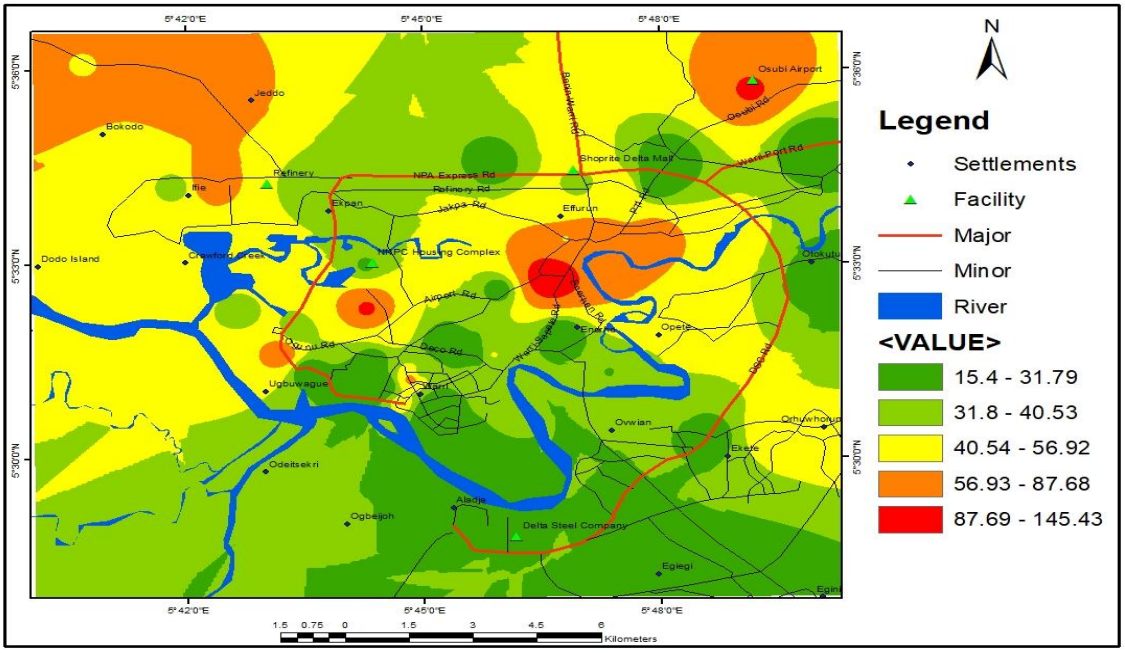


Figure 4.2b. Map showing water quality index distribution in the wet season

4.1.2 Developed regression prediction models

Correlation and regression analysis are useful for interpreting groundwater quality data and relating them to specific hydrogeological processes. These tools are quite useful in characterizing and obtaining firsthand information of the groundwater system than actually going through complex methods and procedures. The degree of linear association between any two of the water quality parameters is measured by the simple correlation coefficient (R). Results showing the interrelationship between some measured insitu water quality parameters of sampled domestic boreholes in the dry and wet seasons as independent variables and laboratory measured concentration of some water quality parameter of sampled boreholes as dependent variables using the data analysis package in Microsoft office excel are presented below.

4.1.2.1 Correlation of some groundwater quality parameters.

The results of the multiple correlation matrix using some laboratory measured water quality parameters(Na^+, K^+,Mg^{2+}, Ca^{2+}, HCO_3^-, SO_4^{2-},Cl^-, Fe^{2+}, Cd^{2+}, Cr^{3+}, Cu^{2+} and Pb^{2+}) interchangeably as dependent variables and pH, EC, TDS and DO as independent variables are presented in Table 4.9(a- o) for both dry and wet seasons.

Table 4.9(a): *Sodium Correlation Matrix*

DS (Dry Season)						WS (Wet Season)					
	pH	*EC*	*TDS*	*DO*	*Na*		*pH*	*EC*	*TDS*	*DO*	*Na*
pH	1					pH	1				
EC	-0.074	1				EC	-0.285	1			
TDS	-0.073	**1**	1			TDS	-0.286	**1**	1		
DO	0.3107	-0.036	-0.037	1		DO	-0.008	-0.06	-0.06	1	
Na	-0.104	**0.8876**	**0.888**	-0.026	1	Na	-0.331	**0.8801**	**0.8805**	-0.056	1

Table 4.9(b): *Potassium Correlation Matrix*

DS (Dry Season)						WS (Wet Season)					
	pH	*EC*	*TDS*	*DO*	*K*		*pH*	*EC*	*TDS*	*DO*	*K*
pH	1					pH	1				
EC	-0.074	1				EC	-0.285	1			
TDS	-0.073	**1**	1			TDS	-0.286	**1**	1		
DO	0.3107	-0.036	-0.037	1		DO	-0.008	-0.06	-0.06	1	
K	-0.194	**0.7218**	**0.7228**	-0.105	1	K	-0.295	**0.7462**	**0.746**	-0.096	1

Table 4.9(c): *Calcium Correlation Matrix*

DS (Dry Season)						WS (Wet Season)					
	pH	*EC*	*TDS*	*DO*	*Ca*		*pH*	*EC*	*TDS*	*DO*	*Ca*
pH	1					pH	1				
EC	-0.074	1				EC	-0.285	1			
TDS	-0.073	**1**	1			TDS	-0.286	**1**	1		
DO	0.3107	-0.036	-0.037	1		DO	-0.008	-0.06	-0.06	1	
Ca	-0.044	**0.9823**	**0.9821**	-0.033	1	Ca	-0.262	**0.9815**	**0.9815**	-0.063	1

Table 4.9(d).: *Magnesium Correlation Matrix*

DS (Dry Season)						WS (Wet Season)					
	pH	*EC*	*TDS*	*DO*	*Mg*		*pH*	*EC*	*TDS*	*DO*	*Mg*
pH	1					pH	1				
EC	-0.074	1				EC	-0.263	1			
TDS	-0.073	**1**	1			TDS	-0.264	**1**	1		
DO	0.3107	-0.036	-0.037	1		DO	-0.041	-0.043	-0.043	1	
Mg	-0.026	**0.8574**	**0.8574**	0.2062	1	Mg	-0.11	**0.9062**	**0.9064**	0.1086	1

Table 4.9(e): *Sulphate Correlation Matrix*

DS (Dry Season)						WS (Wet Season)					
	pH	*EC*	*TDS*	*DO*	*SO_4*		*pH*	*EC*	*TDS*	*DO*	*SO_4*
pH	1					pH	1				
EC	-0.074	1				EC	-0.263	1			
TDS	-0.073	**1**	1			TDS	-0.264	**1**	1		
DO	0.3107	-0.036	-0.037	1		DO	-0.041	-0.043	-0.043	1	
SO_4	-0.053	**0.9356**	**0.9359**	0.0099	1	SO_4	-0.149	**0.9456**	**0.9458**	0.0093	1

Table 4.9(f): *Nitrate Correlation Matrix*

DS (Dry Season)						WS (Wet Season)					
	pH	*EC*	*TDS*	*DO*	*NO_3*		*pH*	*EC*	*TDS*	*DO*	*NO_3*
pH	1					pH	1				
EC	-0.074	1				EC	-0.263	1			
TDS	-0.073	**1**	1			TDS	-0.264	**1**	1		
DO	0.3107	-0.036	-0.037	1		DO	-0.041	-0.043	-0.043	1	
NO_3	-0.141	**0.8985**	**0.8993**	-0.091	1	NO_3	-0.278	**0.9292**	**0.929**	-0.1	1

Table 4.9(g): *Chloride Correlation Matrix*

DS (Dry Season)						WS (Wet Season)					
	pH	*EC*	*TDS*	*DO*	*Cl*		*pH*	*EC*	*TDS*	*DO*	*Cl*
pH	1					pH	1				
EC	-0.074	1				EC	-0.263	1			
TDS	-0.073	**1**	1			TDS	-0.264	**1**	1		
DO	0.3107	-0.036	-0.037	1		DO	-0.041	-0.043	-0.043	1	
Cl	-0.073	**0.9906**	**0.9906**	-0.021	1	Cl	-0.238	**0.9922**	**0.9922**	-0.024	1

Table 4.9(h): *Phosphate Correlation Matrix*

DS (Dry Season)						WS (Wet Season)					
	pH	*EC*	*TDS*	*DO*	*PO_4*		*pH*	*EC*	*TDS*	*DO*	*PO_4*
pH	1					pH	1				
EC	-0.074	1				EC	-0.263	1			
TDS	-0.073	**1**	1			TDS	-0.264	**1**	1		
DO	0.3107	-0.036	-0.037	1		DO	-0.041	-0.043	-0.043	1	
PO_4	0.0514	**0.8072**	**0.8075**	0.0627	1	PO_4	-0.235	**0.8753**	**0.8749**	-0.032	1

Table 4.91(i): *Bicarbonate Correlation Matrix*

DS (Dry Season)						WS (Wet Season)					
	pH	*EC*	*TDS*	*DO*	*HCO_3*		*pH*	*EC*	*TDS*	*DO*	*HCO_3*
pH	1					pH	1				
EC	-0.074	1				EC	-0.263	1			
TDS	-0.073	**1**	1			TDS	-0.264	**1**	1		
DO	0.3107	-0.036	-0.037	1		DO	-0.041	-0.043	-0.043	1	
HCO_3	-0.073	**0.9622**	**0.9622**	-0.068	1	HCO_3	-0.284	**0.9722**	**0.9721**	-0.066	1

Table 4.9(j): *AmmoniumCorrelation Matrix*

DS (Dry Season)						WS (Wet Season)					
	pH	*EC*	*TDS*	*DO*	*NH_4*		*pH*	*EC*	*TDS*	*DO*	*NH_4*
pH	1					pH	1				
EC	-0.074	1				EC	-0.263	1			
TDS	-0.073	**1**	1			TDS	-0.264	**1**	1		
DO	0.3107	-0.036	-0.037	1		DO	-0.041	-0.043	-0.043	1	
NH_4	-0.035	**0.3534**	**0.353**	-0.031	1	NH_4	-0.075	**0.573**	**0.574**	-0.175	1

Table4.9(k): *Iron Correlation Matrix*

DS (Dry Season)						WS (Wet Season)					
	pH	*EC*	*TDS*	*DO*	*Fe*		*pH*	*EC*	*TDS*	*DO*	*Fe*
pH	1					pH	1				
EC	-0.074	1				EC	-0.074	1			
TDS	-0.073	**1**	1			TDS	-0.073	**1**	1		
DO	0.3107	-0.036	-0.037	1		DO	0.3107	-0.036	-0.037	1	
Fe	0.05	**0.9541**	**0.9542**	0.0128	1	Fe	0.0595	**0.7248**	**0.7276**	-0.017	1

Table4.9(l): Cadmium correlation matrix

DS (Dry Season)						WS (Wet Season)					
	pH	*EC*	*TDS*	*DO*	*Cd*		*pH*	*EC*	*TDS*	*DO*	*Cd*
pH	1					pH	1				
EC	-0.074	1				EC	-0.074	1			
TDS	-0.073	**1**	1			TDS	-0.073	**1**	1		
DO	0.3107	-0.036	-0.037	1		DO	0.3107	-0.036	-0.037	1	
Cd	**-0.914**	0.0617	0.0608	-0.294	1	Cd	**-0.914**	0.0617	0.0608	-0.294	1

Table4.9(m): *Chromium Correlation Matrix*

DS (Dry Season)						WS (Wet Season)					
	pH	*EC*	*TDS*	*DO*	*Cr*		*pH*	*EC*	*TDS*	*DO*	*Cr*
pH	1					pH	1				
EC	-0.074	1				EC	-0.074	1			
TDS	-0.073	**1**	1			TDS	-0.073	**1**	1		
DO	0.3107	-0.036	-0.037	1		DO	0.3107	-0.036	-0.037	1	
Cr	**-0.928**	0.171	0.1692	-0.306	1	Cr	**-0.928**	0.171	0.1692	-0.306	1

Table4.9(n): *Copper Correlation Matrix*

DS (Dry Season)						WS (Wet Season)					
	pH	*EC*	*TDS*	*DO*	*Cu*		*pH*	*EC*	*TDS*	*DO*	*Cu*
pH	1					pH	1				
EC	-0.074	1				EC	-0.074	1			
TDS	-0.073	**1**	1			TDS	-0.073	**1**	1		
DO	0.3107	-0.036	-0.037	1		DO	0.3107	-0.036	-0.037	1	
Cu	**-0.852**	0.1803	0.1796	-0.291	1	Cu	**-0.852**	0.1803	0.1796	-0.291	1

Table4.9(o): *Lead Correlation Matrix*

DS (Dry Season)						WS (Wet Season)					
	pH	*EC*	*TDS*	*DO*	*Pb*		*pH*	*EC*	*TDS*	*DO*	*Pb*
pH	1					pH	1				
EC	-0.074	1				EC	-0.074	1			
TDS	-0.073	**1**	1			TDS	-0.073	**1**	1		
DO	0.3107	-0.036	-0.037	1		DO	0.3107	-0.036	-0.037	1	
Pb	**-0.848**	0.1234	0.1226	-0.283	1	Pb	**-0.848**	0.1234	0.1226	-0.283	1

The results of the statistical analysis gave an indication of the interrelationship amongst various parameters. From Tables 4.9(a – k), EC and TDS are the only strong predictors for the tested parameters (cations and anions) in the dry and wet seasons while pH correlates with the heavy metals (Cadmium, Chromium, Copper and Lead) and are presented in Tables 4.9(l – o). The correlation coefficient (R) values of the predictors show strong correlation values of

0.7000 to 0.9922 in all the cations, anions and heavy metals except for ammonium which is in the range of 0.353 and 0.573.The correlation values are higher in the wet season.

4.1.2.2 Regression Models

The results of Regression models (Linear, Exponential, Polynomial and Logarithm) and the coefficient of determination (R^2) values for sodium (Na) are presented in Figure 4.3a to Figure 4.3d and Figure 4.4a to Figure 4.4d) for dry and wet seasons respectively.

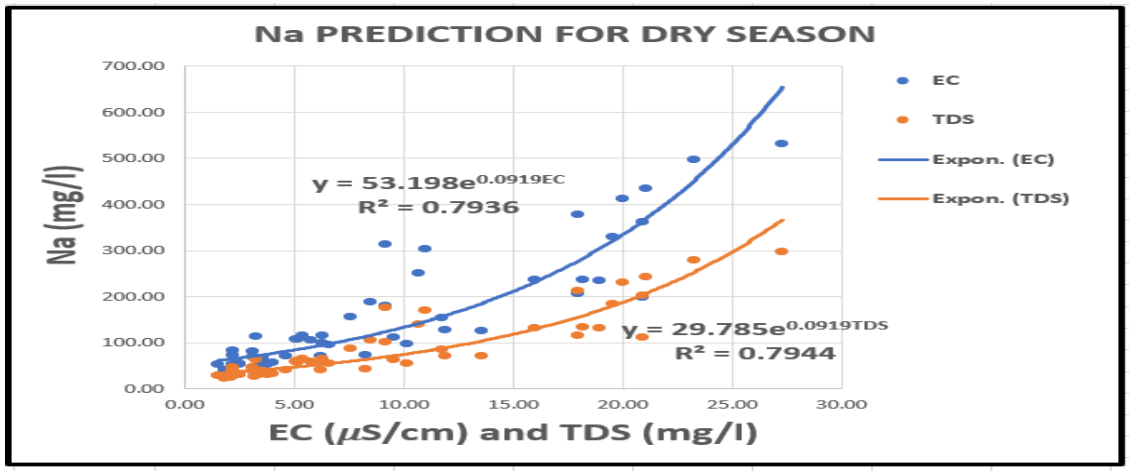


Figure 4.3(a). Exponential regression model for sodium prediction in the dry season

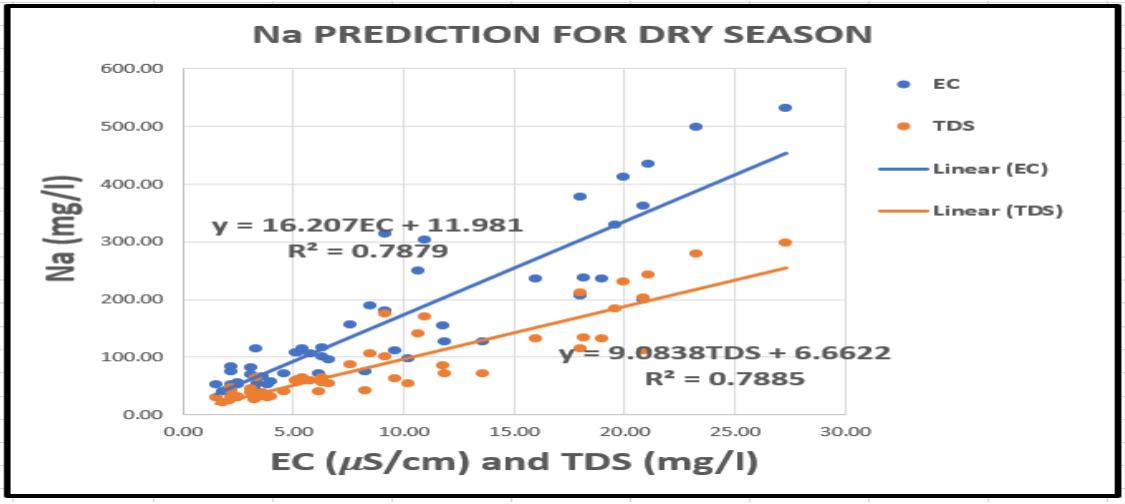


Figure 4.3(b). Linear regression model for sodium prediction in the dry season

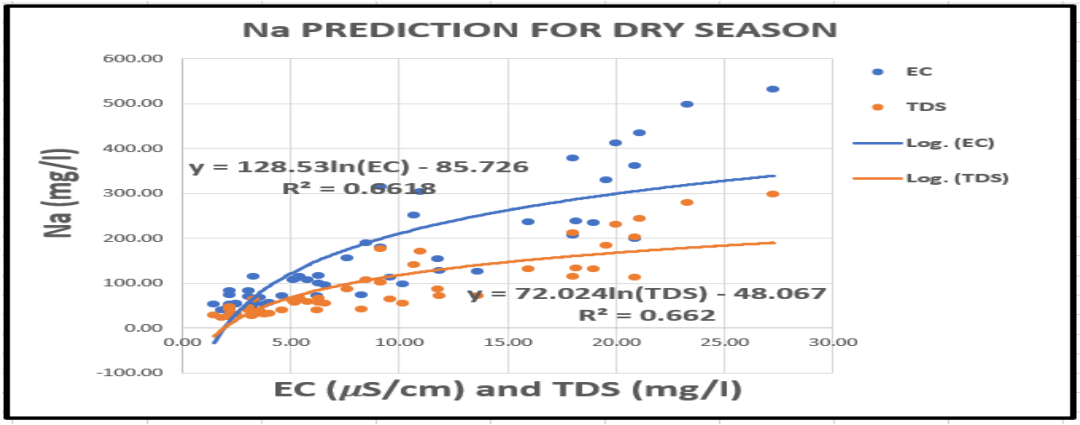


Figure 4.3(c). Logarithm regression model for sodium prediction in the dry season

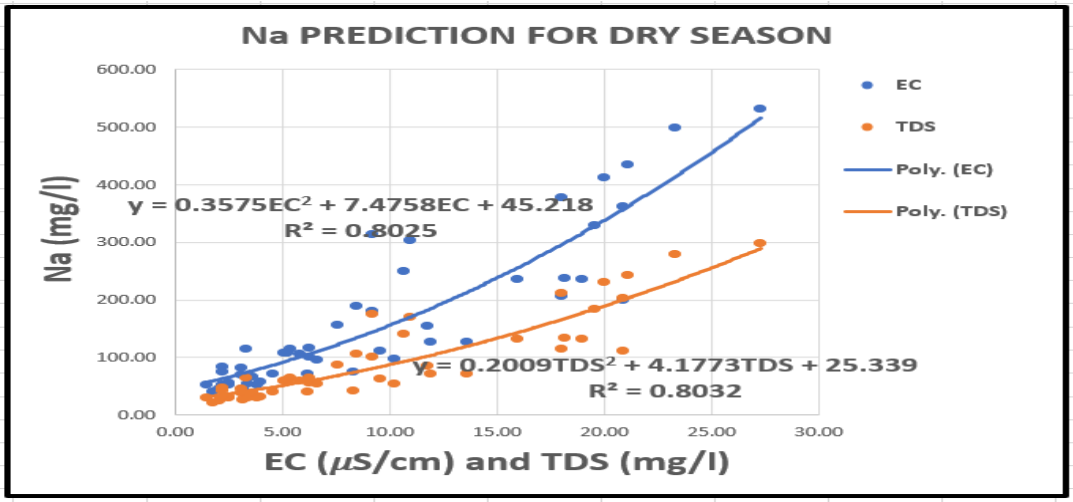


Figure 4.3(d). Polynomial regression model for sodium prediction in the dry season

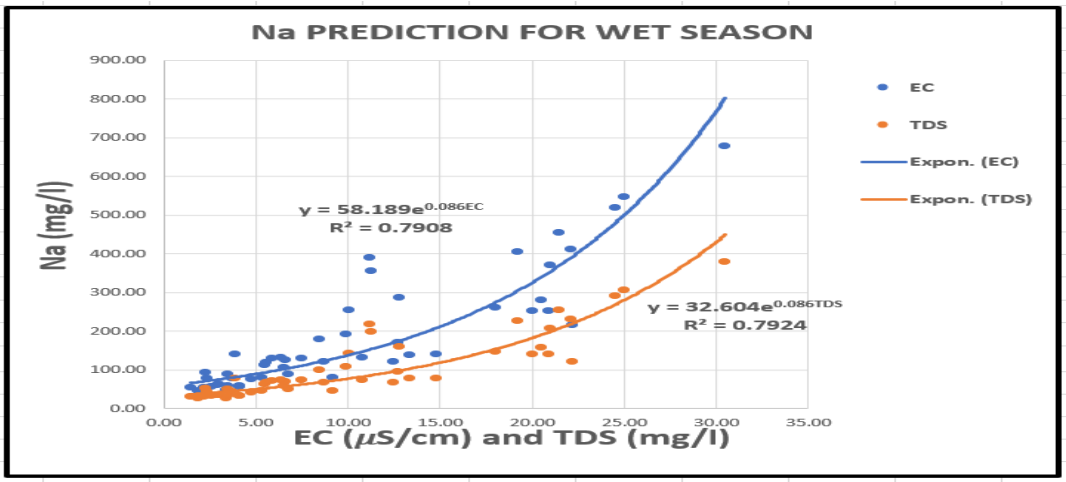


Figure 4.4(a). Exponential regression model for sodium prediction in the wet season

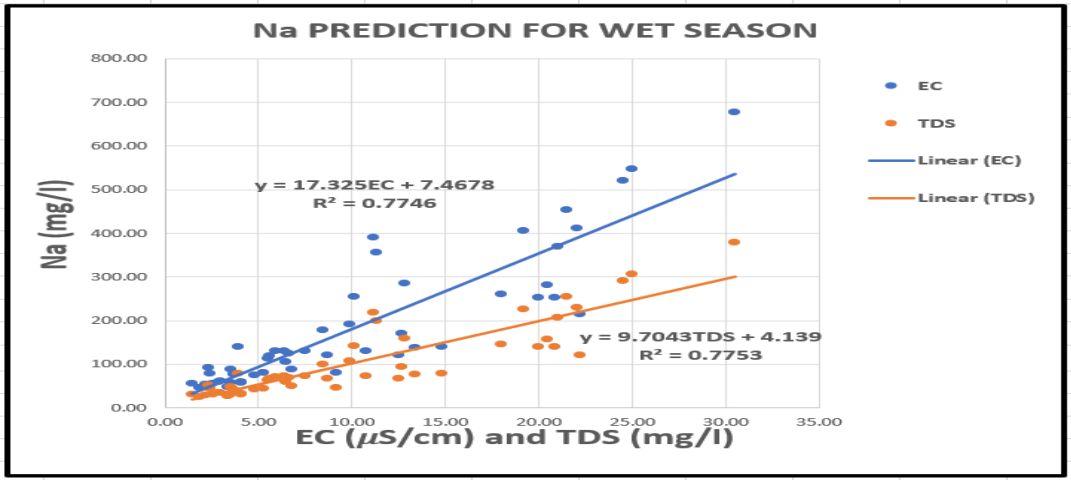


Figure 4.4(b). Linear regression model for sodium prediction in the wet season

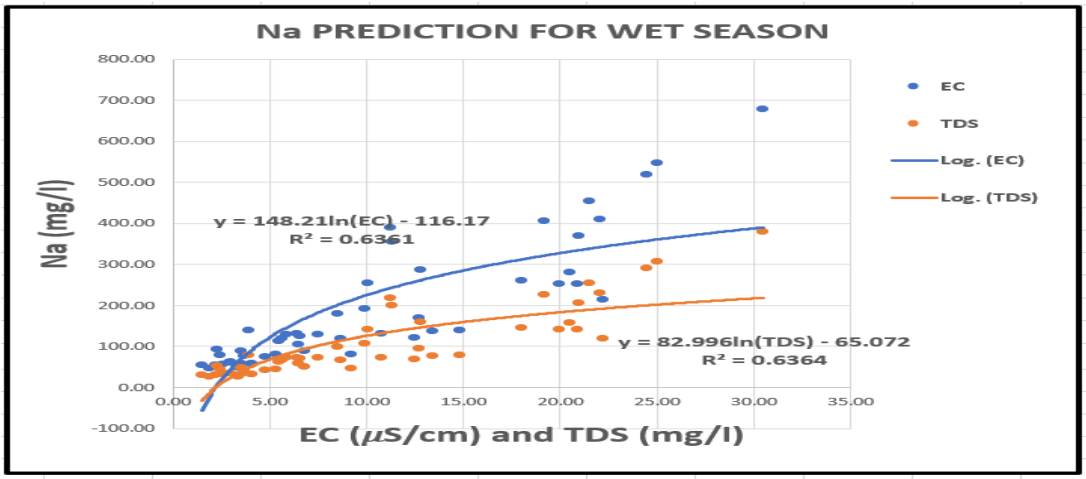


Figure 4.4(c). Logarithm regression model for sodium prediction in the wet season

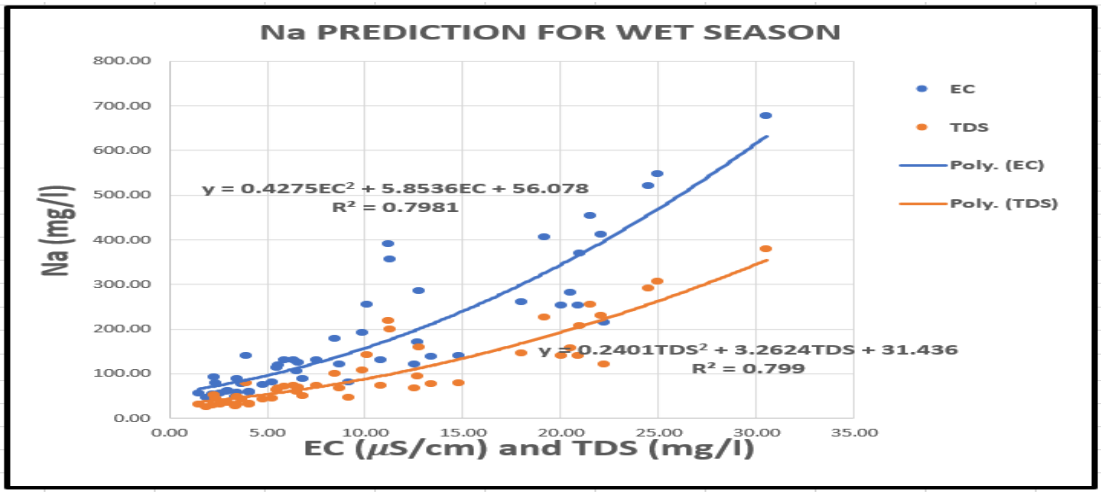


Figure 4.4(d). Polynomial regression model for sodium prediction in the wet season

Results of the regression models and R^2 values for some pairs of parameters which had significant value of correlation in the dry season and wet season are presented in Table 4.10and Table 4.11. Table 4.12contains the standard errors from each of the regression models. The best fitted regression models based on R^2 and standard error values are presented in Table 4.13 and Table 4.14 for the dry and wet seasons respectively.The use of prediction equations gives a rough estimate of the response (dependent) variable, saves time, money and resources.

Table 4.10: *Regression Models and R^2Values for Some Pairs of Parameters with Significant Valuesof Correlation (Dry Season)*

S/N	Para-meters	Regression model types							
		Exponential		Linear		Logarithmic		Polynomial	
		Equation	R^2	Equation	R^2	Equation	R^2	Equation	R^2
1.	Na	$y = 53.198e^{0.0919EC}$	0.7936	y = 16.207EC + 11.981	0.7879	y = 128.53ln(EC) - 85.726	0.6618	$y = 0.3575EC^2$ + 7.4758EC + 45.218	0.8025
		$y = 29.785e^{0.0919TDS}$	0.7944	y = 9.0838TDS + 6.6622	0.7885	y = 72.024ln(TDS) - 48.067	0.662	$y = 0.2009TDS^2$ + 4.1773TDS + 25.339	0.8032
2.	K	$y = 54.683e^{0.6343EC}$	0.6500	y = 100.53EC + 31.652	0.5210	y = 97.509ln(EC) + 166.8	0.4416	$y = -0.9681EC^2$ + 103.61EC + 30.072	0.521
		$y = 30.574e^{0.6358TDS}$	0.6529	y = 56.399TDS + 17.616	0.5224	y = 54.705ln(TDS) + 93.435	0.4428	$y = -0.6043TDS^2$ + 58.322TDS + 16.63	0.5224
3.	Ca	$y = 59.398e^{0.0402EC}$	0.8132	y = 7.7443EC + 19.192	0.9648	y = 159.44ln(EC) - 254.91	0.8875	$y = -0.0246EC^2$ + 9.2635EC + 5.7778	0.9674
		$y = 33.276e^{0.0402TDS}$	0.8128	y = 4.3382TDS + 10.748	0.9645	y = 89.292ln(TDS) - 142.74	0.8867	$y = -0.0137TDS^2$ + 5.183TDS + 3.2882	0.9670
4.	Mg	$y = 60.756e^{1.5294EC}$	0.6492	y = 288.08EC + 26.765	0.7351	y = 129.39ln(EC) + 297.13	0.6208	$y = -11.236EC^2$ + 305.25EC + 22.746	0.7354
		$y = 34.042e^{1.5288TDS}$	0.6486	y = 161.41TDS + 14.977	0.7351	y = 72.444ln(TDS) + 166.41	0.62	$y = -6.1307TDS^2$ + 170.77TDS + 12.784	0.7354
5.	SO_4	$y = 73.329e^{0.5362EC}$	0.7179	y = 104.8EC + 58.399	0.8754	y = 109.94ln(EC) + 221.07	0.8028	$y = -13.074EC^2$ + 163.52EC + 29.47	0.9235
		$y = 41.067e^{0.5363TDS}$	0.7183	y = 58.733TDS + 32.685	0.8758	y = 61.601ln(TDS) + 123.85	0.8029	$y = -7.3339TDS^2$ + 91.667TDS + 16.458	0.924

6.	NO_3	$y = 66.642e^{0.7561EC}$	0.7223	$y = 141.5EC + 44.954$	0.8073	$y = 75.709\ln(EC) + 218.41$	0.5186	$y = -8.8685EC^2 + 166.08EC + 36.328$	0.810
		$y = 37.295e^{0.7572TDS}$	0.7244	$y = 79.349TDS + 25.109$	0.8087	$y = 42.47\ln(TDS) + 122.39$	0.5199	$y = -5.0541TDS^2 + 93.353TDS + 20.194$	0.8115
7.	Cl	$y = 51.923e^{0.0252EC}$	0.8729	$y = 4.7282EC - 2.2353$	0.9814	$y = 178.24\ln(EC) - 427.38$	0.9072	$y = -0.0059EC^2 + 5.3608EC - 12.944$	0.9826
		$y = 29.085e^{0.0252TDS}$	0.8728	$y = 2.649TDS - 1.2682$	0.9813	$y = 99.847\ln(TDS) - 239.41$	0.9069	$y = -0.0033TDS^2 + 3.0011TDS - 7.2277$	0.9825
8.	PO_4	$y = 67.582e^{3.2945EC}$	0.5932	$y = 611.18EC + 48.571$	0.6516	$y = 95.207\ln(EC) + 359.88$	0.5187	$y = -407.07EC^2 + 868.6EC + 25.804$	0.6654
		$y = 37.838e^{3.2969TDS}$	0.5941	$y = 342.57TDS + 27.168$	0.6521	$y = 53.372\ln(TDS) + 201.68$	0.5192	$y = -229.78TDS^2 + 487.87TDS + 14.318$	0.6662
9.	HCO_3	$y = 57.243e^{0.0398EC}$	0.8535	$y = 7.3442EC + 18.676$	0.9258	$y = 137.86\ln(EC) - 201.85$	0.8099	$y = -0.0295EC^2 + 9.2103EC + 1.478$	0.9333
		$y = 32.061e^{0.0398TDS}$	0.8537	$y = 4.115TDS + 10.441$	0.9259	$y = 77.236\ln(TDS) - 113.09$	0.8097	$y = -0.0165TDS^2 + 5.1599TDS + 0.8105$	0.9333
10.	Fe	$y = 0.195e^{0.0003EC}$	0.9154	$y = 7E\text{-}05EC + 0.1945$	0.9103	$y = 0.0108\ln(EC) + 0.1533$	0.7368	$y = 8E\text{-}08EC^2 + 3E\text{-}05EC + 0.1975$	0.9313
		$y = 0.195e^{0.0006TDS}$	0.9156	$y = 0.0001TDS + 0.1945$	0.9104	$y = 0.0108\ln(TDS) + 0.1596$	0.737	$y = 3E\text{-}07TDS^2 + 5E\text{-}05TDS + 0.1975$	0.9314
11.	Cd	NIL	NIL	$y = -0.0032pH + 0.0201$	0.835	$y = -0.018\ln(pH) + 0.032$	0.8536	$y = 0.0012pH^2 - 0.0164pH + 0.0553$	0.8801
12.	Cr	NIL	NIL	$y = -0.0024pH + 0.0146$	0.8612	$y = -0.013\ln(pH) + 0.0232$	0.8753	$y = 0.0007pH^2 - 0.0097pH + 0.0341$	0.8882
13.	Cu	NIL	NIL	$y = -0.3393pH + 2.0357$	0.7268	$y = -1.865\ln(pH) + 3.3363$	0.7678	$y = 0.2799pH^2 - 3.3637pH + 10.101$	0.9144
14.	Pb	NIL	NIL	$y = -0.031pH + 0.1859$	0.7186	$y = -0.169\ln(pH) + 0.3029$	0.7492	$y = 0.0205pH^2 - 0.2528pH + 0.7773$	0.8379

Table 4.11: *Regression Models and R^2Values for Some Pairs of Parameters with Significant Valuesof Correlation (Wet Season)*

S/N	Para-meters	Regression model types							
		Exponential		Linear		Logarithmic		Polynomial	
		Equation	R^2	Equation	R^2	Equation	R^2	Equation	R^2
1.	Na	$y = 3.4623e^{0.0077EC}$	0.6364	y = 0.0447EC + 1.9978	0.7746	y = 9.1908ln(EC) – 35.185	0.7908	$y = -4E\text{-}05EC^2$ + 0.0694EC – 0.2058	0.7953
		$y = 3.4629e^{0.0043TDS}$	0.6361	y = 0.0799TDS + 1.9941	0.7753	y = 9.2125ln(TDS) – 29.953	0.792	$y = -0.0001TDS^2$ + 0.1243TDS – 0.2233	0.7962
2.	K	$y = 58.96e^{0.5028EC}$	0.6946	y = 91.585EC + 26.956	0.5568	y = 113.14ln(EC) + 159.14	0.4392	$y = 21.009EC^2$ + 6.087EC + 81.433	0.5855
		$y = 33.035e^{0.5026TDS}$	0.6961	y = 51.266TDS + 15.112	0.5566	y = 63.334ln(TDS) + 89.105	0.4391	$y = 11.731TDS^2$ + 3.5243TDS + 45.532	0.5851
3.	Ca	$y = 69.407e^{0.0333EC}$	0.7913	y = 7.4796EC + 26.451	0.9634	y = 179.58ln(EC) - 305.05	0.8789	$y = -0.0171EC^2$ + 8.7752EC + 13.071	0.966
		$y = 38.904e^{0.0333TDS}$	0.792	y = 4.1873TDS + 14.819	0.9632	y = 100.49ln(TDS) - 170.64	0.8779	$y = -0.0094TDS^2$ + 4.898TDS + 7.4796	0.9657
4.	Mg	$y = 61.277e^{1.4229EC}$	0.7572	y = 301.99EC + 8.7462	0.8241	y = 155.62ln(EC) + 312.77	0.6613	$y = -3.5679EC^2$ + 308.67EC + 6.7609	0.8242
		$y = 34.341e^{1.422TDS}$	0.7584	y = 169.13TDS + 4.8681	0.8246	y = 87.12ln(TDS) + 175.11	0.6612	$y = -1.8314TDS^2$ + 172.56TDS + 3.849	0.8247
5.	SO_4	$y = 87.048e^{0.405EC}$	0.6877	y = 93.976EC + 73.608	0.8945	y = 124.87ln(EC) + 237.54	0.8255	$y = -8.4154EC^2$ + 145.8EC + 42.223	0.944
		$y = 48.773e^{0.4048TDS}$	0.6887	y = 52.627TDS + 41.2	0.8949	y = 69.896ln(TDS) + 132.99	0.8251	$y = -4.696TDS^2$ + 81.545TDS + 23.686	0.9441
6.	NO_3	$y = 75.724e^{0.5896EC}$	0.7421	y = 129.55EC + 48.998	0.8654	y = 79.574ln(EC) + 231.3	0.4988	$y = 4.4715EC^2$ + 113.39EC + 56.041	0.8667
		$y = 42.444e^{0.589TDS}$	0.7425	y = 72.515TDS + 27.451	0.8651	y = 44.53ln(TDS) + 129.49	0.4983	$y = 2.5425TDS^2$ + 63.327TDS + 31.455#	0.8664

7.	Cl	$y = 58.213e^{0.0226EC}$	0.8669	y = 4.8953EC - 6.2249	0.9847	y = 205.59ln(EC) - 518.16	0.8925	$y = -0.0038EC^2 + 5.3673EC - 15.479$	0.9855
		$y = 32.633e^{0.0226TDS}$	0.8677	y = 2.7407TDS - 3.4816	0.9846	y = 115.07ln(TDS) - 289.97	0.8919	$y = -0.0021TDS^2 + 2.9969TDS - 8.5046$	0.9854
8.	PO_4	$y = 69.886e^{2.5264EC}$	0.6965	y = 540.54EC + 35.437	0.7703	y = 144.13ln(EC) + 420.79	0.6613	$y = 116.01EC^2 + 442.03EC + 47.178$	0.7721
		$y = 39.181e^{2.5232TDS}$	0.6966	y = 302.48TDS + 19.887	0.7695	y = 80.643ln(TDS) + 235.5	0.6604	$y = 65.799TDS^2 + 246.6TDS + 26.546$	0.7713
9.	HCO_3	$y = 64.275e^{0.0361EC}$	0.8687	y = 7.6563EC + 18.824	0.9461	y = 156.27ln(EC) - 240.38	0.8064	$y = -0.0057EC^2 + 8.0494EC + 14.981$	0.9463
		$y = 36.027e^{0.036TDS}$	0.8696	y = 4.2864TDS + 10.545	0.946	y = 87.466ln(TDS) - 134.5	0.8058	$y = -0.0031TDS^2 + 4.4979TDS + 8.4774$	0.9462
10.	Fe	$y = 0.212e^{0.0003EC}$	0.4794	y = 7E-05EC + 0.2116	0.5254	y = 0.0109ln(EC) + 0.1711	0.3572	$y = 9E-07EC^2 + 0.5598EC + 0.0179$	0.9999
		$y = 29.297e^{0.0054TDS}$	0.899	y = 0.5603TDS - 0.0167	0.9999	y = 94.025ln(TDS) - 362.86	0.8988	$y = 2E-07TDS^2 - 3E-05TDS + 0.2192$	0.5915
11.	Cd	Nil	Nil	y = -0.0032pH + 0.0201	0.835	y = -0.018ln(pH) + 0.032	0.8536	$y = 0.0012pH^2 - 0.0164pH + 0.0553$	0.8801
12.	Cr	Nil	Nil	y = -0.0024pH + 0.0146	0.8612	y = -0.013ln(pH) + 0.0232	0.8753	$y = 0.0007pH^2 - 0.0097pH + 0.0341$	0.8882
13.	Cu	Nil	Nil	y = -0.3393pH + 2.0357	0.7268	y = -1.865ln(pH) + 3.3363	0.7678	$y = 0.2799pH^2 - 3.3637pH + 10.101$	0.9144
14.	Pb	Nil	Nil	y = -0.031pH + 0.1859	0.7186	y = -0.169ln(pH) + 0.3029	0.7492	$y = 0.0205pH^2 - 0.2528pH + 0.7773$	0.8379

Table 4.12: *Standard Errors of Regression Models*

S/N	Para-meter	Dry season				Wet season			
		Expo-nential	Linear	Logarith-mic	Polyno-mial	Expo-nential	Linear	Logarith-mic	Poly-nomial
1.	Na	81.52264856	0	26.5432308	22.14836876	0.055266283	0	1.49012E-08	8.338995997
		3.72042E+70	7.62939E-06	16.4552605	488.2020996	0.004194416	1.49012E-08	0.243400047	0.010743713
2.	K	2229798250	0	20.13696329	59.97716307	4.03044E+21	0	3.565512613	6500.272521
		1.88252E+45	NIL	12.49840367	1468.494419	1.12895E+36	4.31584E-05	14.46986378	28507.2117
3.	Ca	6.345017211	NIL	32.92657526	1.524055585	134.8388498	NIL	5.659313726	5.290811562
		5905.819935	3.8147E-06	20.40046541	33.29202969	2014.049105	3.8147E-06	22.95886271	22.8427065
4.	Mg	4.85885E+20	NIL	26.72083275	696.1092906	6.08676E+58	NIL	4.904234336	1103.923191
		2.3626E+107	0.000172633	16.55121754	14898.06178	9.0359E+99	NIL	2.301765217	4450.439648
5.	SO_4	168453289.9	2.15792E-05	22.70413751	809.9797851	6.67273E+17	NIL	3.935173767	2603.759978
		3.08256E+38	0	14.07392678	17821.92822	3.96815E+11	NIL	1.846696299	504.5247464
6.	NO_3	94945260603	NIL	15.6349604	549.434429	1.65899E+25	NIL	2.507708155	1383.500813
		6.26286E+53	0	9.703083882	12281.84287	1.8731E+16	0	1.176510619	1311.284954
7.	Cl	1.632016845	1.3487E-06	36.80903647	0.365525526	23.66915166	NIL	6.478997155	1.175735903
		326.8063847	NIL	22.81195706	8.019248028	2.556379521	4.76837E-07	3.040221803	0.225617966
8.	PO_4	9.06258E+42	0.00012207	19.66156831	25219.40272	2.5773E+103	NIL	4.542136582	35893.97949
		NIL	0.000488281	12.19385432	558382.6703	0	6.10352E-05	2.130638801	7069.255492
9.	HCO_3	5.947109943	NIL	28.47000543	1.827627632	180.6468002	NIL	4.924718543	1.763603854
		5304.295813	5.3948E-06	17.6460416	40.09624014	13.43725396	6.7435E-07	2.310906754	0.333055092
10.	Fe	5.46609E-07	NIL	0.00223035	4.95628E-06	3.01586E-06	5.77451E+40	0.000343504	1.68587E-07
		9.02301E-05	8.23181E-11	0.002467467	0.000729023	0.058882749	5.77451E+40	2.484199661	1.65124E-73
11.	Cd	NIL	NIL	0.000119599	0.001101894	NIL	NIL	0.000119599	0.001101894
12.	Cr	NIL	4.1159E-11	8.63769E-05	0.307518769	NIL	4.1159E-11	8.63769E-05	0.000642772
13.	Cu	NIL	7.45058E-09	0.012391765	0.191970924	NIL	7.45058E-09	0.012391765	4.21468E-08
14.	Pb	NIL	0	0.055177755	0.018824023	NIL	0	0.0011229	0.018824023

The polynomial regression model fits both linear and nonlinear relationships between independent and dependent variables and it provided the best approximation of the relationship between these variables and had higherR^2 values. The best fitted regression models for dry season and wet season are presented in Table 4.13 1nd Table 4.14.

Table 4.13: *Best Fitted Regression Models Based on R^2Value (Dry Season)*

S/N	Para-meters	Regression models	R^2	Model type
1.	Na	$y = 0.3575EC^2 + 7.4758EC + 45.218$	0.8025	Polynomial
		$y = 0.2009TDS^2 + 4.1773TDS + 25.339$	0.8032	Polynomial
2.	K	$y = 54.683e^{0.6343EC}$	0.6500	Exponential
		$y = 30.574e^{0.6358TDS}$	0.6529	Exponential
3.	Ca	$y = -0.0246EC^2 + 9.2635EC + 5.7778$	0.9674	Polynomial
		$y = -0.0137TDS^2 + 5.183TDS + 3.2882$	0.9670	Polynomial
4.	Mg	$y = -11.236EC^2 + 305.25EC + 22.746$	0.7354	Polynomial
		$y = -6.1307TDS^2 + 170.77TDS + 12.784$	0.7354	Polynomial
5.	SO_4	$y = -13.074EC^2 + 163.52EC + 29.47$	0.9235	Polynomial
		$y = -7.3339TDS^2 + 91.667TDS + 16.458$	0.924	Polynomial
6.	NO_3	$y = -8.8685EC^2 + 166.08EC + 36.328$	0.810	Polynomial
		$y = -5.0541TDS^2 + 93.353TDS + 20.194$	0.8115	Polynomial
7.	Cl	$y = -0.0059EC^2 + 5.3608EC - 12.944$	0.9826	Polynomial
		$y = -0.0033TDS^2 + 3.0011TDS - 7.2277$	0.9825	Polynomial
8.	PO_4	$y = -407.07EC^2 + 868.6EC + 25.804$	0.6654	Polynomial
		$y = -229.78TDS^2 + 487.87TDS + 14.318$	0.6662	Polynomial
9.	HCO_3	$y = -0.0295EC^2 + 9.2103EC + 1.478$	0.9333	Polynomial
		$y = -0.0165TDS^2 + 5.1599TDS + 0.8105$	0.9333	Polynomial
10.	Fe	$y = 8E\text{-}08EC^2 + 3E\text{-}05EC + 0.1975$	0.9313	Polynomial
		$y = 3E\text{-}07TDS^2 + 5E\text{-}05TDS + 0.1975$	0.9314	Polynomial
11.	Cd	$y = 0.0012pH^2 - 0.0164pH + 0.0553$	0.8801	Polynomial
12.	Cr	$y = 0.0007pH^2 - 0.0097pH + 0.0341$	0.8882	Polynomial
13.	Cu	$y = 0.2799pH^2 - 3.3637pH + 10.101$	0.9144	Polynomial
14.	Pb	$y = 0.0205pH^2 - 0.2528pH + 0.7773$	0.8379	Polynomial

Table 4.14*: Best Fitted Regression Models Based on R^2 Value (Wet Season)*

S/N	Para-meters	Regression models	R^2	Model type
1.	Na	$y = -4E\text{-}05EC^2 + 0.0694EC - 0.2058$	0.7953	Polynomial
		$y = 9.2125\ln(TDS) - 29.953$	0.792	Logarithm
2.	K	$y = 58.96e^{0.5028EC}$	0.6946	Exponential
		$y = 33.035e^{0.5026TDS}$	0.6961	Exponential
3.	Ca	$y = -0.0171EC^2 + 8.7752EC + 13.071$	0.9660	Polynomial
		$y = -0.0094TDS^2 + 4.898TDS + 7.4796$	0.9657	Polynomial
4.	Mg	$y = -3.5679EC^2 + 308.67EC + 6.7609$	0.8242	Polynomial
		$y = -1.8314TDS^2 + 172.56TDS + 3.849$	0.8247	Polynomial
5.	SO_4	$y = -8.4154EC^2 + 145.8EC + 42.223$	0.9440	Polynomial
		$y = -4.696TDS^2 + 81.545TDS + 23.686$	0.9441	Polynomial
6.	NO_3	$y = 4.4715EC^2 + 113.39EC + 56.041$	0.8667	Polynomial
		$y = 2.5425TDS^2 + 63.327TDS + 31.455$	0.8664	Polynomial
7.	Cl	$y = -0.0038EC^2 + 5.3673EC - 15.479$	0.9855	Polynomial
		$y = -0.0021TDS^2 + 2.9969TDS - 8.5046$	0.9854	Polynomial
8.	PO_4	$y = 116.01EC^2 + 442.03EC + 47.178$	0.7721	Polynomial
		$y = 65.799TDS^2 + 246.6TDS + 26.546$	0.7713	Polynomial
9.	HCO_3	$y = -0.0057EC^2 + 8.0494EC + 14.981$	0.9463	Polynomial
		$y = -0.0031TDS^2 + 4.4979TDS + 8.4774$	0.9462	Polynomial
10.	Fe	$y = 9E\text{-}07EC^2 + 0.5598EC + 0.0179$	0.9999	Polynomial
		$y = 0.5603TDS - 0.0167$	0.9999	Linear
11.	Cd	$y = 0.0012pH^2 - 0.0164pH + 0.0553$	0.8801	Polynomial
12.	Cr	$y = 0.0007pH^2 - 0.0097pH + 0.0341$	0.8882	Polynomial
13.	Cu	$y = 0.2799pH^2 - 3.3637pH + 10.101$	0.9144	Polynomial
14.	Pb	$y = 0.0205pH^2 - 0.2528pH + 0.7773$	0.8379	Polynomial

The result of multiple regression for lead (Pb) using correlated significant predictors are shown in the regression statistics of lead in Table 4.15a and Table 4.15bfor both dry and wet seasons, while the regression statistics Tables for Na, K, Ca, Mg, SO_4, NO_3, Cl, PO_4, HCO_3, NH_4, Fe, Cd, Cr,and Cu for both dry and wet seasons are presented in Appendix V.

Table 4.15(a): *Regression Statistics of Lead (Pb) For Dry Season*

Regression Statistics of Pb for Dry Season	
Multiple R	0.8477
R Square	0.7186
Adjusted R Square	0.7127
Standard Error	0.0121
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1.0000	0.0181	0.0181	122.5759	0.0000
Residual	48.0000	0.0071	0.0001		
Total	49.0000	0.0252			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**0.1859**	0.0152	12.1918	0.0000	0.1553	0.2166	0.1553	0.2166
pH	**-0.0310**	0.0028	-11.0714	0.0000	-0.0367	-0.0254	-0.0367	-0.0254

Table 4.15(b): *Regression Statistics of Lead (Pb) For Wet Season*

Regression Statistics of Pb for Wet Season	
Multiple R	0.8477
R Square	0.7186
Adjusted R Square	0.7127
Standard Error	0.0121
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1.0000	0.0181	0.0181	122.5759	0.0000
Residual	48.0000	0.0071	0.0001		
Total	49.0000	0.0252			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**0.1859**	0.0152	12.1918	0.0000	0.1553	0.2166	0.1553	0.2166
pH	**-0.0310**	0.0028	-11.0714	0.0000	-0.0367	-0.0254	-0.0367	-0.0254

The greater the value of regression coefficient, the better is the fit and more useful the regression variables (Daraigan, Wahdain. BaMosa&Obid, 2011).pH is the only predictor for Pb, Cr, Cd and Cu with a p-value < 0.05. When a significant p-value is > 0.05, it is removed from the regression on the basis that its contribution lacks 95% confidence (Nwaogazie, 2006). While EC and TDS are predictors for other analysed ions (Na, K, Ca, Mg, SO_4, NO_3, Cl, PO_4, HCO_3 and Fe.The multiple regression equations for prediction of ion concentrations using insitu parameters are given in Table 4.16for both seasons.

Table 4.16: *Dry and Wet Seasons Multiple Regression Models for Predicting Some Water Quality Parameters Concentrations Using Measured In-Situ Parameters*

S/N	Parameters	Predicting Equations	
		Dry Season	Wet Season
1.	Na	-0.2430EC+0.5204TDS+ 1.3990	-1.2177EC+2.2548TDS+ 1.9928
2.	K	-0.1012EC + 0.1899TDS +0.4638	0.0836EC – 0.1385TDS + 0.6094
3.	Ca	0.4032EC – 0.4974TDS – 1.7477	0.7937EC – 1.1875TDS – 2.6207
4.	Mg	0.0016EC + 0.0017TDS + 0.0568	-0.0514EC+0.0967TDS + 0.0796
5.	SO_4	- 0.0276EC + 0.0641TDS – 0.3626	-0.1237EC+ 0.2379TDS – 0.5743
6.	NO_3	- 0.0717EC + 0.1381TDS – 0.0938	0.0917EC – 0.1519TDS – 0.1840
7.	Cl	0.2378EC – 0.0540TDS + 1.1129	0.3682EC – 0.2984TDS + 1.8571
8.	PO_4	- 0.0058EC + 0.0122TDS + 0.0135	0.0494EC – 0.0856TDS + 0.0140
9.	HCO_3	- 0.0183EC + 0.2576TDS – 0.8940	0.4042EC – 0.5013TDS – 1.1427
10.	Fe	- 0.0001EC + 0.0002TDS + 0.1945	-0.0043EC+0.0077TDS + 0.2117
11.	Cd	- 0.0032pH + 0.0201	– 0.0032pH + 0.0201
12.	Cr	– 0.0024pH + 0.0146	- 0.0024pH + 0.0146
13.	Cu	– 0.3393pH + 2.0357	- 0.3393pH + 2.0357
14.	Pb	– 0.0310pH + 0.1859	- 0.0310pH + 0.1859

4.1.2.3 Verification and validation of regression models

To verify and validate the derived models for predicting ions during the dry and wet seasons, four water samples were randomly collected from different sampling locations within the study area that were not previously sampled in both dry and wet seasons. Table 4.19 is the GPS coordinates of the sampled points.

Table 4.17: *Locations and GPS Coordinates of Sample Points Used for Validation*

S/N	Sampling Code	Location	UTM coordinates	
			Longitudes(E)	Latitudes(N)
1.	VLA	Central Hospital	802967.81	610627.19
2.	VLB	Hussey College	804744.37	611207.08
3.	VLC	Delta Broadcasting Station (DBS)	802264.70	613348.53
4.	VLD	Ugbolokposo	813568.65	616396.37

4.1.2.4.1 Validation of Regression Equation for Predicting Cations and Anions in the Study area (Dry Season)

The results of the water quality parameters obtained from the characterization of water samples from the four locations are presented in Table 4.18 and the results of predicted concentration of some water quality parameters (dependent variables) using the regression prediction equations and substituting the values for the insitu measured parameters (independent variables) for the dry season and then compared with observed values. The results are presented in Table 4.19(a-n).

Table 4.18(a): *Results of Physico-Chemical Analyses of Water Samples From Four Locations (Dry Season)*

S/N	SL Code	Temp. (^{0}C)	pH	EC (µS/cm)	Turbidity (NTU)	TH (mg/l)	TSS (mg/l)	TDS (mg/l)	DO	BOD	COD	Total Coli. (cfu/ml)	Cations			
													Na^+ (Mg/l)	K^+(Mg/l)	Ca^{2+}(Mg/l)	Mg^{2+} (Mg/l)
1	VLA	27.60	7.12	23.70	7.95	88.66	9.24	25.00	2.40	2.80	2.50	24.00	2.27	2.93	21.78	0.16
2	VLB	25.50	6.63	29.00	3.25	72.92	3.14	160.00	1.80	1.50	2.30	12.00	27.21	29.49	89.30	0.33
3	VLC	28.10	6.72	2.50	6.09	75.76	7.73	56.00	2.52	2.40	2.70	15.20	12.56	9.50	27.45	0.77
4	VLD	25.60	7.60	3.80	7.11	106.11	8.62	123.00	2.45	2.30	2.40	11.00	27.04	24.21	62.43	1.17

S/N	SL Code	Anions						Heavy Metals				
		SO_4^{2-} (Mg/l)	NO_3 (Mg/l)	Cl^- (Mg/l)	HCO_3 (Mg/l)	NH_4 (Mg/l)	PO_4 (Mg/l)	Fe (Mg/l)	Cd (Mg/l)	Cr (Mg/l)	Cu (Mg/l)	Pb (Mg/l)
1	VLA	1.36	5.81	9.57	7.77	3.01	0.24	0.21	0.001	0.05	0.00	0.001
2	VLB	11.84	23.66	16.38	43.02	3.07	2.08	0.60	0.070	0.00	ND	0.020
3	VLC	3.55	8.32	5.30	13.73	2.05	0.51	1.43	0.030	0.02	ND	0.020
4	VLD	8.96	18.73	8.62	32.08	3.08	1.16	0.34	0.020	0.04	0.01	0.090

Table 4.19a: *Sodium Prediction Model (Na = 1.399 – 0.2430EC + 0.5204TDS)*

Sampling Code	EC	0.2430EC	TDS	0.5204TDS	Constant 1.399	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	23.70	5.76	25.00	5.1	1.399	0.74	2.27	1.53
VLB	29.00	7.05	160.00	32.64	1.399	26.99	27.21	0.22
VLC	2.50	0.61	56.00	11.42	1.399	12.22	12.56	0.34
VLD	3.80	0.92	123.00	25.09	1.399	25.57	27.04	1.47

Table 4.19b *Potassium Prediction Model (K = 0.4638 – 0.1012EC + 0.1899TDS)*

Sampling Code	EC	0.1012EC	TDS	0.1899TDS	Constant 0.4638	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	23.70	2.40	25.00	4.75	0.4638	2.81	2.93	0.12
VLB	29.00	2.93	160.00	30.38	0.4638	27.91	29.49	1.58
VLC	2.50	0.25	56.00	10.63	0.4638	10.84	9.50	- 1.34
VLD	3.80	0.38	123.00	23.36	0.4638	23.44	24.21	0.77

Table 4.19c: *Calcium Prediction Model (Ca = 1.7477 – 0.4032EC – 0.4974TDS)*

Sampling Code	EC	0.4032EC	TDS	0.4974TDS	Constant 1.7477	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	23.70	9.56	25.00	12.44	1.7477	20.25	21.78	1.53
VLB	29.00	11.69	160.00	79.58	1.7477	89.52	89.30	- 0.22
VLC	2.50	1.01	56.00	27.85	1.7477	27.11	27.45	0.34
VLD	3.80	1.53	123.00	61.18	1.7477	60.96	62.43	1.47

Table 4.19d: *Magnesium Prediction Model (Mg = 0.0016EC + 0.0017TDS + 0.0568)*

Sampling Code	EC	0.0016EC	TDS	0.0017TDS	Constant 0.0568	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	23.70	0.04	25.00	0.0425	0.0568	0.14	0.16	0.02
VLB	29.00	0.05	160.00	0.272	0.0568	0.38	0.33	- 0.05
VLC	2.50	0.004	56.00	0.0952	0.0568	0.19	0.77	0.58
VLD	3.80	0.0061	123.00	0.2091	0.0568	0.27	1.17	0.90

Table 4.19e: *Sulphate Prediction Model (SO_4= 0.3626 + 0.0276EC + 0.0641TDS)*

Sampling Code	EC	0.0276EC	TDS	0.0641TDS	Constant 0.3626	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	23.70	0.65	25.00	1.60	0.3626	2.61	1.36	- 1.25
VLB	29.00	0.80	160.00	10.26	0.3626	11.42	11.84	0.42
VLC	2.50	0.07	56.00	3.59	0.3626	4.02	3.55	- 0.47
VLD	3.80	0.11	123.00	7.88	0.3626	8.35	8.96	0.61

Table 4.19f: *Nitrate Prediction Model (NO_3= 0.0938 + 0.0717EC + 0.1381TDS)*

Sampling Code	EC	0.0717EC	TDS	0.1381TDS	Constant 0.0938	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	23.70	1.70	25.00	3.45	0.0938	5.24	5.81	0.57
VLB	29.00	2.08	160.00	22.10	0.0938	24.27	23.66	- 0.61
VLC	2.50	0.18	56.00	7.73	0.0938	8.00	8.32	0.32
VLD	3.80	0.27	123.00	16.99	0.0938	17.35	18.73	1.38

Table 4.19g: *Chlorine Prediction Model (Cl = 1.1129 + 0.2378EC – 0.054TDS)*

Sampling Code	EC	0.2378EC	TDS	0.054TDS	Constant 1.1129	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	23.70	5.64	25.00	1.35	1.1129	8.10	9.57	1.47
VLB	29.00	6.90	160.00	8.64	1.1129	16.65	16.38	- 0.27
VLC	2.50	0.59	56.00	3.02	1.1129	4.72	5.30	0.58
VLD	3.80	0.90	123.00	6.64	1.1129	8.65	8.62	- 0.03

Table 4.19h: *Phosphate Prediction Model (PO_4= 0.0135 – 0.0058EC + 0.0122TDS)*

Sampling Code	EC	0.0058EC	TDS	0.0122TDS	Constant 0.0135	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	23.70	0.14	25.00	0.31	0.0135	0.18	0.24	0.06
VLB	29.00	0.17	160.00	1.95	0.0135	1.79	2.08	0.29
VLC	2.50	0.01	56.00	0.68	0.0135	0.68	0.51	- 0.17
VLD	3.80	0.02	123.00	1.50	1.3990	1.49	1.16	- 0.33

Table 4.19i: *Trioxocarbonate Prediction Model (HCO_3= 0.894 + 0.0183EC + 0.2576TDS)*

Sampling Code	EC	0.0183EC	TDS	0.2576TDS	Constant 0.894	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	23.70	0.43	25.00	6.44	0.894	7.76	7.77	0.01
VLB	29.00	0.53	160.00	41.22	0.894	42.64	43.02	0.38
VLC	2.50	0.05	56.00	14.43	0.894	15.37	13.73	- 1.64
VLD	3.80	0.07	123.00	31.68	0.894	32.64	32.08	- 0.56

Table 4.19j: *Iron Prediction Model (Fe = 0.1945 – 0.0001EC + 0.0002TDS)*

Sampling Code	EC	0.0001EC	TDS	0.0002TDS	Constant 0.1945	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	23.70	0.0024	25.00	0.005	0.1945	0.20	0.21	0.01
VLB	29.00	0.0029	160.00	0.032	0.1945	0.22	0.60	0.38
VLC	2.50	0.0003	56.00	0.011	0.1945	0.21	1.43	1.22
VLD	3.80	0.0004	123.00	0.025	0.1945	0.22	0.34	0.12

Table 4.19k: *Cadmium Prediction Model (Cd = - 0.0032ph + 0.0201)*

Sampling Code	pH	0.0032pH	Constant 0.0201	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	7.12	0.0228	0.0201	0.0027	0.001	- 0.001
VLB	6.63	0.0212	0.0201	0.0413	0.070	0.029
VLC	6.72	0.0215	0.0201	0.0416	0.030	-0.012
VLD	7.60	0.0243	0.0201	0.0444	0.020	- 0.024

Table 4.19l: *Chromium Prediction Model (Cr = - 0.0024ph + 0.0146)*

Sampling Code	pH	0.0024pH	Constant 0.0146	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	7.12	0.0024	0.0146	0.0171	0.05	0.033
VLB	6.63	0.0024	0.0146	0.0159	0.00	- 0.016
VLC	6.72	0.0024	0.0146	0.0161	0.02	0.004
VLD	7.60	0.0024	0.0146	0.0182	0.04	0.022

Table 4.19m: *Copper Prediction Model (Cu = - 0.3393ph + 2.0357)*

Sampling Code	pH	0.3393pH	Constant 2.0357	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	7.12	2.42	2.0357	0.38	0.00	- 0.38
VLB	6.63	2.25	2.0357	0.21	0.01	- 0.20
VLC	6.72	2.28	2.0357	0.24	0.01	- 0.23
VLD	7.60	2.58	2.0357	0.54	0.01	- 0.53

Table 4.19n: *Lead Prediction Model (Pb = - 0.0310ph + 0.1859)*

Sampling Code	pH	0.031pH	Constant 0.1859	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	7.12	0.22	0.1859	0.034	0.001	- 0.033
VLB	6.63	0.21	0.1859	0.024	0.020	- 0.004
VLC	6.72	0.21	0.1859	0.024	0.020	- 0.004
VLD	7.60	0.24	0.1859	0.054	0.090	0.036

4.1.2.4.2 Validation of Regression Equation for Predicting Cations and Anions in the Study Area (Wet Season)

Similarly, the results of the analyzed water samples in the wet season are presented in Table 4.20. The predicted concentration of selected ions for the wet season using the regression equations for predicting the parameters concentration in the wet season are represented in Table 4.21a to Table 4.21n.

Table 4.20: *Sample Points Used for Validation (Wet Season)*

S/N	SL Code	Temp. (^oC)	pH	EC (µS/cm)	Turbidity (NTU)	TH (mg/l)	TSS (mg/l)	TDS (mg/l)	DO	BOD	COD	Total Coli. (cfu/ml)	Cations			
													Na (Mg/l)	K (Mg /l)	Ca (Mg/l)	Mg (Mg/l)
1	VLA	35.76	8.32	51.00	15.50	131.85	11.53	42.00	2.40	1.50	5.50	27.25	34.73	6.15	87.24	2.02
2	VLB	27.50	8.35	72.30	5.11	132.77	10.00	33.60	1.80	1.80	4.30	2.30	10.58	2.13	96.57	1.23
3	VLC	29.10	7.22	93.00	6.72	92.09	11.97	48.00	2.52	1.30	3.40	17.06	3.29	3.00	146.14	1.36
4	VLD	26.88	9.50	69.50	6.44	177.55	12.50	59.10	1.45	1.40	3.70	11.47	50.40	1.22	123.04	1.99

S/N	SL Code	Anions						Heavy Metals				
		SO_4^{2-} (Mg/l)	NO_3 (Mg/l)	Cl^- (Mg/l)	HCO_3 (Mg/l)	NH_4 (Mg/l)	PO_4 (Mg/l)	Fe (Mg/l)	Cd (Mg/l)	Cr (Mg/l)	Cu (Mg/l)	Pb (Mg/l)
1	VLA	3.20	10.85	8.18	40.59	6.84	1.08	0.22	0.11	0.09	1.29	0.001
2	VLB	0.42	11.53	18.53	46.13	5.27	0.99	0.62	0.10	0.01	0.03	0.020
3	VLC	1.59	15.54	21.69	60.71	2.76	0.72	1.42	0.05	0.02	ND	0.020
4	VLD	5.54	15.05	9.86	57.72	0.02	1.15	0.32	0.06	0.04	0.02	0.090

Table 4.21a: *Sodium Prediction model (Na = 1.9928 – 1.2177EC + 2.2548TDS)*

Sampling Code	EC	1.2177EC	TDS	2.2548TDS	Constant 1.9928	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	51.00	62.10	42.00	94.70	1.9928	34.59	34.73	0.14
VLB	72.30	88.04	33.60	75.76	1.9928	10.29	10.58	0.29
VLC	93.00	113.25	48.00	108.23	1.9928	3.03	3.29	0.26
VLD	69.50	84.63	59.10	133.26	1.9928	50.62	50.40	- 0.22

Table 4.21b: *Potassium Prediction Model (K = 0.6094 + 0.0836EC – 0.0.1385TDS)*

Sampling Code	EC	0.0836EC	TDS	0.1385TDS	Constant 0.6094	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	51.00	4.26	42.00	5.82	0.6094	4.67	6.15	1.48
VLB	72.30	6.04	33.60	4.65	0.6094	2.00	2.13	0.13
VLC	93.00	7.77	48.00	6.65	0.6094	1.73	3.00	1.27
VLD	69.50	5.81	59.10	8.19	0.6094	1.77	1.22	- 0.55

Table 4.21c: *Calcium Prediction Model (Ca = 2.6207 – 0.7937EC – 0.1875TDS)*

Sampling Code	EC	0.7937EC	TDS	1.1875TDS	Constant 2.6207	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	51.00	40.48	42.00	49.88	2.6207	87.74	87.24	- 0.50
VLB	72.30	57.39	33.60	39.90	2.6207	94.67	96.57	1.90
VLC	93.00	73.81	48.00	57.00	2.6207	147.28	146.14	- 1.14
VLD	69.50	55.16	59.10	70.18	2.6207	122.72	123.04	0.32

Table 4.21d: *Magnesium Prediction Model (Mg = 0.0796 - 0.0514EC + 0.0967TDS)*

Sampling Code	EC	0.0514EC	TDS	0.0967TDS	Constant 0.0796	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	51.00	2.62	42.00	4.06	0.0796	1.52	2.02	0.50
VLB	72.30	3.72	33.60	3.25	0.0796	0.39	1.23	0.84
VLC	93.00	4.78	48.00	4.64	0.0796	0.06	1.36	1.30
VLD	69.50	3.57	59.10	5.71	0.0796	2.22	1.99	- 0.23

Table 4.21e: *Sulphate Prediction Model (SO_4= 0.5743 - 0.1237EC + 0.2379TDS)*

Sampling Code	EC	0.1237EC	TDS	0.2379TDS	Constant 0.5743	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	51.00	6.31	42.00	9.99	0.5743	4.25	3.20	- 1.05
VLB	72.30	8.94	33.60	7.99	0.5743	0.38	0.42	0.04
VLC	93.00	11.50	48.00	11.42	0.5743	0.49	1.59	1.10
VLD	69.50	8.60	59.10	14.06	0.5743	6.03	5.54	- 0.49

Table 4.21f: *Nitrate Prediction Model (NO_3= 0.184 - 0.0917EC - 0.1519TDS)*

Sampling Code	EC	0.0917EC	TDS	0.1519TDS	Constant 0.184	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	51.00	4.68	42.00	6.38	0.184	10.88	10.85	- 0.03
VLB	72.30	6.63	33.60	5.10	0.184	11.55	11.53	- 0.02
VLC	93.00	8.53	48.00	7.29	0.184	15.64	15.54	- 0.10
VLD	69.50	6.37	59.10	8.98	0.184	15.17	15.05	- 0.12

Table 4.21g: *Chlorine Prediction Model (Cl = 1.8571 + 0.3682EC – 0.2984TDS)*

Sampling Code	EC	0.3682EC	TDS	0.2984TDS	Constant 1.8571	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	51.00	18.78	42.00	12.53	1.8571	8.11	8.18	0.07
VLB	72.30	26.62	33.60	10.03	1.8571	18.45	18.53	0.08
VLC	93.00	34.24	48.00	14.32	1.8571	21.78	21.69	- 0.09
VLD	69.50	25.59	59.10	17.64	1.8571	9.81	9.86	0.05

Table 4.21h: *Phosphate Prediction Model (PO_4= 0.014 + 0.0494EC - 0.0856TDS)*

Sampling Code	EC	0.0494EC	TDS	0.0856TDS	Constant 0.014	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	51.00	2.52	42.00	3.60	0.014	1.07	1.08	0.01
VLB	72.30	3.57	33.60	2.88	0.014	0.70	0.99	0.29
VLC	93.00	4.59	48.00	4.11	0.014	0.50	0.72	0.22
VLD	69.50	3.43	59.10	5.06	0.014	1.62	1.15	- 0.47

Table 4.21i: Trioxocarbonate Prediction model(HCO_3 = 1.1427 - 0.4042EC -0.5013TDS)

Sampling Code	EC	0.4042EC	TDS	0.5013TDS	Constant 1.1427	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	51.00	20.61	42.00	21.06	1.1427	40.53	40.59	0.06
VLB	72.30	29.22	33.60	16.84	1.1427	44.92	46.13	1.21
VLC	93.00	37.59	48.00	24.06	1.1427	60.51	60.71	0.20
VLD	69.50	28.09	59.10	29.63	1.1427	56.58	57.72	1.14

Table 4.21j: Iron Prediction model(Fe = 0.2117 – 0.0043EC + 0.0077TDS)

Sampling Code	EC	0.0001EC	TDS	0.0002TDS	Constant 0.2117	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	23.70	0.0024	25.00	0.005	0.2117	0.21	0.22	0.01
VLB	29.00	0.0029	160.00	0.032	0.2117	0.24	0.62	0.38
VLC	2.50	0.0003	56.00	0.0112	0.2117	0.22	1.42	1.20
VLD	3.80	0.0004	123.00	0.0246	0.2117	0.24	0.32	0.08

Table 4.21k: Cadmium Prediction model(Cd = - 0.0032pH + 0.0201)

Sampling Code	pH	0.0032pH	Constant 0.0201	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	8.32	0.027	0.0201	0.007	0.11	0.10
VLB	8.35	0.027	0.0201	0.007	0.10	0.09
VLC	7.22	0.023	0.0201	0.003	0.05	0.05
VLD	9.50	0.03	0.0201	0.01	0.06	0.05

Table 4.21l: Chromium Prediction model(Cr = - 0.0024pH + 0.0146)

Sampling Code	pH	0.0024pH	Constant 0.0146	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value (mg/l) (2) – (1)
VLA	8.32	0.02	0.0146	0.005	0.09	0.09
VLB	8.35	0.02	0.0146	0.005	0.01	0.005
VLC	7.22	0.017	0.0146	0.002	0.02	0.02
VLD	9.50	0.023	0.0146	0.003	0.04	0.04

Table 4.21m: *Copper Prediction Model (Cu = - 0.3393ph + 2.0357)*

Sampling Code	pH	0.3393pH	Constant 2.0357	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value(mg/l) (2) – (1)
VLA	8.32	2.82	2.0357	0.78	1.29	0.51
VLB	8.35	2.83	2.0357	0.76	0.03	- 0.73
VLC	7.22	2.45	2.0357	0.41	0.01	- 0.4
VLD	9.50	3.22	2.0357	1.18	0.02	- 1.16

Table 4.21n: *Lead Prediction Model (Pb = - 0.0310ph + 0.1859)*

Sampling Code	pH	0.031pH	Constant 0.1859	Predicted Value (mg/l) (1)	Measured Value (mg/l) (2)	Residual Value(mg/l) (2) – (1)
VLA	8.32	0.26	0.1859	0.074	0.001	- 0.07
VLB	8.35	0.26	0.1859	0.074	0.020	- 0.054
VLC	7.22	0.22	0.1859	0.034	0.020	- 0.014
VLD	9.50	0.22	0.1859	0.034	0.090	0.06

4.1.3 Geostatistics

The results obtained in building good interpolation models through examination of the data distribution (normality check and transformation), trends in the dataset, variogram fitting and testing, cross validation of models, understanding the spatial autocorrelation and directional influence and generation of prediction maps using the ordinary Kriging interpolation technique in the geostatistical analyst tool in ArcGIS 10.6 software are presented hereafter.

4.1.3.1 Distribution of Datasets (Results of Normality Test)

Figure 4.5a to Figures 4.5c are three histograms (untransformed and transformed)plotted for temperature in the dry season.The adopted histogram for temperature in the dry season is the no transformation histogram with the following parameters mean (27.628), median (27.105), Skewness (0.2149) and kurtosis (1.999) which is close to the criteria for adopting the

histogram with a distribution closest to gaussian distribution.The adopted histogram for all other water quality parameters for both dry and wet seasons are presented in Appendix VI.



(a) No transformation (b) Log transformation (c) Box Cox transformation

Figure 4.5 (a-c). Histogram for normality check for temperature

The mean, median, skewness, kurtosis and the type of transformation applied for each water quality parameter for both dry and wet season are presented in Table 4.22.

Table 4.22: *Transformation Types Used to Normalize Water Quality Parameters for Both Dry and Wet Seasons.*

	Dry Season (DS)					Wet Season (WS)				
Para-meters	Mean	Median	Skew-ness	Kurtosis	Type of Transfor-mation	Mean	Med-ian	Skew-ness	Kurt-osis	Type of Transfor-mation
Temp	27.628	27.105	0.2149	1.999	None	27.467	27.19	0.065	2.236	None
pH	5.410	5.400	-0.015	2.010	None	1.495	1.504	-.0750	2.444	Log
EC	162.74	110.00	1.321	3.820	None	4.954	4.868	0.350	2.061	Log
Turbidity	5.692	1.935	1.835	6.756	None	6.628	3.160	1.649	3.16	None
TH	2.800	2.602	1.026	2.991	Log.	3.181	2.652	1.085	3.428	Log
TSS	6.88	3.5	1.845	6.832	None	11.171	10.375	1.376	5.375	None
TDS	4.249	4.127	0.366	2.057	Log.	4.374	4.284	0.358	2.062	Log
DO	1.047	0.993	0.204	2.144	Log.	1.321	1.163	0.595	1.916	Log
BOD	0.060	0.00	3.705	14.73	None	0.700	0.000	0.615	1.770	None
COD	1.363	1.421	-0.747	3.098	Log.	1.050	1.399	-0.831	2.461	Log
Total Coli	11.129	7.190	0.864	2.386	None	11.576	8.94	0.767	2.388	None
Na	1.933	1.864	-0.050	1.853	Log.	2.043	2.078	-0.128	1.920	Log
K	-0.412	0.000	-0.538	2.466	Log.	0.243	0.299	-0.567	2.689	Log
Ca	2.620	2.501	0.533	2.287	Log.	2.738	2.642	0.538	2.341	Log
Mg	-1.039	-1.204	0.043	2.274	Log.	-0.810	-0.745	-0.123	2.122	Log
SO_4	-0.531	-0.555	0.236	2.070	Log.	-0.407	-0.454	0.301	2.122	Log
NO_3	-0.735	-0.580	-0.674	3.134	Log.	-0.561	-0.371	-0.881	3.747	Log
Cl	3.313	3.199	0.476	2.145	Log.	3.428	3.308	0.429	2.133	Log
HCO_3	2.645	2.638	0.130	2.001	Log.	2.733	2.693	0.139	1.933	Log
NH_4	0.010	0.007	3.2	16.835	None	0.016	0.012	1.194	3.733	None
PO_4	0.193	0.110	1.786	6.423	ArcSine	-1.624	-1.774	0.240	1.978	Log
Fe	-1.583	-1.609	1.696	5.587	Log.	0.225	0.221	-0.021	5.154	ArcSine
Cd	0.0025	0.002	0.6927	2.34	None	0.008	0.0025	0.6927	2.34	None
Cr	0.002	0.002	0.427	2.082	Arcsine	0.002	0.002	0.427	2.082	Arcsine
Cu	0.201	0.1	1.169	3.235	None	0.201	0.1	1.169	3.235	None
Pb	0.018	0.001	0.9272	2.334	None	0.018	0.001	0.9272	2.334	None

4.1.3.2Trend analysis

The plot of the trend analysis forpH during the dry season is presented in Figure 4.6 while the trend analysis plot for other parameters for both dry and wet seasons are presented in Appendix VII.

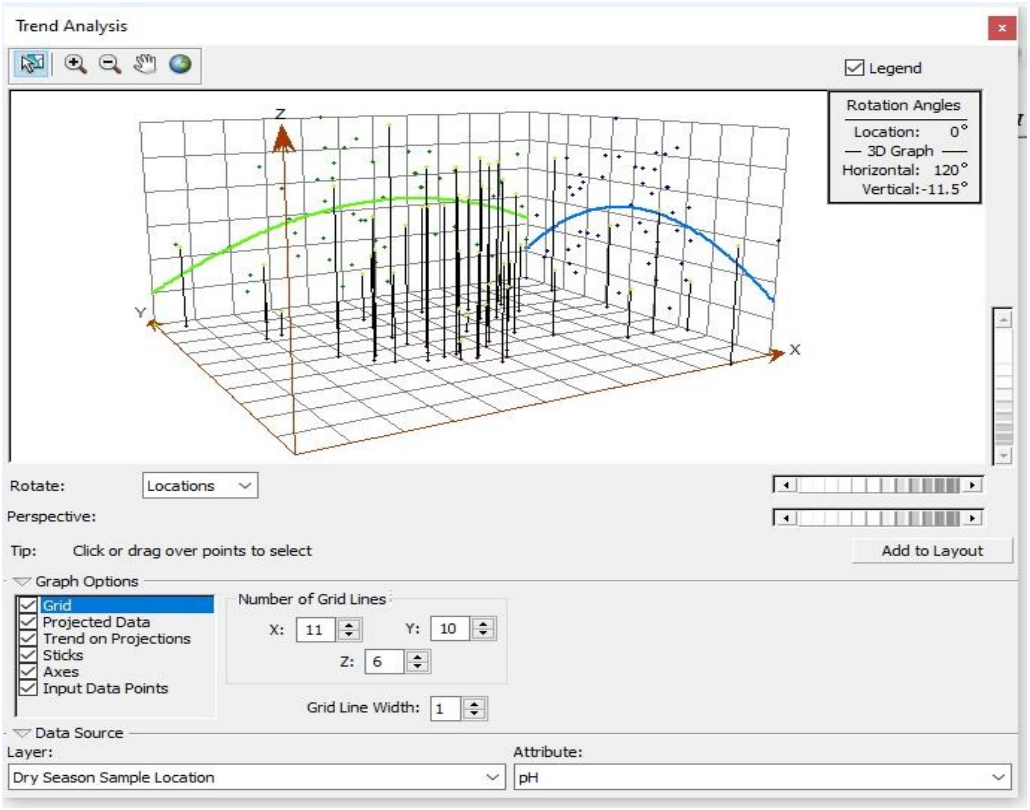


*Figure 4.6.*Trend analysis for pH in the dry season

4.1.3.3 Fitted semivariogram

Results of the eleven (11) Experimental semivariogram models (circular, spherical, tetraspherical, pentaspherical, exponential, Gaussian, rational quadratic, hole effect, K – Bessel, J – Bessel and stable) fitted for ECin the dry season were developed.The best fitted variogram (rational quadratic) for EC showing the variogram parameters (sill, nugget and range) in the dry season is presented in Figure 4.7. The partial sill, nugget and range values

for other selected (best fitted) parameter models are presented in Table 4.23. Similarly, the eleven (11) variogram models and their partial sill, nugget and range values for other water quality parameters for dry and wet seasons are presented in Appendix IX.

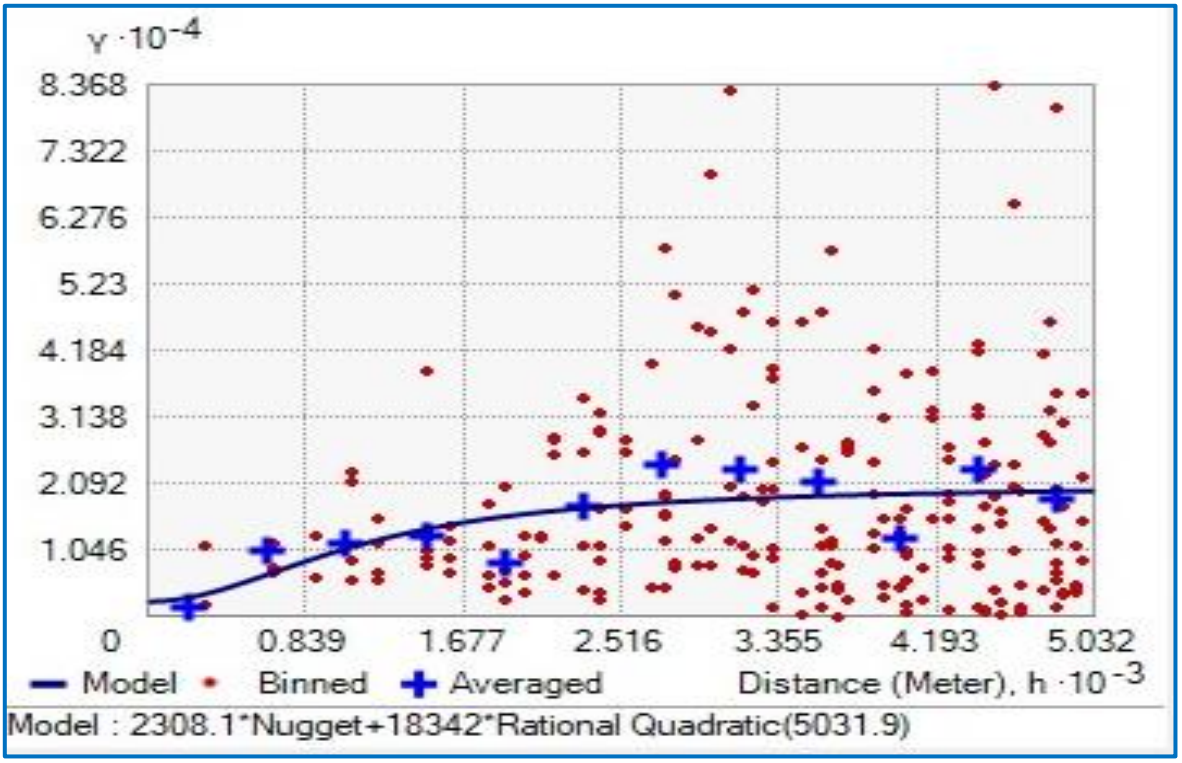


Figure 4.7. Variogram model (Rational Quadratic) for EC in the dry season.

Table 4.23: *Results Of Fitted Semivariogram Models For EC In The Dry Season.*

S/N	Fitted model	Range	Nugget (c_n)	Partial sill($\boldsymbol{\sigma}$)
1.	Circular	3113.5	3077.4	16363
2.	Exponential	4562.3	0.0	21114
3.	Gaussian	3269.8	6360.5	13443
4.	Hole Effect	5031.9	7007.4	10885
5.	J-bessel	4838.5	6771.8	11963
6.	K-bessel	4473.8	0.0	20940
7.	Pentaspherical	9046.2	2105	17395
8.	Rational Quad.	5031.9	2308	18342
9.	Spherical	3467.8	2597.4	16873
10.	Stable	3571.2	4568.3	15450
11.	Tetraspherical	3787.4	2298.1	17182

4.1.3.4 Spatial dependency

The parameters (partial sill, nugget and range) of the best fitted semivariogram (Appendix IX) and similarly for other parameterswere used for the examination of spatial dependency (autocorrelation) between the measured sample points and are presented in Tables 4.24 and 4.25 for oth seasons respectively. The ratio of the nugget variance to the sill givesthe spatial dependence of groundwater quality parameters (Mehrjardi *et al.*, 2008; Nayanaka, Vitharana & Mapa, 2010).

Table 4.24: *Results of Model Parameters and Degree Of Spatial Dependency of Best Fitted Models for Dry Season.*

Water para-meter (mg/l)	Fitted model	Range	Nugget(c_n)	Partial sill ($\boldsymbol{\sigma}$)	Sill *(c)*= $c_n + \boldsymbol{\sigma}$	$\left(\frac{\mathbf{c_n}}{\mathbf{c}}\right)\%$	Degree of Spatial Dependency
Temp.	Pentaspherical	9244.6	1.1003	4.9312	6.0315	18.24	Strong
pH	Gaussian	24657	0.0676	0.3681	0.4357	15.52	Strong
EC	Rational Quad.	5031.9	18342	2308.1	20650.1	88.82	Weak
Turb.	Exponential	24657	0.00	61.428	61.428	0.00	Strong
TH	Pentaspherical	24657	1.8757	0.9634	2.8391	66.07	Moderate
TSS	Hole Effect	13624	52.966	40.404	93.37	56.73	Moderate
TDS	Pentaspherical	3582.8	0.2937	0.2548	0.5485	53.55	Moderate
DO	Stable	24657	0.00	0.2455	0.2455	0.00	Strong
BOD	Gaussian	24657	0.0350	0.0483	0.0833	42.02	Moderate
COD	J-bessel	3432.2	0.2316	0.0923	0.3239	71.50	Moderate
T. Coli.	J-bessel	17579	8.2791	128.35	136.6291	6.06	Strong
Na	Pentaspherical	1435.9	0.5227	0.2090	0.7317	71.44	Moderate
K	Gaussian	24657	0.3234	0.6785	1.0019	32.28	Moderate
Ca	Hole Effect	5131.6	0.2764	0.3143	0.5907	46.79	Moderate
Mg	Rational Quad.	4561.7	0.2588	0.3868	0.6456	40.09	Moderate
SO_4	Hole Effect	4497.9	0.3818	0.7191	1.1009	34.68	Moderate
NO_3	Tetraspherical	2193.9	1.0665	0.2320	1.2985	82.13	Weak
Cl	Rational Quad.	4744.3	0.2734	0.2286	0.502	54.46	Moderate
HCO_3	Gaussian	24657	0.2990	0.6218	0.9208	32.47	Moderate
NH_4	Pentaspherical	2905	0.00023	0.00	0.00023	100.00	Weak
PO_4	Rational Quad.	6183.1	0.01983	0.0117	0.03153	62.89	Moderate
Fe	Stable	1533.5	0.00006	0.000013	0.000073	82.19	Weak
Cd	Exponential	24657	0.00	0.000005	0.000005	0.00	Strong
Cr	J-bessel	6418.1	1.7275E-7	0.000002	2.17E-06	7.95	Strong
Cu	Rational Quad.	24657	0.0316	0.0442	0.0758	41.69	Moderate
Pb	Rational Quad.	24657	0.00005	0.0005	0.00055	9.09	Strong

Table 4.27: *Results of Model Parameters And Degree of Spatial Dependency of Best Fitted Models for Wet Season*

Water parameter	Fitted model	Range(a)	Nugget(c_n)	Partial sill ($\boldsymbol{\sigma}$)	Sill *(c)* = $c_n + \boldsymbol{\sigma}$	$\left(\frac{\mathbf{c_n}}{\mathbf{c}}\right)$ %	Degree of Spatial Dependency
Temp.	K-bessel	5131.2	2.0169	4.4234	6.4403	31.32	Moderate
pH	Circular	1435.9	0.0110	0.0063	0.0173	63.58	Moderate
EC	Rational Quad.	4747.4	0.2939	0.3079	0.6018	48.84	Moderate
Turbidity	Exponential	24688	0.00	56.581	56.581	0.00	Strong
TH	Exponential	24688	0.97196	0.7994	1.77136	54.87	Moderate
TSS	Exponential	17684	109.45	39.39	148.84	73.54	Moderate
TDS	J-bessel	4139.6	0.2027	0.36656	0.56926	35.61	Moderate
DO	Exponential	24688	0.00	0.25833	0.25833	0.00	Strong
BOD	Hole Effect	4228.6	0.0084	0.72612	0.73452	1.14	Strong
COD	K-bessel	3968.7	1.0096	0.00	1.0096	100.00	Weak
T. Coli.	Gaussian	12002	27.452	111.14	138.592	19.81	Strong
Na	Pentaspherical	1435.9	0.5656	0.18319	0.74879	75.54	Weak
K	Gaussian	24688	0.1139	0.74547	0.85937	13.25	Strong
Ca	J-bessel	5236.9	0.2677	0.3465	0.6142	43.59	Moderate
Mg	Hole Effect	3632.3	0.1391	0.4884	0.6275	22.17	Strong
SO_4	Rational Quad.	5033.9	0.5997	0.70375	1.30345	46.01	Moderate
NO_3	K-bessel	4544.1	1.2916	0.70556	1.99716	64.67	Moderate
Cl	Hole Effect	4937.5	0.1401	0.34716	0.48726	28.75	Moderate
HCO_3	J-bessel	1503.4	0.75747	0.00	0.75747	100.00	Weak
NH_4	J-bessel	1961.9	0.0003	0.00	0.0003	100.00	Weak
PO_4	Rational Quad.	5664.7	0.4818	0.31136	0.79316	60.74	Moderate
Fe	Exponential	5085	0.0002	0.00	0.0002	100.00	Weak
Cd	Circular	24688	0.00	0.000005	5E-06	0.00	Strong
Cr	Exponential	24688	0.00005	0.00049	0.00054	9.259	Strong
Cu	Gaussian	24688	0.06365	0.045628	0.10928	58.25	Moderate
Pb	Rational Quad.	24688	0.00005	0.00049	0.00054	9.26	Strong

4.1.3.5 Cross validation

Results obtained from the eleven (11) semi variogram model for pH showing the prediction errors: mean error (ME), root mean square error (RMSE), mean standardized error (MSE), root mean squared standardized error (RMSSE), average standard error (ASE) and R^2 (gradient of the plot of predicted values and measured values for each parameter). However, the semivariogram models for pH are presented in Table 4.26 in the dry season, while that for other parameters are presented in Appendix IX.

Table 4.26**:** *Prediction Errors Of Semivariogram Models For Ph During Dry Season*

S/N	Model Type	Mean Error (ME)	Root Mean Square Error (RMSE)	Mean Standardized Error (MSE)	Root Mean Squared Standardized Error (RMSSE)	Average Standard Error (ASE)
1.	Circular	0.4783	0.6194	0.0730	0.9821	0.6316
2.	Exponential	0.0510	0.6212	0.0778	0.9796	0.6350
3.	Gaussian	0.0457	0.6180	0.0700	0.9830	0.6298
4.	Hole Effect	0.0457	0.6181	0.0699	0.9822	0.6303
5.	J-bessel	0.0457	0.6181	0.0698	0.9822	0.6302
6.	K-bessel	0.0458	0.6182	0.0701	0.9827	0.6300
7.	Pentaspherical	0.0487	0.6198	0.0742	0.9810	0.6327
8.	Rational Quad.	0.0516	0.6211	0.0787	0.9781	0.6358
9.	Spherical	0.0481	0.6195	0.0733	0.9817	0.6319
10.	Stable	0.0457	0.6182	0.0700	0.9830	0.6298
11.	Tetraspherical	0.0483	0.6196	0.0737	0.9814	0.6323

Using the lowest RMSE criterion for choice of the best fitted semivariogram model, the best fitted model for each water quality parameter was selected as the best theoretical variogram with their prediction errors for the purpose of the model prediction (Jeihouni et al., 2015) and presented in Table 4.27 for dry season and Table 4.28 for wet season.

Table 4.27: *Prediction Errors of Best Fitted Models for Water Quality Parameters in the Dry Season.*

Water Parameter (mg/l)	Fitted Semivariogram Model	PREDICTION ERRORS				
		ME	RMSE	MSE	RMSSE	ASE
Temp.	Pentaspherical	0.1330	2.0446	0.0505	0.8548	2.4172
pH	Gaussian	0.0457	0.6180	0.0700	0.9830	0.6298
EC	Rational Quad.	1.0723	140.9794	0.0014	1.2274	115.1871
Turbidity	Pentaspherical	0.5970	78.9627	0.0013	1.2276	64.5221
TH	Stable	-0.0050	0.2533	-0.0203	1.0610	0.2377
TSS	Exponential	0.0150	8.2503	0.0017	1.0180	8.1012
TDS	Pentaspherical	-6.2902	92.3086	-0.0860	1.2989	68.9730
DO	Hole Effect	0.3443	9.1966	0.0269	1.2824	7.1056
BOD	Gaussian	-0.0042	0.2364	-0.0171	1.1028	0.0230
COD	J-bessel	0.0881	2.1930	-0.1012	1.0873	2.6314
Total Coli.	J-bessel	-0.4086	11.6159	-0.0353	0.9841	11.7922
Na	Pentaspherical	0.1682	7.4382	-0.0688	0.7661	12.4683
K	Gaussian	0.0838	0.9440	0.0017	0.6789	1.5816
Ca	Hole Effect	-0.4627	17.3260	-0.1787	1.3301	17.1726
Mg	Rational Quad.	0.0141	0.3966	-0.0441	0.9361	0.5060
SO_4	Hole Effect	0.01979	1.1214	-0.0820	0.8952	1.8696
NO_3	Tetraspherical	0.0459	0.8188	-0.0375	0.5782	1.9975
Cl	Rational Quad.	-0.5567	27.8948	-0.1162	1.1789	28.9000
HCO_3	Gaussian	-0.4019	17.4284	-0.1035	1.0367	20.1584
NH_4	Pentaspherical	-0.0005	0.0153	-0.0208	1.0792	0.0135
PO_4	Rational Quad.	0.0016	0.1890	0.0155	1.1623	0.1594
Fe	Stable	-0.00011	0.0099	-0.2242	1.2377	0.0079
Cd	Exponential	-0.00014	0.0023	-0.0615	0.9985	0.0023
Cr	J-bessel	-0.00006	0.0016	-0.0330	0.9945	0.0016
Cu	Rational Quad.	-0.0082	0.2600	-0.0314	1.1142	0.2289
Pb	Rational Quad.	-0.0007	0.0225	-0.0297	0.9787	0.0231

Table 4.28: *Best Fitted Models for Water Quality Parameters And Prediction Errors For Wet Season*

WaterParameter	Fitted Semivariogram Model	Prediction Errors				
		ME	RMSE	MSE	RMSSE	ASE
Temp.	K-bessel	0.1555	2.2001	0.0554	0.9254	2.3891
pH	Circular	-0.0019	0.6072	-0.0247	0.9984	0.6060
EC	Rational Quad.	-1.3902	154.1596	-0.0873	1.0567	179.7992
TDS	J-bessel	-1.3382	86.6640	-0.1104	1.0874	100.4506
DO	Exponential	0.0443	2.3543	0.0102	0.9515	2.5121
Turbidity	Exponential	0.0872	8.0085	0.0110	1.0287	7.7823
TH	Exponential	-11.9674	87.0415	-0.2965	1.8001	91.5424
TSS	Exponential	0.1338	11.5189	0.0088	1.3359	8.5318
BOD	Hole Effect	0.0309	0.8496	0.0325	0.9509	0.8998
COD	K-bessel	0.3784	2.5905	-0.0922	1.0408	5.1680
Total Coli.	Gaussian	-0.3033	10.7804	-0.0295	0.9721	11.1009
Na	Pentaspherical	0.3113	8.1414	-0.0577	0.7449	14.2406
K	Gaussian	0.1351	1.2892	0.0076	0.6714	2.2635
Ca	J-bessel	-0.6072	20.8012	-0.1654	1.2863	20.7485
Mg	Hole Effect	0.0206	0.4615	-0.0363	0.8317	0.6833
SO_4	Rational Quad.	0.0218	1.5391	-0.0821	0.9528	2.5195
NO_3	K-bessel	0.1633	1.1650	-0.0525	0.7507	3.2942
Cl	Hole Effect	-0.2060	31.6487	-0.0969	1.1155	34.1584
HCO_3	J-bessel	-1.0802	19.7986	-0.1186	0.9660	28.3452
NH_4	J-bessel	-0.0007	0.0165	-0.0390	1.0800	0.0149
PO_4	Rational Quad.	-0.0042	0.2618	-0.1421	1.1544	0.2967
Fe	Exponential	0.0003	0.0136	0.0122	1.2054	0.0111
Cd	Circular	-0.0001	0.0023	-0.0621	0.9934	0.0023
Cr	Exponential	-0.0001	0.0016	-0.0312	0.9871	0.0016
Cu	Gaussian	-0.0063	0.2551	-0.0238	1.1105	0.2256
Pb	Rational Quad.	-0.0007	0.0224	-0.0308	0.9743	0.0231

4.1.3.6 Concentration maps of groundwater quality parameters: The spatial distribution of groundwater quality parameters concentration maps for EC in the dry and wet seasons are presented in Figures 4.8and 4.9. The spatial variation maps for other water quality parameters for both seasons are presented in Appendix X(a) and X(b). The maps generated showed the Surface data which divided the study area into cells, with a data value for each cell within the study area.

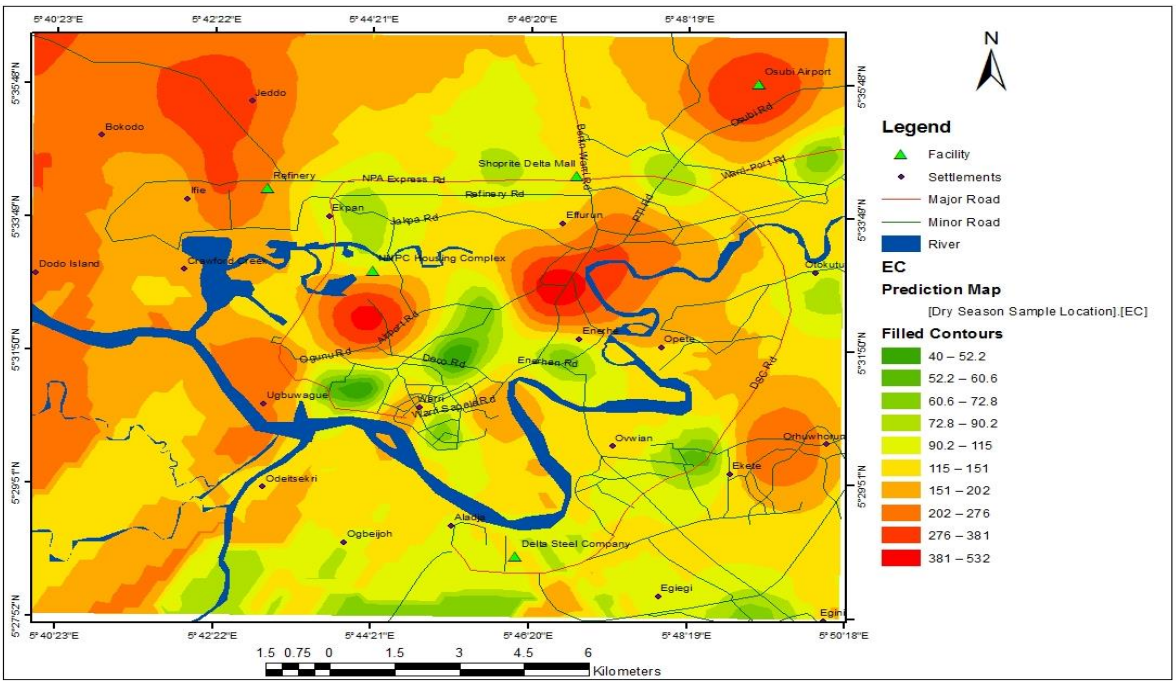


*Figure 4.8.*Concentration map of EC for dry season

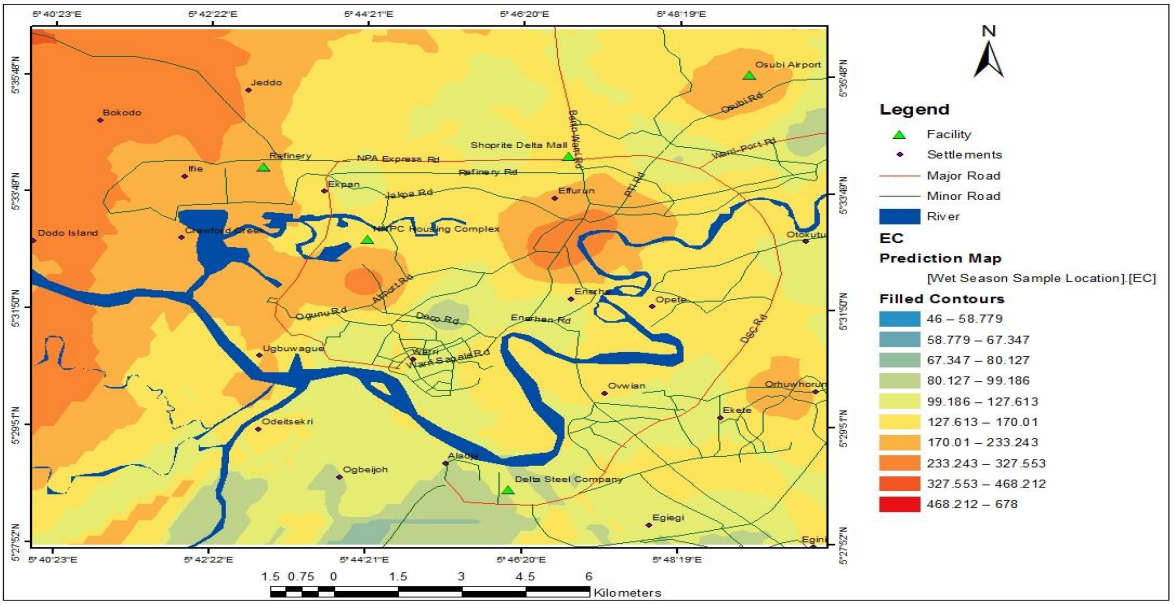


*Figure 4.9.*Concentration map of EC for Wet season

4.2 Discussion

4.2.1. Physico-chemical and biological groundwater quality parameters in the study area. The water quality parameters are discussed in the subsections below.

4.2.1.1 Groundwater quality and its temporal variation

The statistics of the twenty-six (26) of thegroundwater quality parameters and the temporal variationof the concentration values of the parametersin both dry season and wet season are presented in Appendix III (a). Mean values were taken into consideration as characteristics in evaluating the differences during the two (2) seasons.The results from the central tendency and t-test are discussed below.

i. Temperature: The mean temperature values are within the ranges of 23.21 to 32.2^{o}C for dry season and 22.2 to 32.2^{0}C in the wet season.Temperature variations suggests a high temperature environment, with a low temperature variability. The lower temperatures during the dry season are probably as a result of the harmattan cold which causes water temperature to drop. The values for temperature exceeded WHO standard limits except for locations OGD, UGT, UBJ 2, OGB, WAP, OGU, FGC, OKL, UDR, OTO and OKE that have limits within the stipulated standards. The water temperature controls the rate of all chemical reactions.Global warming and urbanization together with development of subsurface infrastructures (e.g., subways, shopping complexes, sewage systems, and Ground Source Heat Pump (GSHP) systems) will likely cause a rapid increase in the temperature of relatively shallow groundwater reservoirs (subsurface thermal pollution).

ii. pH: pH is classed as one of the most important water quality parameters. Measurement of pH relates to the acidity or alkalinity of the water. A sample is considered to be acidic if the pH is below 7, while it is alkaline if the pH is higher than 7. Acidic water can lead to

corrosion of metal pipes and plumping system, while alkaline water shows disinfection in water. The normal drinking water pH permissible standard values range of WHO and NDWQS guidelines range from 6.5 to 8.5. The pH values are in the range of 4.2 to 6.7 and 3.4 to 5.9 and the mean values are 5.41 and 4.49 in the dry and wet seasons respectively. The reduced rate of photosynthetic activity, the assimilation of carbon dioxide and bicarbonates are ultimately responsible for increase in pH, the low oxygen values coincided with high temperature during the dry season. The high precipitation in the study area attributed to the acidic conditions of groundwater in most of the sampling locations. pH levels are increased in the wet season due to high water levels as a result of dilution of alkaline substances (Sisodia and Moundiotiya, 2006). Application of chemical fertilizers, run off from agricultural field, leaching of industrial/domestic waste and sewage inflow and other anthropogenic sources are the possible point and non-point sources that cause the acidity of groundwater.

iii. Electrical Conductivity (EC): The electrical conductivity values are in the range of 40 to 532 and 46 to 678µS/cm and the mean values are 162.74 and 186.68µS/cm for the groundwater samples in dry and wet seasons respectively. The EC values are within the permissible limit of 400µS/cm (WHO, 2011) in most of the groundwater sampling locations except at locations APR, UGT, JED, OSA, OGB, and EDJ in both seasons. Electrical conductivity of water relates to the total concentration of different dissolved solids and ions (ionizable ions) in the water. EC is a function of ions activities and the high values of EC may be due to high concentration of ionic constituents present in the water bodies (LENNTECH, 2016). EC is directly proportional to the total dissolved solids (Nair, Bohjuari, Al-Mariami, Attia and El-Toumi, 2006). Percolation of industrial wastes, agricultural activities, land use, and intrusion of sewage may also enhance the high EC values in the aforementioned sampling

locations which affect the mineral contents and thus the electric conductivity of the water (Scatena, 2000).

iv. Turbidity: Turbidity is the cloudiness of water caused by a variety of particles and is another key parameter in drinking water analysis. The turbidity values are within the ranges of 0 to 37.53NTU for dry season and 0 to 35.77NTU in the wet season with mean values at 5.69 and 6.27NTU in the dry and wet seasons respectively. All turbidity values are below 5 nephelometric turbidity units (NTU), the standard recommended maximum turbidity limit set by WHO and NDWQS for drinking water except for stations ARB, JKR, SHA, EKP, EFM, JED, UBJ 2, OSM, WAP, EDHE, IGM, UDR, MAM, DST, OKE, MOF, FUP, SHP, ROP, ESR and ROR which were above the recommended limit. The turbidity levels for JKR, EFM, JED, PEM, ENE and UDR are low only in the wet season but are high in the dry season as a result of soil runoff. Lower turbidity values during the dry season are probably due to less groundwater recharge and infiltration. Higher levels of turbidity are associated with disease causing bacteria.

v. Total Hardness (TH): Minerals that cause hardness exist to some degree in every water supply. The total hardness values are found to be in the range of 3.72-336.29mg/l together with the mean values which are 51.03 and 55.53mg/l for the groundwater samples in dry and wet seasons respectively (Table 4.3). The total hardness values for all sampling stations are within the WHO permissible limit of 500mg/l. High value of TH is observed in stations OKU, UGT, EDJ, BOA, ORH, MAM, DST and MOF. TH was recorded comparatively highest in the wet season than in dry season. High rate of evaporation increases the concentration of total hardness in groundwater samples (Namdeo, Shrivastava and Sinha, 2013). Percolation of

industrial wastes and domestic wastes, presence of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in water also enhanced the increase TH concentration in these locations.

vi. Total Suspended Solids (TSS): The total suspended solids (TSS) relatively measure the physical or visual observable dirtiness of a water resource. The total suspended solid values are found to be in the range of 0 to 42.47mg/l and 0 to 46.92mg/l with mean values at 6.88 and 11.17mg/l for the groundwater samples in dry and wet seasons respectively. There is no specified limit for this parameter (WHO, 2011). The low levels of TSS in borehole water are quite understandable, as groundwater was originally been filtered by nature and then extracted by filter aided mechanical pumps and because most sample collection points in these areas had filtration systems attached to the taps, thus removing all the suspended particles such as silt, clay, and other inorganic particles. The higher TSS value during the wet season could be due to the increased weathering intensity and groundwater recharge during wet season and the presences of petroleum refining and other petroleum related activities. Lower TSS during the dry season is as a result of water filtration.

vii. Total dissolved solids (TDS): The TDS values are found in the range of 22 to 298mg/l and 26 to 380mg/l with mean values at 91.16 and 104.52mg/l for the groundwater samples in the dry and wet seasons respectively.The TDS values are below the permissible limit of 500mg/l (WHO, 2011) in all of the groundwater sampling stations in dry and wet seasons except in locations BOA and MAM. TDS is the presence of all dissolved salts, that is, TDS are the inorganic matters and small amounts of organic matters which are present as solution in water. It is a function of the sum of ions in solution and the degree of dissolved substances such as metal ions in the water. A higher TDS means that there are more cations and anions in the water. The increased concentration of TDS in the wet season could be attributed to

weathering intensity and the increased amount of groundwater recharge, the addition of solids from sewage, runoff water, and industrial effluents. Maximum value of TDS is found in location BOA in the dry season which could be due to the discharge from industries and untreated waste water (Viswanathan and Meenakshi, 2008). The increase in TDS is also as a result of runoff intrusion and soil disturbance within the sampling locations (Mkwate et al., 2017).

viii. Dissolved oxygen (DO): DO is one of the most important water quality parameters that gives direct and indirect information about the water, e.g. bacterial activity, photosynthesis, availability of nutrients, stratification etc., (Premlata, 2009). The values of DO are found in the range of 1-7.7mg/l and 1.9-9.6mg/l with mean values at 3.22 and 4.29mg/l in dry and wet season respectively (Table 4.3).The DO values are below the permissible limit of 6mg/l (WHO, 2011) in most of the sampling stations. The low dissolved oxygen levels in groundwater may be attributed to the effluents from industrial sources, septic tanks/soakaway pits andleachate from the unengineered waste dumps scattered within the study area. The nitrogen and phosphorus contained in them stimulate the growth of micro-organisms that consumes the dissolved oxygen of water (Sisodia and Moundiotiya, 2006). The difference in initial and final DO give the amount of oxygen consumed by the bacteria during test period. The concentration of DO values are inversely proportional to temperature. High dissolved oxygen concentrations occur during wet season as a result of aeration in the atmosphere through precipitation. The values are depleted during dry season because of high temperature which reduces the oxygen holding capacity of water and percolation of sewage or other wastes in the dry season and increased microbial activity (Kataria *et al.,* 1996; Morrissette and Mavinic, 1978; Moss, 1972, Krishnamurthy, 1990; Sisodia & Moundiotiya, 2006).

ix. Biochemical oxygen demand (BOD): BOD is a measure of the amount of biologically oxidizable organic matter present in water. That is, it is a measure of organic material contamination in water. The values of BOD are found in the range of 0.3 to 1.4mg/l and 0.7 to 2.5 mg/l with mean values at 0.07 and 0.7mg/l for the groundwater samples in dry and wet season respectively. The BOD values are lower than the permissible limit of 10 mg/l (WHO, 2011) in all the groundwater sampling stations in the dry and wet seasons. The high BOD during the dry season could be due to the reduced groundwater recharge, presence of decomposable organic matter (clay), percolation of leachate from solid waste dump sites and organic pollution of water body (organic wastes and sewage) and chemicalpollution from industrial wastes (Mishra, Pradhan & Patel, 2003). BOD value higher than 6mg/l means organic material contamination in water. High BOD registered during wet season may be due to high concentration of dissolved solids in water, high input of organic pollutants and increased biological activities while in dry season, reduced rate of flow and decrease in biological activities due to elevated temperature lowers the BOD (Palharya, Siriah &Malviya, 1993; Shukla, Singh, Rajwanshi, Singh, Gupta, Srivastava &Dass, 1993).The high BOD values could be due to acidification of water by elevated microbial degradation of organic debris and concentrated dissolved solids.

x. Chemical oxygen demand (COD): The COD values are in the range of 1.1 to 8.9 mg/l and 0.3 to 9.2 mg/l in dry and wet season respectively (Table 4.4). The COD values are well below the permissible limit of 10 - 20mg/l (WHO, 2011) in all the groundwater sampling locations in dry and wet seasons. COD is representative of pollution by biodegradable and chemically degradable organic matter (Elangovan &Dharmendirakumar, 2013). It is also an

indication of organic matter susceptible to oxidation by chemical oxidant which is typical of reduced organic as well as inorganic pollution in the groundwater (Bhanja & Mohanta, 2000).

xi. Total Coliform: The Total Coliform values are in the range of 0 to 35MPN/100L and 0 to 36.54MPN/100L with mean values at 11.13 and 11.58MPN/100L for the groundwater samples in dry and wet season respectively (Table 4.2). These values are higher than the WHO, 2011 recommended 10MPN/100L of water in all groundwater sampling locations in the dry and wet seasons with notable variational increase in concentrations levels in the wet season. This is representative of pollution by biodegradable and chemically degradable organic matter in the study area (Elangovan &Dharmendirakumar, 2013). These results are typical of reduced organic as well as inorganic pollution in the groundwater (Bhanja & Mohanta, 2000). The high amount of coliform during the wet season could be due to the fact that water availability favours the movement and reproduction of the organisms. Furthermore, the presence of coliform could be from collapsed septic tanks which occurs more in the wet season and movement of leachate from open dumpsites.

xii. Sodium (Na): It is a natural component of water. The mean values of sodium are observed at 9.3 and 10.34mg/l concentrations which were also in the range of 1.5 to 27.3mg/l and 1.5 to 30.5mg/l for the groundwater samples in the dry and wet seasons respectively (Table 4.2). High content of sodium in groundwater may be from the release of the soluble products during the weathering of rocks and minerals (Udayalaxmi, Himabindu &Ramadass, 2010). Higher values of Na, K, Mg and Ca in wet seasons could be attributed to the high dissolution of rock colouring the mineral of these metals. High level of Na leads to nausea, vomiting and stomach cramps. Distribution of Na is similar to that of DO, BOD and COD. Majority of the

study area has the range of less than 15mg/l. Maximum ranges of more than 20mg/l is located as small patches in the low-lying areas and in the clay zones.

xiii. Potassium (K): The K concentration mean values exist in the study area at 0.1 to 3.9mg/l and varies in ranges of 0.1 to 4.2 mg/l and 1.3 to 1.74 mg/l for groundwater samples in dry and wet season respectively. Potassium concentration is influenced by the cation exchange mechanism (Narain & Chauhan, 2000). The low values of potassium may be due to the absence of geochemical strata in the study area (Mahananda, Mohanty & Behera, 2010). Distribution of K shows similarity to that of Na, having most of its range in the study area less than 5mg/l. This range showed significant correlation with BOD in the wet seasons. Naturally, water has much lower concentrations of K as compared with Na. During weathering, K^+ tend to be either adsorbed or fixed in the soils or weathered products especially in the clay minerals. As a result, the concentration of K^+ in natural waters is relatively less. As opposed to the case of Na distribution, K also does not show any serious differential concentration.

xiv. Calcium (Ca): The mean values of calcium are found to be at 4 and 69mg/l varying from 4.1 to 90.2mg/l in the dry periods and 18.54 to 21.42mg/l in the wet periods (Tables 4.2 and Appendix II (A and B). This range coincides with the range of K, with the maximum concentration as90.2mg/l which can be related to oxidation of organic matter (Narain & Chauhan, 2000). The calcium values are within the stipulated standard by the WHO in all of the groundwater sampling locations in both seasons except for location APR. High content of calcium is recorded in few sampling stations in both dry and wet seasons and is likely caused by precipitate soaps, anionic surfactants and aniomic emulsifiers.

xv. Magnesium (Mg): Magnesium is one of the most common minerals that make water hard. The obtained Mg concentration ranged between 0.1 and 1.9mg/l in the dry season and 0.11 to 2.4mg/l in the wet season respectively, with an average concentration of 0.47and0.59mg/l in both dry and wet seasons respectively. High content of magnesium is recorded in a few sampling stations in both dry and wet seasons. The concentration of magnesium depends upon exchange equilibria and the presence of the ions like sodium. The higher concentrations of magnesium values recorded during wet season could be due to dissolution of the underground deposits of magnesium minerals of sedimentary rock (Azrina, Khoo, Idris&Razman, 2011; Vasanthavigar, Srinivasamoorthy& Chidambaram, 2010). Generally, magnesium maintains equilibrium in most waters (Ishaku et al., 2011). In the study area, Mg content is less than Ca and most of the sampled areas show levels less than 5mg/l. Maximum content of above 10mg/l is recorded in clayey and in some low-lying areas.

xvi. Sulphate (SO_4): Range of SO_4 concentration values are between 0.12 to 5.92mg/l and 0.14 to 8.08mg/l, with mean values of 1 and 1.2mg/l for samples in the dry and wet seasons respectively. The sulphate values were observed to be lower in the wet season than in the dry season which may be due to dilution effect. Sulphate in water is due to dissolved Ca/Mg/Fe.The higher sulphate concentration during the dry season could be attributed to the reduction in groundwater recharge resulting from low precipitation, higher temperature and evaporation during the dry season which, also reflects the dissolution of sulphides from interstratified peat within the geological formation. The elevated concentration of SO_4 may be also due to the fact that the Deltaic plain is a sequence of sands and silt with local intercalation of peat and sulphur-rich clays or high-level combustion of sulphur containing hydrocarbon fuels in the study area. The dissolution of sulphides such as pyrite from the

interstratified material by percolating water also produces SO_4 ions in water. Gaseous emissions from increasing heavy traffic flow and petroleum activities also contribute significant amount of sulphur to groundwater. It could also be from the direct consequence of oxidation of sulphur containing compounds after rainwater has been charged to ground water resources.

xvii. Nitrate (NO_3): The levels of nitrate are from 0.02 to 3.27mg/l and 0.01 to 4.12mg/l with average values at 0.83and 1.06mg/l for the groundwater samples in dry and wet season respectively. Nitrate pollution is strongly associated with runoff from agricultural activities (fertilizer use), leakages from septic tanks, sewage, erosion of natural deposits. The percolation of domestic sewage, industrial wastes, dumping of garbage and leakage of septic tanks enhance the nitrate value (Jameel & Hussain, 2011). Also, the higher nitrate concentration during the dry season could be attributed to the reduction in groundwater recharge resulting from low precipitation, higher temperature and evaporation during the dry season. The high concentration levels of nitrate and chloride are due to organic pollution resulting from sewage mixing, higher animal waste, poor sewerage and solid waste disposal system, and increased temperature and evapo-transpiration of water, leaky sewers, large number of septic tanks and soak pits, and practice of sewage discharge through open surface drains (Haran, 2002; Majagi, Vijaykumar & Rajashekhar, 2008; Shanthi & Ramaswamy, 2002; Sivakumar, Mohanraja & Azeez, 2000).

xviii. Chloride (Cl): Chloride parameter has values ranging from 10.3-117mg/l and 12.3-147.1mg/l, mean concentration values stand at 34.89 and 39.41mg/l in dry and wet seasons. The chloride values are within the standard requirement of 5mg/l (WHO, 2011) in both seasons. High content of chloride in groundwater at these locations may result from both

natural and anthropogenic sources such as run-off containing salts, the use of inorganic fertilizers, landfill leachates, septic tank wastes, animal feeds, industrial effluents, irrigation drainage and salt water intrusion water additives used to control microbes and disinfect water (Bundela, Sharma, Pandey, Pandey & Awasthi, 2012). Soil porosity and permeability also has a key role in building up the chloride concentration in these stations (Chanda, 1999).

xix. Bicarbonate (HCO_3): The analyzed HCO_3 levels range from 3.1 to 82.3mg/l in the wet season and 3.1 to 79.5mg/l in the dry season, and similarly, with an average value of 19.62 to 21.92mg/l in the study area. The bicarbonate values are all within the WHO recommended limit of 125mg/l at the sampling stations in wet and dry seasons. This may be due to the action of dissolution of atmospheric CO_2 and CO_3 released from organic decomposition (Umapathy, 2011). The nature of rock type in the study area is another important factor that contributes to the presence of bicarbonate. The primary source of bicarbonate ions in groundwater is the dissolution of carbonate minerals in the study area. The decay of organic matter present in the soil releases carbon dioxide (CO_2). Water charged with CO_2 dissolves carbonate minerals, as it passes through soils and rocks to give bicarbonates.

xx. Ammonium (NH_4): Ammonia recorded a mean value of 0.01mg/l, Minof 0mg/l, Max of 0.09mg/l with standard deviation of 0.02mg/l in the dry season and a mean value of 0.02mg/l. Min of 0 mg/l, Max of 0.06mg/l with standard deviation of 0.02mg/l in the wet season.The permissible limit are values lesser than 1.5mg/l in both seasons, with NCAT, SHA, EKP, UCE, UBJ 2, OSM, OGU, FGC, AJA, WAG, OKL, WAP, ESL, IGM, MAM, MOF, ROP, ESR and PTR stations recording levels below detectable limits. The presence of high values of ammonium observed could be due to dissolved gases and degradation of organics, pollution from sewage attributed to areas of poor waste management, old boreholes and are

usually localized. The average values of ammonia recorded highest in wet season compared to dry season, which could be due to acidification of water by elevated microbial degradation of organic debris and concentrated dissolved solids in wet period. Furthermore, NH_4 temporal variational increases during the seasons may be due to anthropogenic activities from surface run-off and agricultural activities (Nightingale &Simenstad, 2001).

xxi. Phosphate (PO_4): The values of phosphate are found in the range of 0.01 to 0.79 mg/l and 0.04 to 0.91 mg/l for the groundwater samples in dry and wet seasons respectively (Appendix II (A and B)), and average values of 0.19 to 0.22mg/l in both seasons. The phosphate values exceed the permissible limit of 0.3mg/l (WHO, 2011) in sampling locations EFG, APR, EFM, OGD, UGT, UBJ 1, OSA, OGB, EDJ, EDHE, OKR, ESL, ORH, SHP and ROR in wet and dry seasons. The excess concentration of phosphate may be due to percolation of domestic sewage and agricultural inputs in the study area. During the natural process of weathering, the soils/rocks gradually release the phosphorus as a phosphate ion which are soluble in water and mineralize phosphate compounds breakdown. Moreover, the phosphate levels recorded in this study are relatively high which could explain the presence of photosynthetic bacterial activity in the water.

xxii. Iron (Fe): The Fe values are in the range of 0.2 to 0.24mg/l and 0.19 to 0.26mg/l with mean values of 0.21 and 0.22mg/l for the groundwater samples in dryseason and wet season respectively. Fe values are higher in the dry season probably due to reduced groundwater recharge. The Fe values were below the permissible limit of 0.3mg/l (WHO, 2011) in all the groundwater sampling stations for the dry and wet seasons. Iron occurs naturally in soil, sediments and groundwater, and can be found in many types of rocks. The presence of iron in ground water is attributed to the nature of the geological formation, from natural deposits,

improper waste disposal sites, industrialization, natural water recharge, corrosion of iron containing metals which are part of distribution channel and water-soil/rock interaction.Surface water charged with atmospheric and biogenic CO_2 infiltrates into the subsurface and aggressively attack aluminosilicates including feldspar and micas present in the formation liberating cations such as iron, calcium, and magnesium into the water and leaving residues of clay minerals (Amangabara&Ejenma, 2012). These weather conditions resulting from long duration and intensive rainfall couple with high temperature accelerate weathering of the geologic formation in the area. The weathering processes release the iron element into waters, under oxygen-poor conditions, occurring mainly as binary iron. But under acidic and neutral, oxygen-rich conditions it becomes part of many organic and inorganic chelation complexes that are generally water soluble and the dissolved iron is mainly in the form of $Fe(OH)_2^+$ (aq) (Amangabara&Ejenma, 2012). Similarly, high values of iron recorded in the wet season could be due to acidification of water by elevated microbial degradation of organic debris and concentrated dissolved solids in wet period. The measure of deviation shows 0.01 for both seasons. This indicates that the source of contamination remains the same throughout the season.

xxiii. Cadmium (Cd): The Cd values are found to be in the range of 0.00 to 0.01mg/l and 0.00 to 0.01mg/l with mean values of 0.001mg/l and 0.003mg/l for the groundwater samples in dry and wet season respectively. Cd concentrations are higher in the wet season probably due to groundwater recharge. All locations are well below detection limits for this parameter except for 15 locations with OKU, APR, JKR, EKP, UCE, EFM, OGD, AJA, OKR, AGS, ENE, UDR, OTO and MAM having limits of <0.001mg/l in both seasons. The high Cd levels in these areas could be attributed to effluents containing heavy metals discharged by chemical

and petroleum industries in and around those areas such as paints, pigments, plastic stabilizers, mining and smelting operations, and other industrial operations such as electro plating and fossil fuel, fertilizer, and sewage sludge disposal. Cd also occurs naturally in rocks and soils and may have entered the water when there is contact with soft groundwater or surface water. High concentration of Cd in the water sample might be due to corrosion of galvanized steel pipes used for piping of water distribution. These galvanized steel pipes are plated with zinc, which usually has 1% of Cd. Similarly, Cd can also come from fittings with cadmium soldering (El-Harouny, El-Dakroory, Attalla, Hasan & Hegazy, 2008).

xxiv. Chromium (Cr): The Cr values are in the range of 0.00 to 0.002 mg/l and 0.00 to 0.002mg/l with mean values of 0.0001 and 0.0001mg/l for the groundwater samples in dry and wet season respectively. All measured locations are within the acceptable limit of 0.05mg/l. The concentration of Chromium and Copper in the study area could be attributed to the dumping of wood treated with chemicals made from salts of Arsenic, Chromium and Copper in mixed soluble formulation (as copper-chrome arsenate preservative) being used to prevent fungi and pest attack which provide a potential source of chemical spills and drainage from the treated wood within and around the refinery, which support the earlier findings of Ndiokwere, (2004). Similarly, the contamination of Cr might have also resulted from erosion of natural deposits within the surrounding areas, industrial and laboratory effluents around the study area could also be a source of Chromium, (Braide, Izonfuo, Adiukwu, Chindah&Obunwo, 2004).

xxv. Copper (Cu): Cu values are in the range of 0.01 to 0.19mg/l and 0.01 to 0.19mg/l with mean values of 0.2 and 0.2mg/l for the groundwater samples in dry and wet season respectively. Furthermore, Cu levels recorded between 0.01mg/l minimum to 0.19mg/l

maximum. Cu was not detected in OKU, APR, JKR, AJA, OKR, AGS, ENE, UDR, OTO and MAM study locations. Cu values do not show significant variation for both seasons. These values suggest industrial activities within the area which are responsible for the elevated levels of heavy metals in water.

xxvi. Lead (Pb): Seasonal comparison of lead shows that all locations where groundwater was sampled are well below the acceptable level. Values measured depict average limits of 0.01 to 0.36mg/l in the dry season concentrations and 0.01 to 0.36mg/l in the wet season. The mean values are 0.02 and 0.02mg/l in the dry and wet seasons respectively.All measured locations are within the acceptable limit of 0.01mg/l. Pb in groundwater could have resulted from indiscriminate dumping of electronic wastes, oil, batteries and oil exploration and processing activities. Lead enrichment in these areas could have resulted from NNPC refinery and petrochemical wastes in the northwestern part of the study area and from leachates associated with unregulated dumpsites that have been traditionally used for waste disposal. Also, higher concentration of Pb may be due to the piping used for the water distribution system (Hanaa & Azza, 2000) and also the surrounding soil which may have a higher amount of Pb, which may be leached into the water (Dissmeyer, 2000).

Heavy metals contamination in drinking water poses a threat to humans and is often the root cause various severe health issues such as cancer and organs (lungs, liver, kidney, bone, blood and other vital organs) damage. They can also bring about reduced mental and central nervous functions that can lead to learning difficulties, memory impairment and behaviooral issues in the form of aggression and hyperactivity. They are slow poisons to mans health as their effect is not immediate.

4.2.1.1.1 Paired sample student t-test

The result in Table 4.2 shows that the water sample parameters tested have higher mean values during the wet season except for BOD, CODand Cu. The result of the sample student t – test for the water samples also shows that parameters such as temperature, total coliform and Cd have their p – values, higher than the significance level (= 0.05), hence indicating no significant seasonal variation, while all other parameters have p – values greater than the significant levels hence showing significant seasonal variation. The filtration of water into the soil is accompanied by percolation and this could explain the reason for the non-significant seasonal variation in the concentration of most of the groundwater parameters. Comparing the seasonal variation in terms of the concentration of the parameters across the study area depicts the influence of certain factors such as precipitation, groundwater recharge and weather.

4.2.1.2 Comparison of groundwater quality parameters in warriwith WHO drinking water standards.

The results of the physico-chemical analyses and microbial composition of groundwater samples collected from the domestic water boreholes are summarized in Table 4.4. These values were compared to WHO permissible limit.

i. Temperature: The mean temperature value is$27.27 \pm 2.4^{o}\mathrm{C}$ and $27.47 \pm 2.52^{o}\mathrm{C}$ in the dry and wet seasons respectively. While the WHO permissible limit for temperature is 25^{o}C. All values for temperature are well above permissible limit except for sample locations OGD, UGT, UBJ 2, OGB, WAP, OGU, FGC, OKL, UDR, OTO and OKE in both seasons.16% of the sampled boreholes had their temperature values within WHO permissible limit and 84% were above the permissible limit in the dry season. While20% of the sampled boreholes are within limit and 80% are above the WHO permissible in the wet season. Temperature changes

could trigger changes in physical, chemical, and microbial processes in the subsurface environment, resulting in groundwater quality changes (Banks, 2008).Carbonate precipitation, silicate dissolution, and mobilization of cations (Na, NH_4, K, Mg, and Ca), heavy metals and trace elements and dissolved organic carbon (DOC) as well as progression to strongly reductive conditions, such as sulphate reducing and methanogenic conditions, could be observed (Bonte, van Breukelen&Stuyfzand, 2013b).

ii. pH: The mean pH values are 5.41 ± 0.62in the dry season and 4.49 ± 0.54 in the wet season and ranges from 4.2 to 6.7 and 3.4 to 5.9 in the dry and wet seasons respectively.All the boreholes had their pH values showing weak acidity and below the WHOpermissible limit (6.5 to 8.5) for potable drinking water. This implies that the water in these boreholes were majorly acidic and not recommended for consumption without treatment. Of all the samples of groundwater analyzed, 44% have values of pH above the average value of 4.95. This is characteristic of the acidity of the tested water. pH is most important in determining the corrosive nature of water. A sample is considered to be acidic if the pH is below 7, while it is alkaline if the pH is between 7 and 14. In the dry season, where the pH levels are relatively low, the state of other water quality parameters is affected. pH affects mucous membrane, causes bitter taste and corrosion. The lower the pH value the higher is the corrosive nature of water, pH is positively correlated with electrical conductance (Gupta, Sunita & Saharan, 2009). Acidic water can lead to corrosion of metal pipes and plumping system, while alkaline water shows disinfection in water. The water quality depletes when metals become more soluble in the water making disease causing pathogens to thrive in the water. This results in indirect health problems to humans (Khan, Shahnaz, Jehan, Rehman, Shah & Din, 2013) and also affects the geological formation (Sojobi, 2016) of the soil. The higher pH values

observed suggests that carbon dioxide, carbonate-bicarbonate equilibrium is affected more due to change in physicochemical condition (Karanth, 1987). The water could be treated with lime before use to bring pH level to the desired level. pH is changed due to different dissolved gases and solids.

iii. EC values range from 40 to 532 $\mu S/cm$ with mean concentration of$162.74 \pm 127.37 \mu S/cm$in the dry season and ranges from 46 to $678 \mu S/cm$ with mean value of $62.5 \pm 149.96 \mu S/cm$in the wet season. Concentration limits for EC in all locations are well below the WHO recommendation of $400 \mu S/cm$ apart from APR, UGT, JED, OSA, OGB and EDJ in both seasons.EC and turbidity in 22% of the boreholes are within limit while 78% were above limit in the dryseason. Conductivity does not have direct impact on human health. It is determined for such purposes such as determination of mineralization rate (existence of minerals such as potassium, calcium, and sodium) and estimating the number of chemical reagents used to treat water (Cidu, Frau & Tore, 2011; Kavcar, Sofuoglu&Sofuoglu, 2009; Khan, Hussain, Saboor, Jamila& Kim, 2013; and Muhammad, Shah & Khan, 2011). High conductivity may lead to lowering the aesthetic value of the water by giving mineral taste to the water. High conductivity increases corrosive nature of water. It is critical to monitor the EC of water if it is to be used for industrial and agricultural activities. Water with high conductivity may cause corrosion of metal surface of equipment such as boiler. It is also applicable to home appliances such as water heater system and faucets. Food-plant and habitat-forming plant species are also eliminated by excessive conductivity (Jia, Li, Qin & Liu, 2010; Katsoyiannis & Zouboulis, 2013).69% of the boreholes had their BOD, COD and DO values well within permissible limits while only 31% had values of these parameters above the permissible limit in the dry season. In the wet season 72% were within limit and 28% were above limits.

iv. Turbidity had mean values of 5.69±7.84NTU in the dry season and 6.27±7.53 NTU in the wet season. Standard WHO limits for turbidity is 5NTU.Turbidity is related to the content of diseases causing organisms in water, which may come from soil runoff. All turbidity values are below the standard recommended maximum turbidity limit set by WHO for drinking water except for locations ARB, JKR, SHA, EKP, EFM, JED, UBJ 2, OSM, WAP, EDHE, IGM, UDR, MAM, DST, OKE, MOF, FUP, SHP, ROP, ESR and ROR which were above the recommended limit. The turbidity levels for JKR, EFM, JED, PEM, ENE and UDR are low only in the wet season but are high in the dry season as a result of soil runoff. Lower turbidity values during the dry season are probably due to less groundwater recharge and infiltration. Higher levels of turbidity are associated with disease causing bacteria and indicative of potential pollution and decreased water quality.

v. Total Hardness (TH) have concentration ranges of 3.72 to 336.29mg/l, with mean level at 51.03±91.94mg/l in the dry season but 3.72 to 336.29mg/l and average level of 55.53±90.38mg/l in the wet season. The total hardness values for all sampling stations are within the WHO permissible limit of 500mg/l. High value of TH is observed in stations OKU, UGT, EDJ, BOA, ORH, MAM, DST and MOF. Poor lathering with soap; deterioration of the quality of clothes; scale forming.

vi. Total suspended solid (TSS): The mean values TSS in the dry season and wet seasons are6.88±9.18mg/l, 11.17±10.39mg/l in the wet season. 50% of the groundwater samples analyzed have concentrations of TSS below the mean value of 9.03mg/l. There is no specified limit for this parameter (WHO, 2011). This tells of the water samples being significantly clear of suspended organic and inorganic particles.

vii. The Total dissolved solid (TDS): The water samples have average values of91.16 ± 71.36mg/l in the dry season and104.52 ± 83.96mg/l in the wet season. All locations have values below the WHO recommended standards of 500mg/Lin both seasons except in locations BOA and MAM. The amounts of total solids are influenced by organic materials. TDS concentration is affected by the presence of bicarbonates, carbonates, sulphates and chlorides of calcium (Subba Rao, Gurunadhi&Guptha, 1998; Deepali, Sapna & Srivastava, 2001). TDS causes gastrointestinal irritation (Jain, Kumar & Sharma, 2003). High value of TDS influences the taste, hardness, and corrosive property of the water (Haran, 2002; Joseph & Jaiprakash, 2000; Subhadra, Barbaddha, Hazel& Dolly, 2003).The high concentrations of TDS are due to leaching of solid wastes from the ground surface as well as enhanced seepage from domestic sewages and some industrial activities within the study area. This suggests that the water is aesthetically unsatisfactory for drinking and bathing. Water containing high TDS concentration may cause laxative or constipation effects, undesirable taste, gastro-intestinal irritation, corrosion or incrustation (Ch, Sainath & Rabbani, 2016).

viii. Dissolved Oxygen (DO): The mean DO concentration values are3.22 ± 1.66mg/l in the dry season and4.29 ± 2.42mg/l in the wet season. In the dry season, locations JKR, OKR, ROP and ESR have concentration limits above the set limit of 6 (WHO, 2011), while in the wet season, locations EKP, UCE, EFM, OGD, UGT, JED, UBJ 1, UBJ 2, OSM, OSA, OGB, WAP, OGU, EDJ, EDHE, FGC, AJA, WAG, ESL, IGM, AGS, BOA, IYA, PEM, ORH, ENE, UDR, OTO, BDE, UPE, MAM, DST, OKE, MOF, FUP and ROR have levels within the standard limit. 18% of the water samples analyzed were above the standard limit, suggestive of bacterial and pollutant presence (which could be either untreated or partially treated sewage, organic discharges and also anoxic discharges) in the water. The DO values

are below the acceptable limit of 6mg/l (WHO, 2011) in most of the sampling stations. Increase in phytoplankton and microbial activity contribute to low DO values and consequently increase in BOD and COD.The low DO values don't give water the desired tastelessness. Oxygen is known to degrade metals through internal oxidation, therefore high DO values corrode water lines, boilers and heat exchangers.

ix. Biochemical oxygen demand (BOD) has mean concentration values of0.07 ± 0.36MPN/ 100l in the dry season and 0.7 ± 0.48MPN/100l in the wet season. Forty two (42) locations, OKU, ARB, NCAT, APR, SHA, EKP, UCE, EFM, UGT, JED, UBJ 1, UBJ 2, OSM, OSA, OGB, WAP, OGU, EDJ, AJA, WAG, OKL, OKR, MRQ, ESL, IGM, BOA, IYA, PEM, ORH, UDR, OTO, BDE, UPE, DST, OKE, MOF, FUP, SHP, ROP, ESR, ROR and PTR had concentration limits below the detection levels in the dry season, while in the wet season, all values were within the standard limits apart from a few others which were still below detection limits. Also, in the dry season, the concentration of BOD is completely within set limits. This is typical of water having a low degree of organic pollution. The BOD values are lower than the permissible limit of 10 mg/l (WHO, 2011) in all the groundwater sampling stations in the dry and wet seasons. Though lower than WHO permissible limit, the relatively high BOD values in some locations show that the overall groundwater quality in the study area is doubtful and it raised some concern especially in the dry season. High BOD decreases level of dissolved oxygen.

x. Chemical oxygen demand (COD) values range from concentration levels of 1.1 to 9.2mg/l, and with a mean concentration level of4.36 ± 1.89mg/l in the dry season, while it ranged from 0.3 to 9.2mg/l with a mean value of 3.92 ± 2.49mg/l in the wet season.The COD values are well below the permissible limit of 10 - 20mg/l (WHO, 2011) in all the groundwater sampling

locations in dry and wet seasons. COD is representative of pollution by biodegradable and chemically degradable organic matter (Elangovan &Dharmendirakumar, 2013). It is also an indication of organic matter susceptible to oxidation by chemical oxidant which is typical of reduced organic as well as inorganic pollution in the groundwater (Bhanja & Mohanta, 2000). Both BOD and COD are key indicators of the environmental health of a surface water supply.

xi. Total coliform: The biological parameter measured is Total Coliform counts. The bacterial composition of the groundwater analyzed had mean concentration of $11.13 \pm 11.58 MPN/100l$ and $11.58 \pm 11.19 MPN/100l$in the dry and wet seasons respectively while the WHO permissible standard is 10NMP/100l.The observed contaminations of groundwater by pathogens may be attributable to the existence of high-water table resulting from high rainfall, soil characteristics or the presence of fecal matter in the study area resulting from poor and failed septic tanks and as well as leachate from unengineered waste dumps which is common during higher recharge period of the year and the shallowness of the aquifers. The presence of coli form bacteria is indicative of feacal contamination.Bacteriologically, 54% of the boreholes had Total Coliform concentrations within the permissible limits with 46% above limit in both the dry and wet seasons. Results of the analyses of biological parameters for sampled domestic boreholes in dry season and wet season are given in Table 4.4. Domestic borehole systems can become contaminated with potentially harmful bacteria and other microorganisms. Total coliform includes organisms that can survive and grow in water. Hence, they are not used as an indicator of faecal pathogens, but they can be used to assess the cleanliness and integrity of distribution systems (USEPA, 2009). Total coliform bacteria (excluding E. coli) should be absent immediately after disinfection, and the presence of these organisms indicates inadequate treatment. The presence of total coliforms in distribution

systems and stored water supplies can reveal re-growth (WHO, 2011). its seasonal comparison states that this parameter is above the standard limit. The obtained values for the total coliform counts in the groundwater samples are significantly high (with an increased associated risk of water borne illnesses), which shows that up to 45 percent of shallow groundwater samples are hydraulically connected to on-site disposal systems and as such not fit for drinking.

xii. Sodium: Na has average limits of $9.3 \pm 6.98 mg/l$ in the dry season and mean concentrations of $10.34 \pm 7.62 mg/l$ in the wet season. These are well below WHO standard limit of 40mg/l. Sodium concentration is one of the important parameters in the classification of irrigation water. Water containing a large proportion of sodium with carbonate as predominant anion are termed alkaline water and those with chloride or sulphate as predominant anion are termed as saline water and these affects plant growth (Todd, 2007). Majority of the study area has the range of less than 15mg/l. Maximum ranges of more than 20mg/l is located as small patches in the low-lying areas and in the clay zones.

xiii. Potassium: Mean concentration values of K are $1.3 \pm 0.91 mg/l$ in the dry season and $1.74 \pm 1.22 mg/l$ in the wet season.The values of potassium are below the WHO permissible limit of 20mg/l in all the sampling locations.

xiv. Calcium: Ca concentration mean value is $18.54 \pm 16.15 mg/l$ in the dry season and $21.42 \pm 19.68 mg/l$ in the wet season. The WHO limit for Ca is 75 mg/l, values for all locations were less than 100mg/l for both seasons. The presence of Ca^{+} in groundwater is a good indicator of its hardness. The calcium values are within the stipulated standard by the WHO in all of the groundwater sampling locations in both seasons except for location APR.

The presence of calcium causes hardness of water and interferes in dyeing, textiles, paper industry etc.

xv. Magnesium: The Mg parameter had values from 0.1 to 1.9mg/l, and a mean concentration of $0.47 \pm 0.38 mg/l$, and from 0.11 to 2.4mg/l, and mean value of $0.59 \pm 0.45 mg/l$ in the dry and wet seasons respectively. Values for all locations in the study area are well below the acceptable limit. High concentration of Mg may cause laxative effect particularly on new boreholes and other problems associated with calcium in water. Mg deficiency is associated with structural and functional changes. It is essential as an activator of many enzyme systems (Narain & Chauhan, 2000). However, 78% of the boreholes had their magnesium concentrations exceeding the limit during the wet season with only 14% within the standard limit in the dry season.

xvi. Sulphate: The obtained SO_4 concentration mean values are $1 \pm 1.14 mg/l$ and $1.2 \pm 1.51 mg/l$ in the dry and wet seasons respectively. SO_4 values for all of the samples are within the WHO maximum permissible limits of 250mg/l. High limits of sulphate impart a bitter taste to water (Bhalerao & Khan, 2000).It may increase the acidity and toxicity of open-wells and borehole water resources. Sulphate in water affects taste, causes gastro-intestinal irritation and calcium sulphate scale. Its ingestion causes dehydration and laxative effects.

xvii. Nitrate: The NO_3 concentration mean value of $0.83 \pm 0.81 mg/l$ in the dry season and $1.06 \pm 1.08 mg/l$ in the wet season were recorded. The nitrate values are less than the WHO permissible limit of 50mg/lall through the sampling stations. Nitrate in drinking water is highly deleterious to human health and it is recommended that nitrate in water for domestic use be less than 10mg/l of water. Its effect on infants below the age of six months include

shortness of breath and blue-baby syndrome.High nitrate and lead levels observed have been associated with agrochemicals and wastewater from farms and homes.

xviii. Chlorine had average values of $34.89 \pm 26.69 mg/l$ for the dry season and $39.41 \pm 30.4 mg/l$ in the wet season. The values are within the standard requirement of 5mg/l by WHO in both seasons. Excessive chloride in drinking water causes eye/nose irritation, stomach discomfort and increases the corrosive character of water.

xix. Bicarbonate: The HCO_3 mean concentration value stands at $19.62 \pm 16.69 mg/l$ and $21.92 \pm 19.05 mg/l$ in the dry and wet seasons respectively. All locations have values for this parameter <125mg/l in both seasons whichare within the WHO recommended limit of 125mg/l. Carbonate causes product imbalance, unsatisfactory production and short product life. Nitrate and chloride concentration exceeding the permissible limits is an indicator of pollution. High incidence of nitrate can be attributed to be the major cause of water related diseases such as typhoid, cholera, diarrhea, jaundice and methemoglobinemia/blue baby syndrome in humans (Durfor&Baker, 1964; Hudak, 2000; WHO, 1985). Non wholesome water supply, poor sanitation and inefficient solid waste collection and disposal system worsen the situation of water contamination (Degaonkar, 2003). Furthermore, of the samples analyzed 35% of them have concentration above the mean and 65% lesser than it. These concentrations are thus fairly acceptable and are representative of the level of hardness of the water. It is clear from Table 4.2 that the concentration of cations is lower in the order; Ca<Na<K<Mg.

xx. Ammonium: Measured NH_4 levels indicate mean levels of $0.01 \pm 0.02 mg/l$ in the dry season and $0.02 \pm 0.02 mg/l$ in the wet season.Permissible WHO standard for $NH_4$is below 1.5mg/l. The values of sample concentrationsareless than 1.5mg/l in both seasons, with

NCAT, SHA, EKP, UCE, UBJ 2, OSM, OGU, FGC, AJA, WAG, OKL, WAP, ESL, IGM, MAM, MOF, ROP, ESR and PTR stations recording levels below detectable limits. NH_4 causes corrosion of copper and zinc alloys by formation of complex ions.

xxi. Phosphate: The analyzed PO_4 concentration mean value of $0.19\pm0.17mg/l$ in the dry season and $0.28\pm0.24mg/$ in the wet season were recorded. In the dry season, locations APR, EFM, UGT, UBJ 1, OSA, OGB, EDJ, OKR, ORH, SHP and ROR have values of PO_4 above the acceptable limits, and in the wet season, locations EFG, APR, EFM, OGD, UGT, UBJ 1, OSA, OGB, EDHE, OKR, ESL, ORH, SHP and ROR have concentration limits above recommended standards. The phosphate values exceed the permissible limit of 0.3mg/l (WHO, 2011) in sampling locations EFG, APR, EFM, OGD, UGT, UBJ 1, OSA, OGB, EDJ, EDHE, OKR, ESL, ORH, SHP and ROR in wet and dry seasons. Persistence of high concentrations of phosphate in groundwater body can reduce its recreational use and also inhibit its use, stimulate microbial growth, rancidity and mold growth (Oluyemi, Adekunle, Adenuga& Makinde, 2010).75% of the boreholes had their PO_4 values within permissible limit in both seasons.

xxii. Iron: The iron content of the study location suggests mean concentration value of$0.21\pm0.01mg/l$ in the dry season and $0.22\pm0.01mg/l$ in the wet season. The iron levels in both seasons show concentration levels well below WHO standard limit of 0.3mg/l for drinking water. Also, iron was discovered to show increased concentration levels in all study locations for the wet season over the dry, except in SHA and FUP areas. This is suggestive of the action of seepage and corrosion infiltrating the groundwater in the study area. Thus, indicating toxicity, and its consumption would cause costly damages and other issues. Iron in water gives it a reddish-brown colour and increase turbidity (Mkwate *et al.*, 2017). Presence

of Iron in drinking water in large quantity is responsible for haemochromtosis, impart objectionable taste and colour (WHO, 1985; Rowe, Quigley & Booker, 1995). Iron will cause staining of laundry, dishes, utensils and even glassware. Iron can affect the flavours and colour of food and water. It may react with tannins in coffee, tea and some alcoholic beverages to produce a black sludge which affects both taste and appearance (Agunwamba, 2000; Al-layla, Shamim & Middle-Brooks1978).This study further supports the report of high Iron concentrations in groundwater in Nigeria (WHO, 2006).

xxiii. Cadmium: The mean value of cadmium is $0.00 \pm 0.002 mg/l$ in the dry season, and $0.00 \pm 0.002 mg/l$ in the wet season. All locations are well above detection limits for this parameter except for 21 locations with IYA and ESR having limits of <0.001mg/l in both seasons. The Cd values are all within the permissible limit of 0.003mg/l in all the sampling locations in dry and wet seasons except for stations JED, UBJ 1 and UBJ 2 which were observed to be more than the WHO standard limit in both seasons. The groundwater in these areas may not be safe for drinking purpose especially without treatment because of heavy metal contamination (Chamon, Blum, Gerzabek, Ullah, Rahman & Mondol, 2005). Excess Cadmium in drinking water quality can lead to severe gastro-intestinal upset (WHO, 1984) and also renal or kidney problems (Schmoll, Howard, Chilton & Chorus, 2006). Cadmium in water causes carcinogenic ailments (Dahunsi, Owamah, Ayandiran&Oranusi, 2014; Khan et al., 2013), vomiting and diarrhea and lower levels for longer period can cause kidney impairment (USEPA, 1993; Mkwate *et al.*, 2017).

xxiv. Chromium: the mean concentration of $0.00 \pm 0.001 mg/l$ in the dry season and$0.00 \pm 0.001 mg/l$ in the wet season were recorded. All measured locations are within the acceptable limit of 0.05mg/l. The Cr values did not exceed the permissible limit of 0.05mg/l

(WHO, 2011) in all the groundwater sampling stations in dry and wet seasons except for stations JED, UBJ 1 and UBJ 2 which showed increased concentrations more than the required limit.Though, Chromium was found to be within the standard limit of WHO (2006) for drinking water quality, high concentration of Chromium could cause digestive tract cancer in man, or increase the risk of lung cancer in man (Todd & Mays, 2005).

xxv. Copper: The mean Cu concentration value was $0.2 \pm 0.246 mg/l$ in the dry season and$0.2 \pm 0.246 mg/l$ in the wet season. The Cu values are lower than the permissible limit of 2mg/l (WHO, 2011) in all the groundwater sampling stations in dry and wet seasons except for stations JED, UBJ 2, OSM and EDHE which were in excess concentrations of 2mg/l. Copper in water affects both its quality and safety. Presence of Copper in excess in drinking water is responsible for nausea (Araya, Gowing & Dise, 2010). A high level of copper in water gives it a metallic or unpleasant bitter taste. Consumption of high level of copper can cause nausea, vomiting, diarrhea, gastric (stomach) complaints and headache. Cu was not detected in ARB, NCAT, OGD, EDHE, IGM, AGS, OKE, UGT, OSA, OKL, OKR and MRQ study locations.

xxvi. Lead: the mean values are $0.02 \pm 0.023 mg/l$ and $0.02 \pm 0.023 mg/l$ for the dry and wet seasons. The Pb values were all below the permissible limit of 0.01mg/l (Table 4.4) in all the groundwater sampling stations in dry and wet seasons. Locations SHP and ROR showed increased Pb content in the dry season while, locations UDR and ROP revealed reduced Pb concentration in the wet season. High concentrations cause kidney damage, brain damage, miscarriage in pregnant woman, convulsion and neurological damage in children and damage to the male reproductive organ (Khan et al., 2013; Owamah, 2019; USEPA, 1993). High Pb levels are generally indicative of potential pollution and decreased water quality. Cadmium

and Pb, which have no known beneficial effects, may become toxic to plants and animals if their concentrations exceed certain values (Adriano, 1996).

From the foregoing, it could be inferred that, the groundwater quality in Warri and its environs is contaminated more in the wet season than in the dry season and the reason for this, are as highlighted in Section 4.2.1.2 above. The level of detected heavy metals in groundwater quality in the study area further confirm the findings of (Tengrui, Al-Harbawi, Lin, Jun & Long, 2007) who reported that, these metals are brought into groundwater system by human activities such as industrial, landfill among others.

4.2.1.3 Water quality index (WQI) of Warri

From the results of WQI classification, only 34% were placed as Excellent, 44% were Good, 10% were Poor, 10% were Very poor and 2% were unsuitable for drinking purposes in the dry season, while in the wet season only 32% were placed as Excellent, 40% were Good, 12% were Poor, 14% were Very poor and 2% were unsuitable for drinking as stated earlier in Table 4.6. Though the concentration of water quality parameters where higher in the wet season, the WQI was better in the wet season. This could be attributed to dilution and some of the pollutants that would have infiltrated and percolated into groundwater are being transported into surrounding rivers and creeks. Also, WQI is based on chemical parameters only as biological assessments are not included in WQI evaluation. From the rating, domestic boreholes in Warri are moderately suitable for drinking but will require treatment. On the whole, the studied locations significantly indicate contamination from pollution sources, however, this influence is only for a few locations as most locations suggests otherwise. Thus,

the groundwater condition of Warri and its environs are not adversely overwhelmed. Figures 4.2a and 4.2b present the WQI zoning map.

From the groundwater quality parameters compared to the WHO standard and results from the evaluated WQI, it is recommended that for optimal water quality for domestic use, the water from the boreholes should be treated at least by chlorination. This is to ensure that the water from these locations don't impact the health of the consumers negatively.

4.2.2 Regression prediction models of water quality parameter

Regression model is quite useful in characterizing the relationship and dependence between the parameters analyzed. This could be used in the study to explain the nature of the dependent variables and how they are influenced by the independent variables. Only correlation coefficients above 0.7 were chosen since these indicated very high correlation.

4.2.2.1 Correlation analysis of water quality parameters

Correlation matrix for different water quality parameters along with the significance level (2 tailed) are shown in Tables 4.10(a-o) for both dry and wet seasons. Results of the statistical analysis which are shown Tables 4.10(a-o) gave an indication that EC and TDS have significantly high and positive correlationwith Na, K, Ca, Mg, SO_4, NO_3, Cl, PO_4 and HCO_3in both seasons but weak and moderate correlation with NH_4 in the dry and wet seasons respectively.The R values between EC/TDS and the water quality parameters are: Na(0.8876/0.888), K(0.7218/7228),Ca(0.9823/0.9821), Mg(0.8574/0.8574), SO_4(0.9356/0.9359), NO_3(0.8985/0.8993), Cl(0.9906/0.9906), PO_4(0.8072/0.8075 and HCO_3(0.9622/0.9622)in the dry season and Na(0.8801/0.8805), K(0.7462/746), Ca(0.9845/0.9845), Mg(0.9062/0.9064), SO_4(0.9456/0.9458), NO_3(0.9292/0.929),

Cl(0.9922/0.9922), PO_4(0.8753/0.8749) and HCO_3(0.9722/0.9791) in the wet season. The EC/TDS R values for NH_4 are (0.3534/0.353) and (0.573/0.574) for dry and wet seasons respectively. The study showed good correlation between EC and other water quality parameters and also showed that multiple regression model can predict EC at 5% level of significance (Adhikari & Mal, 2019). Only pH showed significantly strong but negative correlation with the heavy metals in both seasons except for Fe that is positive. The results of R values of pH for the heavy metals (dry/wet seasons) are Fe(0.9541/0.9542), Cd(-0.914/-0.914), Cr(-0.928/-0.928), Cu(-0.852/-0.852) and Pb(-0.848/-0.848).

Also, from the correlation results, it is observed that EC and TDS are strongly correlated with a correlation coefficient of one (1) as expressed by Rusydi, (2018). The relationship is not always linear and is strongly influenced by salinity and material content. The analysis of TDS concentration from EC value can be used to give an overview of water quality (Rusydi, 2018).

4.2.2.2 Regression models of water quality parameters

Results of multiple regression model in predicting some waterbqualiy parameters are presented in Table 4.10 and Table 4.11. Regression coefficients represent the mean change in the response variable for one unit of change in the predictor variable while holding other predictors in the model constant. The independent variables such as EC and TDS were significant in predicting values of the dependent variables. The multiple R^2 values indicate the variability in Na, K, Ca, Mg, SO_4, NO_3, Cl, PO_4 and HCO_3 in both seasonsamdcould be ascribed to the combined effect of EC and TDS. This is in line with a study by Adhikari and Mal, (2019). They studied statistical approaches for hydro geochemical characterization of groundwater in west Delhi, India. The study showed good correlation between EC and other water quality parameters. The regression multiple correlations (R) of all dependent variables

with some insitu groundwater independent variable parameters obtained were well above 0.7000 and suggests that EC and TDShad strong relationship with dependent variables but with the exception of NH_4 which is less than 0.4 and 0.6 in both seasons. pH showed a strong negative relationship with Cd, Cr, Cu and Pb with coefficient of correlation values.This is supported in the regression equation (model) obtained for each groundwater parameter.

4.2.2.3 Validation of regression equation for predicting cations and anions in the study area in both dry season and wet seas*on*

From Tables 4.16(a – n) and 4.20(a – n), the residuals (difference between the measured values and the predicted values) of the concentration varies from 0 to $\pm$ 1.5 which shoed that there are no much variations between the predicted concentrations and the measured concentrations. The developed equations can be utilized for predicting the mentioned constituents in order to have firsthand information on water quality before detailed laboratory analysis where necessary. This will encourage monitoring of groundwater quality by giving an insight into the concentration of cations and anions within the study area, save time and resources.

4.2.3 Geostatistics (Kriging Interpolation)

Results from the kriging interpolation are discussed in the subsections below.

4.2.3.1 Distribution of data set

From the normality check using plotted histograms in the dry season, it was observed that data set of Temperature, EC, Turbidity, TH, TSS, TDS, Total Coli, SO_4, NO_3, PO_4, Fe, Cd, Cr, Cu and Pb were not skewed implying they were normally distributed and satisfied

normality check. Other parameters whose data did not show normal distribution were normalized/transformed by the logarithmic and Box-Cox transformations in the ArcGIS 6.0 software. NH_4 were transformed by Box Cox. While pH, DO, BOD, COD, Na, K, Ca, Mg, Cl and HCO_3violated normal distribution and were transformed using the logarithmic transformation. In the wet season, pH, DO, BOD, Total Coli, SO_4, NO_3, Fe, Cd, Cr, Cu and Pb were normally distributed and were not transformed. Temperature, EC, COD, HCO_3 and NH_4 were transformed through Box Cox. While logarithmic transformation was the best transformation for TH, TDS, Na, K, Ca, Mg, Cl and PO_4. The criteria for adopting the best transformation was based on the transformation that produced a skewness of or close to zero (0) and a kurtosis of nearly three (3) with a mean and media values almost the same. The best transformations for water quality parameters for both seasons are presented in Table 4.21.

4.2.3.2 Trend of groundwater quality parameters

The results obtained from the trend analysis of the geostatistical analyst tool for the groundwater quality parameters showed flat lines represented in red and blue indicating that there was no trend between sampled points i.e.,large-scale trends were absent.

4.2.3.3 Fitted semivariograms

In dry season, exponential model was best fitted for seven (7) water quality parameters namely pH, Turbidity, TDS, COD, Na, Fe and Cd. K-bessel semivariogram model was best fitted for Temperature, K and HCO_3. EC, TH and Cr were best fitted with Rational Quadratic model. Circular model was used for TSS, Total Coliform and NO_3 while Gaussian semivariogram model was fitted for DO and Ca. Also, J-bessel model was used for BOD. Hole Effect model was used for Mg, SO_4, NH_4 and Cu. Stable model was used for Cl.

Tetraspherical model was the best fitted model for PO_4. Pb was best fitted with Pentaspherical model. The results showed that the best semivariogram model based on RMSE varies for each water quality parameter. The best fitted semivariograms for each water quality parameter are presented in Tables 4.24 and 4.25.

In wet season, Exponential and J-bessel model was best fitted models for five (5) water quality parameters each, namely TH, TDS, Na, PO_4, Fe and Turbidity, Ca, Pb, DO, COD respectively. Temperature and BOD were best fitted with K-bessel model. Rational Quadratic model was best fitted for pH, EC, Cl and Cu. Circular model was best fitted for K, NO_3 and HCO_3. The Gaussian semivariogram model was best fitted for Total Coliform and NH_4, while SO_4, Cd and Cr were best fitted with Hole Effect. TSS and Mg also, were best fitted with Stable semivariogram model. Fitted semivariogram models for each of the water quality parameter provided information about the range, nugget and partial sill (model parameters) which are used to measure the degree of spatial dependency of sampled borehole points as a result of distance between them (Bohling, 2005). It also provides the input parameters that are utilized for the Kriging interpolation.

4.2.3.4 Spatial dependency (autocorrelation)

The water quality parameters showed relatively moderate degree of spatial dependency which made it possible to represent water quality phenomenon within the study area. Turbidity, TH, TDS, BOD, Total Coliform, K, Ca, Mg, NH_4, PO_4, Cd, Cr and Pb showed strong spatial dependency, pH, EC, TSS, SO_4, HCO_3, Fe and Cu were of weak spatial dependency and temperature, DO, COD, Na, NO_3 and Cl showed moderate spatial dependency in the dry season. In the wet season, TH, TDS, DO, BOD, Total Coliform, K, Cl, NH_4, PO_4 and Pb were of weak spatial dependency, temperature, EC, turbidity, COD, Ca, NO_3, Cr and Cu showed

moderate spatial dependency, while pH, TSS, Na, Mg, SO_4, HCO_3, Fe and Cd showed strong spatial dependency.

4.2.3.5 Cross validation

The objective of cross-validation is to help make an informed decision about which model provides the most accurate predictions. It gives the researcher an idea of how well the model predicts the unknown values inorder to assess prediction performances of the models. Measurement errors could have been due to errors in measurement devices, human recording errors, changes in measurement conditions and data integration (Bohling, 2005). The primary use for this tool is to compare the predicted value to the observed value in order to obtain useful information about some of your model parameters. The statistics calculated on the prediction errors serve as diagnostics that indicate whether the model is reasonable for decision making and map production. To judge if a model provides accurate predictions is verified by:

a. The predictions are unbiased, indicated by a mean prediction error close to 0.
b. The standard errors are accurate, indicated by a root-mean-square standardized prediction error close to 1.
c. The predictions do not deviate much from the measured values, indicated by root-mean-square error and average standard error that are as small as possible.

The ratio between the predicted and the measured values were close to a line with a slope 1:1 and having R^2 close to 1(0.875 – 0.985). The prediction errors were also found to be minimal. The prediction results showed that the mean errors were close to 0, the root mean square error and the average standard error were small and the root mean square-standardized errors were

close to 1. The best fitted model parameters and degree of spatial dependency are in Tables 4.27 and 4.28 for dry and wet seasons.

4.2.3.6 Groundwater prediction maps.

The prediction maps showed the concentration of water quality parameters in the study area. The maps identified areas that are most sensitive and as such needed protective measures and continuous monitoring. These areas have Warri River cutting across them thus accumulating the highest concentration of contaminants through runoff, industrial and sewage discharge, permeating into groundwater. Also, there is a regional groundwater flow from the East to West as well as the North to the South as a result of water finding its path (into the river), and with rainfall as the most recharging source. Therefore, a lot of contaminants tend to accumulate and infiltrate into the groundwater within areas close to the Warri River. The centre of the study area is a built-up zone which also shows the impact of urbanization and other activities on groundwater quality. Variation map through ArcGIS show these sensitive zones under threat and prone to danger for serious monitoring and decision making. The prediction maps of the spatial distribution of groundwater quality parameters using Ordinary Kriging method in ArcGIS geostatistical wizard aretherefore evaluated below.

The prediction maps in Appendix XA(a) and Appendix XB(a) showed the spatial variation of groundwater temperaturein the study area.The lower temperatures distribution during the dry season are probably as a result of the harmattan cold which causes water temperature to drop. From the map, it is seen that water temperature levels range from 31.15^0C through 32.20^0C in Otokutu, Benin-Warri Road, NPA Express Road, Refinery Road, Airport Road, Deco Road and Warri Town areas dropping slightly and steadily to 28.72^0C from Ogbeijoh, Opete, PTI

Road, Osubi Road, Ajamimogha, Okumagba Layout and Osubi Airport areas down to 23.64^0C towards Crawford Creek, Ubeji 1, Ubeji 2, Ogunu and Pessu Market around Dodo Island and Warri River in the dry season. However, in the wet season, the water temperature levels show significant increases in Enerhen Road, Effurun Market and Jakpa Road by Okumagba Estate and Warri-Sapele Road. Highest 30.49^oC-32.2^oC within Effurun and Enerhen while majority of the study area has its temperature well within permissible standards. The refinery does not have adverse impact on the temperature of groundwater during the dry season.

In Appendix XA(b)and Appendix XB(b), the spatial distribution map of pH showed that the study area from the dry to wet season showed comparable increases due to high water levels causing scaling. Low values of pH are found majorly in Warri GRA, Warri Portand Bendel Estate areas followed by some parts like Ogborode, Effurun Market, FUPRE, Pessu Market, Iyara, Okuokoko, Osubi Market, Mofor, Federal Government College, Effurun GRA, Agbassa and Udu Road areas indicating acidic concentrations levels of groundwater, through PTI Road, DSC Township, Osubi Airport, Shagholoh, Warri GRA, Okere Road,Ogunu and at Urhobo College Effurun locations. Areas that are less populated to include PTI Road, FUPRE, Warri GRA, DSC Township, Udu Road, Bowen Avenue, Enerhen and Urhobo College Effurun, have higher pH values ranging from 5.61 to 5.90 indicating slightly acidic levels of groundwater conditions in the dry season. This may be due to more pollution of water bodies from man-made activities such as release of domestic sewage and industrial effluents to water bodies. In dry season, the higher level of pH observed was in central and south western parts of the study area. In the rainy season, the higher level of pH was distributed in northern parts of the study area. The reason for increased pH level in coastal

region is related to the chloride of seawater ormarine clay (Anbazhagan, 2004; Anitha, Charmaine & Nagaraja, 2011; Tjandra, Kondhoh&Mohammed, 2003). Also, in the wet season, its acidity spread through to Mammy Market, Edjeba Housing Estate, Ughoton, Niger CAT, Iyara, Essi Layout and Udu Road areas, with similar reduction in water acidity in Ubeji 1, Ubeji 2, Okumagba Estate, Ogunu, Esisi Road, Upper Erejuwah and Edjeba Housing Estate axis areas. This increase in pH levels result in the acidic conditions of water in the dry season becoming fairly neutral to alkaline in the wet season. pH levels are high in areas with heavy vehicular movements especially,in Warri town and Warri Port Road. While about 67% of the study area is acidic with pH values between 4.17 to 5.84.

Electric conductivity of water relates to the total concentration of dissolved ions in the water. The spatial distribution maps of EC in Figures 4.8 and 4.9 indicate high levels of EC in central and northern parts of the study area in both seasons. These high levels of ECare as a result of influences from domestic and industrial wastes, agricultural runoff and seawater intrusion in the concerned areas. The recommended limit for EC is 400 $\mu S/cm$.Low EC ranges in the dry season, maybe due to reduced ionic concentrations. But the Ubeji 1, Ubeji 2, PTI Road and Orhuwhorun areas showed concentration levels (46.00 to 327.55 $\mu S/cm$) more than the other areas. This may be due to introduction of substances from sewage and runoff water that accumulates at the downstream section of the river located in Crawford Creek through NNPC Housing Complex, where the contaminants percolate into the groundwater especially during rainy season. In the dry season (Figures 4.8 and 4.9), the maximum concentration levels decreased from 532.00 $\mu S/cm$ to 456.14 $\mu S/cm$ in Odeitsekri, Shoprite Delta Mall, Ekpan, Deco Road, Ovwian and Benin-Warri Road areas which may thus, be due to reduction in infiltration and leaching of substances into groundwater. EC is

highest in areas with electronic wastes, and from the map ranges from 381.09 to 532.00 $\mu S/cm$. These areas include; Edjebah, Okumagba Estate, Airport Road and Osubi Airport.The distribution map of EC for wet season showed that the concentration distribution is still within the desirable standard for drinking apart from Dodo Island, Bokodo, Airport Road, Enerhen Road and Osubi Road locations. These concentrations in the wet season vary spatially from 468.21 – 678$\mu S/cm$.Areaswithinacceptable limits of 40.00mg/l to 381.09$\mu S/cm$and 46.00 to 327.55$\mu S/cm$are in locations close to Ekpan, Jakpa Road, Uguwague, DSC Road, PTI Road, Niger CAT, DSC Township and Orhuwhorunthrough to Egiegi, Egini, Mammy Market, Aladja as well asOsubi Market in addition, continuing intoWarri GRA and Okere Road, but steadily decreasing further in Upper Erejuwah, Esisi Road, Udu Road, Igbudu Market, Mofor and Okuokokoaxis along Warri Port Road andDeco Roadbefore terminating at Ogbeijoh.

Turbidity in water usually results from the underlying geologic formation. Values are generally within the range of 0.00 to 37.53NTU. From the spatial variation map (Appendix XA(d) and Appendix XB(d)), turbidity levels in the dry season indicate value ranges from 0.09 to 28.49NTU spreading out through all areas in Warri except for Okumagba Estate,Robbinson Plaza, Warri GRA, Warri Port, Bowen Avenue, Iyara, Ugbuwague, Agbassa, Urhobo College Effurun, DSC Township, Otokutu, Okuokoko,Osubi Airport and Mammy Marketareas that showed the highest concentration levels, and shrinking in further during the wet season to areas includingOsubi Road,Effurun GRA, Osubi Market, Okumagba Layout, Upper Erejuwah and Esisi Road areas through to Ajamimogha and thenEdjebah and Udu Road areas due to increased levels of precipitation.

Hardness is attributed principally to Ca and Mg. Hardness also considered as total hardness is expressed in mg/l of equivalent $CaCO_3$.Most parts of the study area have hard water, as

hardness is more than 8.27mg/l. Every part of Warri, however, has hardness values below the desirable limits, DSC Road,Mofor, DSC Township, Otokutu andOrhuwhorunsettlements have been reported of hardness more than 142mg/l. TH is high at the south western part towards Egiegi and moderate in Aladja, Ogbeijoh, Jakpa Road, Effurun Market, Osubi Airport andEnerhen. Increased levels of TH were also observed in Delta Steel Company, Opete, Okuokoko, Osubi Road, Ogunu Road, Warri Port, Crawford Creek, Bokodo, Shagholoh and the Refineryvicinity that reduce spatially down the variation map (Appendix XA(e) and Appendix XB(e)) through toOgbeijoh, Benin-Warri Road, Warri Port Road and Ejiniin the dry season. These levels show exponential increases all through the same areas of the variation map in the wet season due to percolation of industrial and domestic wastes in these locations. Hard water is not good for industrial purposes as it is hard, but it can be used for domestic purposes as there is no considerable health effect due to hardness apart from the fact that it forms scum in pipes and does not form lather with soap easily.

High TSS values of about 36.28-39.93mg/l were observed around a major abattoir in Udu Harbour and areas aroundOrhuwhorun, Ekete and Ogbeijoh where the effluents are discharged into a moving stream and thereafter find their way eventually into the ground.The spatial distribution map of TSS in Appendix XA(f) and Appendix XB(f) reveal that concentration levels are generally low for the groundwater conditions in the study area for this parameter. Levels ranges from 0.00mg/l, in Ogborode, Ughoton, Jeddo, Ugbuwague, Warri Port, Aladja and Osubi Airport axis showing variational increases through to every other sampling area, in Okere Road, OgunuRoad, Federal Government College, Okumagbe Estate, Udu Road, Urhobo College Effurun and DSC Road down to 42.00mg/l concentration levels in the dry season. Increasingly low values of this parameter, in the dry season, are recorded at

averages of 7.68mg/l from Jeddo, Army Barracks, Jakpa Road, Effurun Market, Warri Port Road, Ekete, DSC Township, Warri GRA, Ogbeijoh and Egiegi areas spreading outward to cover the entire map of the study area, to 1.00mg/l concentration levels. This variation interchanges in the wet season at OsubiAirport, Deco Road, Upper Erejuwahand Okuokoko areas where groundwater conditions record low levels of TSS and then increase centrally through to other places to include, Ifie, Refinery, Ekpan, NPA Express Road, Niger CAT, Refinery Road, Egini and Shoprite Delta Mall areas together with Dodo Island, Bokodo, NNPC Housing Complex, Edjeba Housing Estate, Ogunu, Delta Steel Company, Ovwian and Ugbuwagueas well as Bowen Avenue, Essi Layout,Iyara, Pessu Market,Enerhen Road, Robbinson Plaza, Opete, Otokutu and Warri Port Road locations ranging highest in concentration levels. The presence of petroleum and petroleum related activities caused increase in levels of TSS in the wet season than the dry season due to effluent discharges.

In Appendix XA(g) and Appendix XB(g), DO levels in groundwater exceeded the limit for about 38% of the study area more than the desirable limit set at 6mg/l. High DO concentrations occur during wet season as a result of aeration in the atmosphere through precipitation (Sisodia and Moundiotiya, 2006). The river channel experiences oxygen diffusion which increases the oxygen holding capacity. In Appendix XB(g), the affected areas reduced because high temperature decreases the oxygen holding capacity of water (Sisodia and Moundiotiya, 2006). Spatial variation for the wet season includes average values of 1.9 through to 9.6mg/l all through the study area indicating loss of this parameter in concentration levels which may be due to factors like, hightemperature, waste dumps percolation and thereby reducing microbial activity in the water.

Spatial distribution map (Appendix XA(h) and Appendix XB(h)) of BOD for the dry season shows that areas around Delta Steel Company, Udu Road, Odeitsekri, Federal Government College, Agbassa,Igbudu Market, Upper Erejuwah,Ughoton, Ogborode, Jeddo, Ubeji 1, Ubeji 2 and Refineryaxis record highest with values ranging from 0.60 to 1.00mg/l spreading out radially through the map covering all other areas of the study area to an average low of 0.05mg/l especially in Warri Town and Ekpan areas. The high BOD during the wet season could be due to thepresence of decomposable organic matter (clay), percolation of leachate from solid waste dump sites, organic, sewage, and industrial wastes (Mishra et al., 2003). BOD value higher than 6mg/l means organic contamination (rise in concentration) even when the groundwater recharge increases in the wet season. Value ranges in the wet season are much higher than that of the dry, with Bokodo, Dodo Island, Aladja, Delta Steel Company, Egini, Orhuwhorun, Otokutu and Warri Port Road axis starting out with levels less than 1mg/l through to more than 2mg/l in Osubi Airport, Osubi Road, PTI Road, Effurun Market, FUPRE, NNPC Housing Complex, Jakpa Road, Ekpan, Refinery Road, Marine Quarters and NPA Express Road areas.

The spatial distribution map of COD in Appendix XA(i) and Appendix XB(i) showed that the concentration level is within the desirable limit of 10mg/l. COD concentration of groundwater poses no health risks in both seasons. COD limits are relatively low in areas around Dodo Island, Bokodo, Ifie, Crawford Creek, Odeitsekri, Ogunu Road, Deco Road, Ekpan, Jeddo, Ugbuwague, Okere Road, PTI Road, Enerhen, Mammy Market and Benin Warri Road axis. These limits further show spatial variation increasing towards the north and south west in places around Refinery, Warri Sapele Road, Delta Steel Company, Egiegi, Egini, DSC Road, Ekete, Warri Port Road, Otokutu, Ovwian, Osubi Road, Osubi Airport, Opete and Jakpa Road

areas that increase exponentially northwards in Refinery Road, Shoprite Delta Malland Ogbeijoh together with NNPC Housing Complex and Aladja in the dry season. But in the wet season, limits reach high levels in places around Osubi Airport, Osubi Road, Ogbeijoh, Aladja, Delta Steel Company, Effurun, Shoprite Delta Mall, Warri Port Road and Warri Town. Similarly, Deco Road, Ekete, Mofor, Egeigi, Warri Sapele Road, Ovwian, Refinery, Odeitsekri and PTI Road axis show averages between 3.70 to 6.20mg/l which reduce further centrally from Ifie, Jeddo, Crawford Creek Island, Ogunu Road, Airport Road and Opete axis.

These values of Total Coliform are higher than the WHO (2011) recommended 10MPN/100L of water in all groundwater sampling locations in the dry and wet seasons with notable variational increase in concentrations levels in the wet season. This is representative of pollution by biodegradable and chemically degradable organic matter in the study area (Elangovan & Dharmendirakumar, 2013). The spatial variation of Total Coliform in the dry season indicates its increased distribution centrally in Egeigi, Mofor,Delta State Company,Warri GRA, Upper Erejuwah, Robbinson Plaza, Ogunu Road, Ughoton, Ogborode, Jeddo, NPA Express Road, Shoprite Delta Mall, PTI Road, Effurun Market, Effurun GRA, Otokutu and Osubi Road areas throughout all other areas.From the map, rise in concentration excesses occur between 3.36 to 23.01MPN/100L in the wet season, however, spatial increases are felt in averages between 12.36 to 34.45MPN/100L with the highest values located around Udu Road, Enerhen, Ogunuand Osubi Airport areas,as depicted in Appendix XA(j) and Appendix XB(j).

The spatial distribution map of sodium (Na) shows that concentration of sodium is below the WHO bench mark limit (40 mg/l) in north and south western parts of the study area. The map, Appendix XA(k) show a higher concentration in the central and northern sectors of the study

area in the dry season. It indicates that the level of Na in groundwater is attributed to the direct cation exchange process through the seawater – freshwater incursion whereas in the wet season Na concentration was high compared to the dry season, attributable to the rainfall in the study area. The desirable limit for sodium (Na) in drinking water is 200mg/l. In all parts of the study area as shown in Appendix XA(k) and Appendix XB(k), high values of Na are due to silicate weathering and dissolution of soil salts (Narshima et al., 2013). Spatial distribution range in exponential increases from Ogbeijoh and Egeigi areas through to Ughoton, Ogborode, Shagholoh, Jeddo, Niger CAT, Army Barracks, Mammy Market, Urhobo College Effurun, Enerhen, Mofor, DSC Townshipand DSC Road locations in the dry season. The distribution map of Na shows its variation in reduced levels around Delta Steel Company, Warri Sapele Road, Bowen Avenue, Agbassa,Federal Government College, Ugbuwague, Warri Port, Warri GRA, Odeitsekri and Udu Road areas which then increases radially throughout the study area reaching a record high of 30.50mg/l in places around Airport Road, Bokodo, Jeddo and Osubi Airport in the wet season.

Spatial variation map of potassium (K) in Appendix XA(l) and Appendix XB(l) exhibit the same pattern with Na. K distribution in Bokodo, Dodo Island, Jeddo and Ifie areas towards the Warri River, showed highest concentration more than other parts of the study area in the dry season averaging at 3.51mg/l. There is no guideline limit set for potassium (EU, 2014; NSDWQ, 2007). Concentrations of K normally found in drinking water are generally low and do not pose health concerns (WHO, 2008). In the wet season therefore, the K concentrations show increased variation in concentration levels that reached a range of 3.41 to 4.20mg/l and least at 0.1 to 0.33mg/l. Low K concentration levels are seen in Warri Central through Ugbuwague, Pessu Market, Essi Layout, Iyara, Bowen Avenue, Aladja, Igbudu Market, Warri

Town, Warri Port, Ajamimogha, Upper Erejuwah, Warri Sapele Road, DSC Road, Otokutu, Okuokoko and Osubi Airport areas. All around of study area show that the concentration level of potassium in groundwater is lower than the WHO desirable limit of 20 mg/l.

The desirable limit of Calcium (Ca) in drinking water is 75mg/l. Spatial variation map of Ca Appendix XA(m) and Appendix XB(m) showed its distribution in Edjeba Housing Estate, Ekpan, Jakpa Road, NPA Express Road, Marine Quarters, Refinery Road, Deco Road, Ogbeijoh, Enerhen Road, Okuokoko and Warri Port Roadareas as well as Okere Road, Udu Road, Mofor, Ekete, DSC Road, DSC Township, Opete, FUPRE, Urhobo College Effurun, Otokutu, Shoprite Delta Mall, Okumagba Estate, Okumagba Layout and Warri Townareas and highest at Jeddo, Ubeji 1, Ubeji 2, Ogunu Road, Bokodo, Effurun, Okuokoko and Orhuwhorunareas which are within the stipulated standard by the WHO, in all of the groundwater sampling locations in both seasons. High content of calcium is recorded in few sampling stations in both dry and wet seasons, with increases in the wet season in ranges 1.15-1.49mg/l noticeable in NPA Express Road, Otokutu, Effurun GRA, Ekpan, Jakpa Road, Deco Road, Ogbeijoh, Aladja, Egeigi, Egini, Essi Layout, Ovwian, Opete, Warri Port Road, PTI Road, Shoprite Delta Mall, Refinery and Refinery Road areas. High amount of Ca in the area may be attributed to geological formation encountered in the flow history (Narshima et al., 2013). Higher Ca is also an indication of water hardness.The spatial distribution map shows that groundwater of the north and central partshas concentration levels of calcium above the desirable limit. While most of other parts show the concentration level of calcium within the desirable limit.

The spatial variation map of Mg in Appendix XA(o) and Appendix XB(o) revealed that the concentration of magnesium in domestic boreholes is less than the WHO desirable limit

(30mg/l) in all parts of the study area. The higher values are found in Ubeji 1, Ubeji 2, Bokodo, Jeddo, Ogborode, Shagholoh and Ekpan areas. The values decrease as it spreads out from the northern and south western axes in both seasons. Magnesium appears to be of the same range towards the northern parts of the study area in the dry and wet seasons. Higher Mg is due to dissolution of magnesium calcite, gypsum and dolomite from source rock. It is an indication that groundwater within these areas is generally hard. Very small parts of the study area have values of magnesium which are below the desirable limit (0.2 mg/l). The concentration level of magnesium is above the desirable limit in most parts of Warri.

The spatial distribution map of Sulphate show that in most parts of the study area, the level of sulphate in groundwater is well below the desirable limit in both seasons, however, for places like,Warri River, Ogunu, Ogborode, Ubeji 1, Ubeji 2, Refinery, Ogunu Road, Bendel Estate, Effurun, Okuokoko, FUPRE, Orhuwhorun and Opeteareasshowing considerable high concentration.The recommended limit of Sulphate (SO_4) is 250mg/l. There is no health threat with regards to SO_4 in the study area as shown in Appendix XA(p) and Appendix XB(p). Sulphate occurs naturally in drinking water. It is evidently noticed that concentration levels for this parameter is distributed radially with levels ranging from 7.00mg/l to 0.13mg/l in the dry and wet seasons to all other areas in a south western direction.

The spatial distribution map of Nitrate shows that the level of nitrate concentration in groundwater is well below the desirable limit of 50mg/l (WHO, 2011) as shown in Appendix XA(q) and Appendix XB(q)in all parts of the study area. Hence this parameter does not pose any threat to the consumers. Nitrate pollution is as a result of nitrate excess from industrial production and higher concentrations is an indication of potential pollution of agricultural related contaminants. Values of NO_3 in the both seasons suggest increases in a North Eastern

direction, through Dodo Island, Bokodo, Ugbuwague, Crawford Creek, Ogunu Road, Airport Road, Jeddo, Ifie, Effurun, Odeitsekri, Osubi Road and Osubi Airport areas covering everywhere around the study area from the Warri River. Pollution from nitrate could be prevented by legislation compelling industries to treat wastewater before discharge.

The spatial distribution map of Chloride in Appendix XA(r) and Appendix XB(r)shows that some parts of the study area have concentration level of chloride in groundwater above the desirable limit,spreading radiallyfrom Bokodo, Dodo Island and Jeddo through Refinery and Ugbuwague into Warri Town, Esisi Road, Jakpa Road, Ovwian, Mofor, Opete, Warri Port Road and Otokutu before transcending west into Ogbeijoh, Egiegi, Deco Road and Delta Steel Company, steadily decreasing in concentration levels from 147.10 to 10.09mg/l. In most of the areas, the chloride values are above the desirable limit (5 mg/l) which is similar in variation to that of Mg. High concentrations of Cl were also observed in the northern part close to the Warri River and in Effurun and Osubi axesfor both seasons. Concentrations of chloride appear higher in north eastern parts of the study area, which may be due to pollution from chloride rich effluents of sewage and municipal waste, sea water intrusion and irrigation return flow from agricultural activities. Continuous monitoring is therefore needed in this part of the study area.

The spatial distribution map of HCO_3 in Appendix XA(s) and Appendix XB(s) exhibits almost the same pattern with BOD in the wet season and K in the dry season. The recommended limit for HCO_3 is 125mg/l. Its distribution revealed that the concentration level of HCO_3 is quite high in the northern parts of Warri to include, Dodo Island, Bokodo, Crawford Creek, Ifie, Refinery, Jeddo, Refinery Road, Ugbuwaguеareas and then reducing following a north – south orientation comprising of Odeitskri, Egiegi, Ekete, Orhuwhorun,

Otokutu, Effurun andOsubi Road areas towards the right-of-centre in the dry season. In the wet season however, the same variational distribution is observed except for increases in concentration levels from that of the dry, of areas to include, Ekpan, Jakpa Road, OgunuRoad, Upper Erejuwah, Enerhen, Enerhen Road and OsubiAirport. Higher HCO_3 during wet season may be due to action of CO_2 upon the basic material of soil and granitic rock (Vasanthavigar et al., 2010). The areas affected are accumulated with these dissolved minerals during both seasons.

Ammonium (Appendix XA(t) and Appendix XB(t))is spatially distributed eastward from Osubi Airport through NNPC Housing Complex and northwards from Okere Road, Ogunu Road, Ekpan and Ifie areas, meeting at the centre and spreading out from there into all other places with concentration levels ranging from 0.00-0.091mg/l in the dry season. The wet season distribution shows reductionby the average value of 0.03mg/l spreading outwards from the centre to all areas of the study area, with lower values less than 2mg/l recorded southwards in the same pattern as in the dry season. This could be due to acidification of water by elevated microbial degradation of organic debris and concentrated dissolved solids in the wet period.

The spatial distribution of PO_4 during the study period is shown in Appendix XA(u) and Appendix XB(u). The phosphate values do not exceed the permissible limit of 0.3 mg/l (WHO, 2011) in majority of the locations excluding, Jeddo, Ugbuwague, Airport Road, Okumagba Layout, Effurun, PTI Road, Osubi Road, Osubi Airport and Orhuwhorunareas close to the Warri River in the wet and dry seasons. The excess concentration of phosphate may be due to percolation of domestic sewage and agricultural inputs in the study area. PO_4

indicate exponential increases in concentration levels in the wet season in all parts of the study area.

The recommended limit for Iron (Fe) is 0.3mg/l. Spatial variation map of Fe concentration in Appendix XA(v) and Appendix XB(v) consist of values which are all well below standard limits. It further shows that the concentration distribution is relatively high in many parts of the study area likeUghoton, Ogborode, Warri Port, Warri GRA,Urhobo College Effurun, Ekete, Enerhen, Osubi Road and Orhuwhorun areas whilethe rest are all of low values following a central distribution pattern.Fe poses a significant health threat as it occurs naturally in soil sediments as well as groundwater and can be found in many types of rocks (WHO, 2008). In both seasons, the variation for this parameter is significant. The presence of iron in ground water is attributed to the nature of the geological formation, improper waste disposal, industrialization, natural water recharge and water-soil/rock interaction.

Cadmium (Cd) concentrations are all within the recommended limits for both seasons. The Cd values are generally within the permissible limit of 0.003mg/l in its spatial variation map shown in Appendix XA(w) and Appendix XB(w). Its distribution consists of concentration levels higher than WHO recommended limits for human consumption in both seasons and it is noticeable in DSC Road, DSC Township, Refinery Road, Opete, Warri Port Road, Jeddo and Ogbeijohroutes. The Bokodo and Jeddo areas indicate a sharp increase in Cd levels in the concentrations of 0.007 to 0.008mg/l which is significant. The high Cd levels in these areas could be attributed to effluents containing heavy metals discharged by chemical and petroleum industries in and around those locations.

The Chromium (Cr) values are all within the permissible limit of 0.05 mg/l (WHO, 2011). The spatial variation shows moderate levels of Cr in the dry season at places around, Airport Road, NNPC Housing Estate, Jakpa Road, Warri Town, Ogbeijoh, Aladja, Delta Steel Company, Mofor, Warri Port Road, OsubiMarket, Shoprite Delta Mall, Shagholoh and Refinery areas away from the centre in directions north, south west and south east in the study area. This follows similarly for the wet season, that reduced concentrations levels of Cr are located upland north while gradually decreasingin all areas around the study area. Undetectable Cr levels exist in the south western part of the spatial distribution map (Appendix XA(x) and Appendix XB(x)). Areas with low levels of Cd concentration in the wet season include, Odeitsekri, Ugbuwague, DSC Road, PTI Road, Refinery Road, Osubi Airport, Bokodo and Jeddoareas. Industrial and laboratory effluents around the study area could be a source of Chromium, (Braide et al., 2004).

Copper (Cu) values do not show significant variation for both seasons. The Cu values are lower than the permissible limit of 2mg/l (WHO, 2011) in all the groundwater sampling locations in dry and wet seasons of the variability map of the study area (Appendix XA(y) and Appendix XB(y)). Locations with high levels of Cu follow course to include,Ogbeijoh, Delta Steel Company, Egeigi, Egini, Ifie, Refinery, Ekete, Warri Sapele Road, Ovwian, Crawford Creek,Enerhen Road, Otokutu, Osubi Road, Osubi Airport, Dodo Island, Ughoton, Ogborode, Bokodo and Jeddo areas. These values suggest industrial activities within the area which are responsible for the elevated levels of heavy metals in water.

The lead (Pb) values were all below the permissible limit of 0.01mg/l in all the groundwater sampling stations in dry and wet seasons. The spatial distribution of Pb in the study area reveals high levels of Pb in places around Ughoton, Jeddo, Ogborode, Ifie, Edjeba Housing

Estate, Refinery, NPA Express Road, NNPC Housing Complex, Ekpan, Jakpa Road areas in the dry season. While in the wet season, increased Pb concentration levels are located around Ogunu Road, Ogbeijoh, Aladja, Egiegi, Enerhen Road, Airport Road, Effurun, PTI Road, Warri Port Road, Otokutu, Refinery Road and Udu Roadareaseastwards in the study area. This is depicted in the spatial variational map in Appendix XA(z) and XB(z). Pb in groundwater could have resulted from indiscriminate dumping of electronic wastes, oil, batteries and oil exploration and processing activities.

CHAPTER FIVE

CONCLUSIONS, RECOMMENDATIONS and CONTRIBUTIONS TO KNOWLEDGE

5.1 Conclusions

Arising from this study, the following conclusions are made.

i. The spatial and temporal distribution of groundwater quality parameters varied throughout the study area and the groundwater quality parameters had higher concentrations during the wet season than in the dry season.

ii. The contaminants were more prevalent around industrial areas, solid waste dump sites, in areas with poor sewage disposal systems especially in high urban areas.

iii. The groundwater within the study area is mostly acidic with high chloride and total coliform concentrations.

iv. The order of abundance of cations concentration of groundwater in the study area are $Ca^{2+} > Na^{+} > K^{+} > Mg^{2+}$ while those of anions are $HCO_3^{-} > Cl^{-} > NH_4 > NO_3^{-} > SO_4^{2-} > PO_4$.

v. The various physicochemical parameters of most of the groundwater samples exceeded the WHO permissible limits for drinking water.

vi. The evaluated WQI showed most areas had poor to unsuitable water quality status, mostly due to high acidity, hardness and high iron content.

vii. The empirical (statistical) regression models can predict groundwater quality parameters with 5% level of significance andhad been found to be a useful technique in predicting the concentration of some groundwater quality parameters using EC,

TDS, DO and pH as independent variables since they are strong predictors of other groundwater quality parameters.

viii. The spatial dependency of most water quality parameters showed strong to weak and varied with season.

ix. The groundwater quality parameter prediction maps clearly showed the variability of the concentration of studied parameters in the study area.

5.2 Recommendations

From the research findings, the following recommendations are made:

i. Boreholes should be well and properly sited far from septic tanks, open dump sites and other likely sources of contamination and the possible sources of contamination should be regulated.

ii. Since most of the boreholes were of shallow depth (16m to 17m), the study should be enhanced by studying groundwater quality at greater depths in the near future.

iii. The application of regression models to predict and estimate groundwater quality parameters and the use geostatistical interpolation methods in monitoring groundwater quality should be encouraged and reviewed more frequently.

iv. This study strongly recommends continuous groundwater monitoring in and around the study area for planning and implementation in order to meet water supply demand without compromising the ability of future generations to meet water quality requirements.

v. Government should endeavour to provide central water schemes with some degree of specific treatment facilities, establish regulatory bodies to ensure proper registering,

siting and spacing of boreholes, test water quality and give approvals before water from boreholes are consumed.

vi. Government should register, enforce available guidelines and monitor all boreholes to ensure the suitability of water from these boreholes for human consumption by enacting stringent laws to check the wanton drilling of boreholes by individuals and.

vii. Appropriate and adequate treatments should be applied in all water sources.

5.3 Contributions to Knowledge

This study has contributed to knowledge in the following ways;

i. Established an understanding of the spatio-temporal distribution of groundwater quality parameters by using WQI in Warri as well as the development of suitable management practices to protect the groundwater resources.

ii. The groundwater quality parameters regression prediction models provided an excellent means for the monitoring of parameter values within realistic degree of accuracy that can be used as rapid means in obtaining first hand information of the groundwater quality than actually going through complex methods.

iii. The prediction maps will be used by stakeholders in providing potable water as the required treatments at each area is known

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APPENDICES

APPENDIX I
PHOTOGRAGRAPHS OF THE RESEARCH WORK



Plate A: Water sample collection froma borehole



Plate B: Obtaining coordinate with a hand-held GPS at one of the sample collectionlocations



*Plate C:*Ice chest with polyetelene bottles containing water samples



*Plate D:*Use of spectrophotometer to determine the concentration of some chemical parameters



Plate E: EDTA titrimetry for the analysis of calciun, potassium and total hardness



Plate F: Use of turbidity meter to measure turbidity of water samples

APPENDIX II(A) Results of physico-chemical and bacteriological parameters during dry season (DS)

Sampling Location (SL)	SL Code	Temp. (°C)	pH	EC (µS/cm)	Turbidity (NTU)	TH (mg/l)	TSS (mg/l)	TDS (mg/l)	DO (mg/l)	BOD (mg/l)	COD (mg/l)	Total Coli. (MNP/100L)	CATIONS				ANIONS						HEAVY METALS				
													Na (Mg/l)	K (Mg/l)	Ca (Mg/l)	Mg (Mg/l)	SO_4^{2-} (Mg/l)	NO_3 (Mg/l)	Cl^- (Mg/l)	HCO_3 (Mg/l)	NH_4 (Mg/l)	PO_4 (Mg/l)	Fe (Mg/l)	Cd (Mg/l)	Cr (Mg/l)	Cu (Mg/l)	Pb (Mg/l)
Okuokoko	OKU	28.85	6.10	46.00	0.35	194.00	0.00	26.00	5.80	ND	3.60	32.12	3.20	0.50	5.20	0.20	0.15	0.14	12.00	3.10	0.003	0.01	0.20	ND	ND	ND	ND
Effurun GRA	EFG	26.70	5.80	180.00	0.62	5.80	5.00	101.00	4.90	0.50	5.50	0.00	9.20	1.90	20.80	0.80	1.48	1.20	35.40	24.30	0.007	0.23	0.21	ND	ND	0.002	ND
Army Barracks	ARB	26.95	5.60	72.00	6.31	17.32	15.67	40.00	4.30	ND	8.90	11.00	4.60	0.70	7.80	0.20	0.33	0.27	14.80	9.20	0.003	0.10	0.20	0.002	0.001	0.010	ND
Niger CAT	NCAT	25.50	4.80	100.00	2.11	4.79	16.01	56.00	5.40	ND	5.80	30.19	6.30	1.00	11.00	0.50	0.71	0.52	25.20	7.80	ND	0.06	0.20	0.005	0.004	0.310	0.040
Airport Road	APR	28.80	6.20	532.00	0.31	28.71	0.00	298.00	4.20	ND	4.90	0.00	27.30	1.00	69.00	1.90	5.92	1.95	117.00	57.40	0.021	0.53	0.24	ND	ND	ND	ND
Jakpa Road	JKR	30.60	5.90	199.00	16.10	4.28	10.00	112.00	6.70	1.10	3.80	Nil	20.90	1.90	14.60	0.80	1.28	0.82	43.50	21.50	0.008	0.15	0.21	0.001	ND	0.001	ND
Shagholoh	SHA	25.70	4.90	108.00	2.60	25.02	0.00	57.00	5.30	ND	5.70	Nil	5.20	0.40	12.50	0.40	0.44	0.11	24.00	11.20	0.005	0.05	0.20	0.004	0.004	0.310	0.040
Ekpan	EKP	29.20	5.10	74.00	0.91	5.13	0.00	42.00	1.90	ND	1.70	13.00	8.30	1.90	4.00	0.60	0.43	0.02	18.00	6.00	ND	0.02	0.20	0.002	0.003	0.100	0.050
Urhobo College	UCE	29.20	5.90	54.00	0.00	14.57	23.00	30.00	1.50	ND	2.50	0.00	3.40	0.40	5.90	0.10	0.19	0.15	12.40	5.80	ND	0.03	0.20	0.001	ND	0.002	ND
Effurun Market	EFM	30.70	6.20	314.00	16.70	4.60	10.00	176.00	3.10	ND	3.50	5.02	9.20	2.40	42.20	0.70	2.19	1.94	58.20	48.80	0.029	0.54	0.21	0.001	0.001	0.200	ND
Ogborode	OGD	23.40	5.20	206.00	0.00	30.68	0.00	115.00	1.40	0.80	3.80	Nil	18.00	2.50	17.90	0.30	1.41	1.28	38.40	29.10	0.014	0.15	0.21	0.003	0.002	0.120	0.010
Ughoton	UGT	25.60	4.20	412.00	0.25	302.00	1.00	231.00	3.00	ND	7.70	0.00	20.00	3.90	49.00	1.20	3.40	3.27	87.00	50.10	0.026	0.32	0.22	0.005	0.005	0.900	0.050
Jeddo	JED	28.60	4.70	378.00	12.60	5.84	12.00	212.00	2.10	ND	2.50	25.98	18.00	2.20	46.00	1.00	2.92	1.90	85.30	42.40	0.020	0.28	0.22	0.005	0.003	0.420	0.060
Ubeji 1	UBJ 1	25.84	4.50	304.00	0.60	4.36	N/A	170.00	3.10	ND	4.80	4.80	11.00	3.10	38.70	0.60	2.57	1.74	58.90	44.00	0.007	0.33	0.21	0.006	0.004	0.700	0.060
Ubeji 2	UBJ 2	24.95	5.10	106.00	14.20	3.75	N/A	59.00	2.20	ND	2.50	5.91	5.80	1.00	12.60	0.30	0.61	0.57	25.20	10.00	ND	0.10	0.20	0.003	0.003	0.090	0.030
Osubi Market	OSM	28.07	4.60	53.00	37.53	16.32	32.67	30.00	2.00	ND	3.00	33.33	3.80	0.40	5.30	0.10	0.23	0.29	12.00	5.80	ND	ND	0.20	0.006	0.004	0.700	0.060
Osubi Airport	OSA	28.28	4.60	434.00	2.07	4.54	1.20	243.00	3.20	ND	4.50	10.67	21.10	2.60	57.70	1.10	2.51	2.95	99.80	41.60	0.008	0.79	0.22	0.006	0.004	0.600	0.050
Ogbuwangue	OGB	23.21	5.80	362.00	3.40	22.87	0.00	203.00	3.60	ND	1.90	30.53	20.90	1.80	43.40	1.00	2.64	2.64	77.90	40.90	0.005	0.52	0.22	0.001	0.001	0.010	ND
Warri Port	WAP	24.00	5.20	83.00	13.40	4.21	11.00	47.00	1.50	ND	3.20	0.00	2.20	0.10	11.90	0.10	0.35	0.46	17.80	11.00	ND	0.10	0.20	0.003	0.002	0.100	0.010
Ogunu	OGU	23.70	6.10	156.00	0.00	5.75	0.00	87.00	1.00	ND	2.70	12.05	7.60	1.20	19.90	0.30	0.48	0.46	33.60	18.80	0.008	0.09	0.21	0.001	ND	ND	0.010
Edjebah	EDJ	25.20	5.60	498.00	0.70	281.00	0.00	279.00	3.00	ND	8.40	6.97	23.30	2.50	59.00	1.20	3.44	2.68	91.30	79.50	0.004	0.48	0.23	0.001	0.002	0.019	ND
Edjeba H. Estate	EDHE	29.00	6.70	115.00	13.90	4.82	10.00	65.00	3.00	0.50	6.90	0.00	5.40	2.40	12.70	0.30	1.00	0.91	24.90	13.30	0.001	0.24	0.20	ND	ND	ND	ND
Fed. Govt. College	FGC	23.50	5.40	108.00	0.00	28.04	0.00	61.00	2.90	0.90	1.20	28.50	5.20	1.00	12.00	0.30	0.68	1.03	19.50	17.60	ND	0.19	0.20	0.002	0.001	0.060	0.020
Ajamimogha	AJA	25.40	6.30	74.00	1.80	4.42	3.00	42.00	2.00	ND	2.70	15.11	2.20	0.70	10.90	0.20	0.26	0.81	18.80	5.40	ND	0.10	0.20	0.000	ND	ND	ND
Warri GRA	WAG	25.00	5.90	57.00	1.20	26.25	6.00	32.00	2.50	ND	1.20	5.90	4.00	0.40	5.80	0.10	0.12	0.57	13.60	5.30	ND	0.14	0.20	0.001	ND	0.001	ND
Okumagba Layout	OKL	26.00	5.30	40.00	0.00	12.97	0.00	22.00	5.30	ND	3.90	Nil	1.80	0.30	5.00	0.20	0.15	0.21	10.30	3.10	ND	0.06	0.20	0.002	0.002	0.100	ND
Okere Road	OKR	25.20	6.30	189.00	0.40	30.28	1.00	106.00	6.40	ND	3.10	35.00	8.50	2.50	21.30	1.00	1.00	0.43	40.40	25.00	0.009	0.34	0.21	0.001	0.000	ND	ND
DECO Road	MRQ	25.90	4.90	116.00	0.00	4.31	0.00	65.00	4.20	ND	5.90	11.00	6.30	1.80	12.40	0.50	0.43	0.55	26.50	12.90	0.006	0.06	0.20	0.003	0.003	0.300	0.030
Essi Layout	ESL	30.00	5.60	235.00	0.88	12.00	1.00	132.00	2.30	ND	4.80	5.40	19.00	1.70	22.50	0.30	1.17	0.98	55.50	23.10	ND	0.11	0.21	0.001	0.002	0.100	ND
Igbudu Market	IGM	27.65	4.70	126.00	13.20	19.96	13.03	71.00	2.20	ND	6.30	0.00	13.60	1.90	7.50	0.30	0.78	0.72	24.00	18.00	ND	0.14	0.20	0.006	0.003	0.500	0.060
Agbassa	AGS	25.40	6.40	82.00	0.60	4.73	0.00	46.00	2.90	0.70	4.70	30.70	3.10	0.50	10.60	0.20	0.20	0.10	16.60	11.90	0.008	0.11	0.20	ND	ND	ND	ND
Bowen Avenue	BOA	27.84	5.40	52.00	0.77	205.00	10.00	29.00	2.10	ND	7.10	11.50	1.50	0.20	7.50	0.20	0.37	0.30	11.70	6.00	0.020	0.10	0.20	0.002	0.002	0.250	ND
Iyara	IYA	25.70	5.00	96.00	0.00	11.67	0.00	54.00	2.10	ND	3.90	4.80	6.60	1.00	9.50	0.20	0.33	0.05	18.20	14.70	0.008	0.07	0.20	0.004	0.002	0.400	0.030
Pessu Market	PEM	25.80	5.30	107.00	0.40	5.86	0.00	60.00	1.70	ND	5.50	31.22	5.10	0.70	13.20	0.30	0.21	0.02	21.50	15.30	0.016	0.05	0.20	0.003	0.002	0.200	ND
Orhunworun	ORH	26.76	4.80	154.00	0.58	253.00	7.00	86.00	2.10	ND	3.20	0.00	11.80	1.90	13.70	0.30	0.98	0.95	32.20	19.60	0.007	0.37	0.20	0.004	0.004	0.500	0.020
Enerhen	ENE	29.00	5.00	97.00	0.40	12.00	<1.00	54.00	2.60	1.40	6.60	12.23	10.20	0.90	7.00	0.50	0.54	0.58	21.80	10.10	0.016	0.12	0.20	0.002	0.002	0.300	0.020
Udu Road	UDR	25.40	5.50	53.00	5.20	5.29	8.00	30.00	2.10	ND	5.40	6.12	2.50	0.60	7.00	0.10	0.12	0.31	12.10	5.40	0.031	0.09	0.20	0.001	0.001	0.020	ND
Otokutu	OTO	24.80	5.30	67.00	0.77	13.22	0.96	38.00	2.20	ND	5.30	0.57	3.60	0.20	8.50	0.10	0.22	0.09	16.40	6.30	0.008	0.11	0.20	0.003	0.002	0.030	ND
Bendel Estate	BDE	30.70	4.40	71.00	2.16	13.60	1.00	40.00	2.20	ND	7.10	15.67	6.20	1.00	6.20	0.20	0.18	0.24	17.70	5.90	0.005	0.10	0.20	0.008	0.005	0.700	0.060
Upper Erejuwah	UPE	31.20	4.70	112.00	3.27	3.72	0.50	63.00	1.60	ND	3.90	8.23	9.60	0.90	9.50	0.40	0.90	1.20	20.50	16.00	0.011	0.04	0.20	0.006	0.003	0.500	0.050
Mammy Market	MAM	27.26	5.70	114.00	5.11	192.28	3.50	64.00	2.80	0.30	2.40	25.90	3.30	0.90	15.60	0.60	0.38	0.41	28.70	10.10	ND	0.14	0.20	0.001	0.001	0.100	ND
DSC Township	DST	27.30	5.70	329.00	15.34	336.29	42.47	184.00	2.40	ND	3.20	0.00	19.60	2.50	39.00	0.40	1.13	1.36	76.60	33.20	0.039	0.22	0.22	0.001	0.001	0.080	ND
Okumagba Estate	OKE	24.70	6.10	237.00	6.13	13.74	10.00	133.00	1.70	ND	1.10	12.92	18.20	2.10	22.00	0.60	1.27	1.44	49.80	29.70	0.035	0.29	0.21	ND	0.001	ND	ND
Mofor	MOF	29.50	4.80	45.00	9.00	266.69	17.52	25.00	1.70	ND	5.80	11.13	2.10	0.30	5.50	0.30	0.18	0.10	10.60	4.90	ND	0.05	0.20	0.005	0.002	0.400	0.030
FUPRE	FUP	29.22	5.10	236.00	7.81	13.91	11.00	132.00	4.80	ND	1.80	6.37	16.00	1.40	23.80	1.10	1.12	0.98	49.90	30.50	0.091	0.17	0.21	0.005	0.003	0.100	0.020
Otokutu	SHP	31.13	5.70	127.00	5.13	4.91	5.29	71.00	5.30	ND	5.70	7.41	11.90	0.70	10.40	0.40	0.61	0.53	27.50	14.80	0.008	0.45	0.20	0.001	0.001	0.010	0.006
Robbinson Plaza	ROP	32.20	6.10	55.00	20.06	13.95	12.22	31.00	7.70	ND	4.90	0.07	2.50	0.20	7.10	0.20	0.12	0.17	12.90	5.80	ND	0.09	0.20	0.001	ND	0.100	ND
Esisi Road	ESR	27.40	5.90	52.00	19.65	19.34	6.10	29.00	6.00	ND	5.20	34.20	2.20	0.30	6.90	0.10	0.16	0.22	11.90	5.50	ND	0.10	0.20	0.001	ND	0.001	ND
Udu Road	ROR	31.50	4.40	250.00	20.01	13.49	13.00	140.00	1.30	ND	4.40	12.80	10.70	2.30	30.00	0.50	1.28	0.83	49.90	36.60	0.007	0.31	0.21	0.007	0.005	0.700	0.070
Pet. Training Inst.	PTR	29.91	5.90	70.00	0.05	20.39	23.09	39.00	5.70	ND	3.90	2.11	3.10	0.50	9.30	0.30	0.21	0.17	16.90	6.50	ND	0.10	0.20	ND	ND	ND	ND
Minimum Value	Min	23.21	4.20	40.00	0.00	3.72	0.00	22.00	1.00	0.30	1.10	0.00	1.50	0.10	4.00	0.10	0.12	0.02	10.30	3.10	0.00	0.01	0.20	0.00	0.00	0.00	0.01
Maximum Value	Max	32.20	6.70	532.00	37.53	336.29	42.47	298.00	7.70	1.40	8.90	35.00	27.30	3.90	69.00	1.90	5.92	3.27	117.00	79.50	0.09	0.79	0.24	0.01	0.01	0.90	0.07
Mean	Mean	27.27	5.41	162.74	5.69	51.03	7.30	91.16	3.22	0.78	4.36	12.10	9.30	1.30	18.54	0.47	1.00	0.83	34.89	19.62	0.01	0.19	0.21	0.00	0.00	0.25	0.04
Median	Median	27.11	5.40	110.00	1.94	13.55	5.00	62.00	2.70	0.75	4.15	9.45	6.45	1.00	12.20	0.30	0.58	0.56	24.45	14.00	0.01	0.11	0.20	0.00	0.00	0.10	0.04
Standard Deviation	SD	2.40	0.62	127.37	7.84	91.94	9.18	71.36	1.66	0.36	1.89	11.58	6.98	0.91	16.15	0.38	1.14	0.81	26.69	16.69	0.02	0.17	0.01	0.00	0.00	0.25	0.02
WHO Standard	WHO		6.5-8.5	-	5		30	500	5	5	40	0	-	-	75	-	400	50	250	100	-	5	0.1	0.003	-	-	0.01
NSDWQ Standard	NSDWQ		6.5-8.5	1000	5		-	500	-	-	-	10	200	-	-	0.2	100	50	250	-	-	-	0.3	0.003	0.05	1	0.01
EU Standard	EU		6.5-9.5	2500	-		-	-	-	-	-	10	200	-	-	-	250	50	250	-	0.5	-	0.2	0.005	0.05	0.2	0.01

APPENDIX II(B): Results of physico-chemical and bacteriological parameters during wet season (WS)

Sampling Location (SL)	SL Code	Temp. (°C)	pH	EC (µS/cm)	Turbidity (NTU)	TH (mg/l)	TSS (mg/l)	TDS (mg/l)	DO (mg/l)	BOD (mg/l)	COD (mg/l)	Total Coli. (MNP/100L)	CATIONS				ANIONS						HEAVY METALS				
													Na (Mg/l)	K (Mg/l)	Ca (Mg/l)	Mg (Mg/l)	SO_4^{2-} (Mg/l)	NO_3 (Mg/l)	Cl (Mg/l)	HCO_3 (Mg/l)	NH_4 (Mg/l)	PO_4 (Mg/l)	Fe (Mg/l)	Cd (Mg/l)	Cr (Mg/l)	Cu (Mg/l)	Pb (Mg/l)
Okuokoko	OKU	29.03	5.40	48.00	0.53	202.24	10.75	27.00	6.50	1.50	5.30	27.35	3.40	0.60	5.30	0.18	0.15	0.14	12.30	3.10	0.009	0.04	0.22	ND	ND	0.010	0.010
Effurun GRA	EFG	26.86	4.70	192.00	1.73	14.19	22.38	108.00	6.00	2.20	7.50	0.09	9.90	2.50	21.70	0.83	1.78	1.26	36.40	26.30	0.018	0.31	0.23	0.001	0.001	0.020	0.080
Army Barracks	ARB	27.12	4.30	75.00	7.42	25.57	25.05	42.00	6.60	2.20	7.40	15.77	4.80	0.80	8.00	0.26	0.35	0.28	15.20	9.50	0.009	0.11	0.22	0.002	0.001	0.040	0.180
Niger CAT	NCAT	25.32	4.10	105.00	3.23	13.05	27.84	59.00	8.80	1.80	2.40	32.69	6.50	2.10	10.60	0.48	0.69	0.67	20.30	13.60	0.012	0.06	0.22	0.003	0.002	0.120	0.210
Airport Road	APR	29.10	5.10	678.00	1.34	36.97	14.78	380.00	6.50	ND	5.20	9.85	30.50	1.20	90.20	2.40	8.08	4.12	147.10	71.10	0.061	0.77	0.26	ND	ND	0.010	0.020
Jakpa Road	JKR	31.80	4.90	215.00	15.00	12.55	9.90	120.00	9.50	1.50	5.70	4.13	22.20	2.60	15.60	0.93	1.11	0.96	46.50	22.50	0.001	0.29	0.23	ND	ND	0.020	0.060
Shagholoh	SHA	26.70	4.40	113.00	5.67	33.30	0.00	63.00	7.30	1.70	4.40	4.13	5.50	0.40	13.50	0.47	0.45	0.11	26.60	12.20	ND	0.06	0.19	0.002	0.001	0.100	0.180
Ekpan	EKP	28.70	5.10	81.00	9.10	13.42	17.38	46.00	2.20	1.30	0.50	6.24	9.20	2.70	4.10	0.58	0.62	0.04	19.20	6.10	ND	0.09	0.22	ND	0.001	0.010	0.050
Urhobo College	UCE	28.30	4.90	58.00	1.23	22.86	6.98	32.00	2.10	ND	0.60	0.06	3.50	0.40	6.70	0.13	0.20	0.16	13.00	6.10	ND	0.06	0.22	ND	0.001	0.005	0.090
Effurun Market	EFM	31.90	5.10	390.00	16.00	12.90	8.88	218.00	3.50	ND	4.00	0.08	11.20	3.30	53.90	1.07	2.88	2.64	72.80	56.10	0.051	0.67	0.23	ND	0.000	0.020	0.050
Ogborode	OGD	22.20	5.10	252.00	0.34	22.38	0.00	141.00	2.10	0.70	7.40	0.02	20.90	3.50	19.60	0.80	1.81	1.72	47.00	36.60	0.023	0.33	0.23	ND	0.001	0.010	0.060
Ughoton	UGT	24.90	3.80	454.00	0.52	310.31	14.38	254.00	3.40	ND	5.10	3.11	21.50	4.00	56.20	1.31	3.62	3.96	93.80	53.10	0.025	0.47	0.24	0.005	0.002	0.150	0.310
Jeddo	JED	29.80	4.20	405.00	12.55	14.16	12.01	227.00	2.50	ND	0.50	24.67	19.20	3.20	51.80	1.03	2.92	2.87	86.40	44.40	0.036	0.59	0.24	0.002	0.001	0.070	0.250
Ubeji 1	UBJ 1	26.84	3.90	356.00	6.06	12.93	46.92	199.00	3.70	ND	1.40	7.60	11.30	3.50	46.90	1.13	3.02	2.83	68.90	48.80	0.015	0.68	0.23	0.005	0.002	0.170	0.230
Ubeji 2	UBJ 2	25.85	4.20	125.00	14.52	12.09	11.74	70.00	2.40	ND	0.80	4.80	6.60	1.50	14.50	0.48	0.68	0.68	30.50	10.50	0.001	0.12	0.22	0.002	0.002	0.060	0.150
Osubi Market	OSM	28.67	4.60	57.00	35.77	24.67	0.02	32.00	2.30	1.90	6.40	36.54	4.10	0.40	5.70	0.11	0.20	0.39	13.00	6.10	ND	0.09	0.22	0.001	0.001	0.010	0.050
Osubi Airport	OSA	28.28	4.10	520.00	3.09	12.90	0.01	291.00	3.80	ND	6.70	14.52	24.50	4.10	66.70	1.32	4.83	3.41	107.80	59.60	0.015	0.91	0.24	0.004	0.002	0.100	0.240
Ogbuwangue	OGB	24.41	4.10	411.00	3.88	31.24	11.00	230.00	4.40	ND	2.70	26.52	22.10	3.70	50.20	1.19	3.24	3.05	89.20	42.50	0.011	0.83	0.24	0.003	0.002	0.110	0.220
Warri Port	WAP	24.50	3.80	93.00	15.00	4.16	0.00	52.00	2.30	ND	0.70	1.19	2.30	0.10	13.60	0.17	0.58	0.79	18.60	12.60	0.005	0.18	0.22	0.005	0.002	0.150	0.350
Ogunu	OGU	23.10	4.90	179.00	0.02	14.13	10.84	100.00	1.90	ND	0.30	16.05	8.50	1.40	23.00	0.46	0.54	0.69	39.50	19.50	ND	0.12	0.20	0.001	0.001	0.010	0.080
Edjebah	EDJ	26.10	3.80	548.00	0.89	272.61	13.40	307.00	3.40	1.80	6.10	10.36	25.00	4.20	68.20	1.35	4.21	3.10	98.60	82.30	0.016	0.90	0.25	0.005	0.002	0.150	0.260
Edjeba H. Estate	EDHE	30.20	4.20	131.00	14.00	13.20	11.75	73.00	3.90	0.80	2.10	0.07	6.40	2.70	14.70	0.38	1.02	1.05	28.40	14.00	0.010	0.39	0.22	0.002	0.001	0.060	0.190
Fed. Govt. College	FGC	23.00	4.50	130.00	0.03	36.41	0.11	72.00	3.10	1.20	0.70	31.94	5.90	1.20	14.90	0.41	0.85	1.19	24.60	18.30	0.008	0.22	0.22	0.001	0.001	0.070	0.150
Ajamimogha	AJA	25.40	4.90	79.00	2.65	12.79	3.50	44.00	2.50	ND	1.40	16.88	2.40	0.70	11.90	0.23	0.20	0.94	19.00	6.10	0.003	0.13	0.22	ND	ND	ND	0.110
Warri GRA	WAG	26.60	4.80	59.00	2.45	34.61	23.38	33.00	2.90	ND	0.60	18.00	4.10	0.40	5.90	0.11	0.20	0.66	13.30	6.10	ND	0.16	0.22	0.001	ND	0.040	0.060
Okumagba Layout	OKL	24.80	4.40	46.00	0.03	21.32	1.23	26.00	8.90	1.70	4.40	0.01	1.90	0.30	5.40	0.17	0.15	0.27	12.30	3.70	ND	0.12	0.22	0.001	0.001	0.100	0.160
Okere Road	OKR	26.10	5.50	254.00	0.78	38.62	8.05	142.00	8.70	1.30	5.40	25.54	10.10	3.50	24.80	1.06	1.31	0.59	59.50	32.00	0.017	0.47	0.23	ND	ND	0.020	0.030
DECO Road	MRQ	26.90	4.30	130.00	0.09	12.65	15.90	73.00	9.10	1.60	6.40	13.55	7.50	2.10	14.70	0.68	0.56	0.75	28.30	13.70	0.012	0.10	0.22	0.002	0.001	0.070	0.150
Essi Layout	ESL	29.20	3.90	252.00	0.99	20.33	16.82	141.00	2.90	ND	4.10	9.65	20.00	2.90	24.10	0.38	1.15	1.30	57.10	24.90	0.007	0.39	0.23	0.005	0.002	0.160	0.200
Igbudu Market	IGM	28.05	4.00	140.00	15.00	11.62	0.00	79.00	2.80	ND	5.70	4.00	14.80	2.30	8.60	0.64	0.88	0.95	26.10	19.20	0.010	0.11	0.22	0.004	0.002	0.110	0.230
Agbassa	AGS	26.60	5.90	88.00	2.01	4.73	7.00	49.00	3.60	1.20	4.00	33.97	3.50	0.80	12.20	0.20	0.24	0.18	23.50	5.20	0.015	0.18	0.22	ND	ND	ND	0.010
Bowen Avenue	BOA	27.54	4.80	55.00	0.77	213.32	13.03	31.00	2.80	ND	4.40	11.55	1.50	0.30	7.80	0.18	0.16	0.13	12.40	6.10	0.030	0.14	0.22	0.001	0.001	0.010	0.050
Iyara	IYA	25.70	4.70	120.00	0.00	19.98	0.00	67.00	2.80	ND	2.00	3.90	8.70	1.30	11.00	0.42	0.35	0.08	25.20	15.60	0.016	0.11	0.22	0.002	0.001	0.030	0.070
Pessu Market	PEM	25.80	4.80	119.00	0.32	14.16	10.00	67.00	2.40	ND	5.90	26.45	5.60	0.90	15.30	0.30	0.28	0.02	24.10	16.00	0.025	0.09	0.20	0.002	0.001	0.010	0.070
Orhunworun	ORH	26.76	4.50	170.00	0.85	245.00	9.87	95.00	2.70	ND	2.40	0.02	12.70	2.10	14.60	0.68	1.00	1.26	34.80	21.60	0.013	0.49	0.22	0.002	0.001	0.030	0.150
Enerhen	ENE	30.20	4.90	121.00	0.04	20.24	1.00	68.00	3.00	2.10	7.10	0.09	12.50	1.40	8.10	0.43	0.54	0.68	28.10	11.70	0.025	0.13	0.22	ND	ND	0.010	0.030
Udu Road	UDR	24.20	5.10	60.00	5.00	13.54	26.00	34.00	2.00	ND	3.70	0.02	2.90	0.60	7.20	0.11	0.14	0.41	14.10	6.10	0.045	0.09	0.22	ND	ND	0.020	0.050
Otokutu	OTO	24.80	4.90	81.00	0.77	13.22	0.96	45.00	3.00	ND	1.40	0.57	5.30	0.80	8.90	0.25	0.22	0.01	19.30	7.70	0.016	0.12	0.22	ND	ND	0.010	0.080
Bendel Estate	BDE	30.70	4.20	89.00	2.16	13.60	1.00	50.00	3.00	ND	2.10	15.67	6.80	1.20	9.00	0.30	0.18	0.24	22.70	6.10	0.010	0.11	0.22	0.002	0.001	0.080	0.250
Upper Erejuwah	UPE	31.20	4.80	131.00	3.27	3.72	0.50	73.00	2.60	ND	4.70	8.23	10.80	1.30	10.10	0.55	0.91	1.26	23.60	19.80	0.019	0.09	0.22	0.001	0.001	0.030	0.060
Mammy Market	MAM	27.26	5.10	140.00	5.11	192.28	3.50	78.00	3.60	1.10	6.10	25.90	3.90	1.20	19.60	0.72	0.52	0.69	35.10	11.30	0.007	0.19	0.22	ND	0.001	0.010	0.050
DSC Township	DST	27.30	3.40	370.00	15.34	336.29	42.47	207.00	3.30	1.10	1.10	0.00	21.00	3.10	45.00	0.50	1.38	1.40	82.50	38.60	0.053	0.29	0.24	0.005	0.002	0.190	0.350
Okumagba Estate	OKE	24.70	3.60	281.00	6.13	13.74	10.00	158.00	2.20	ND	0.50	12.92	20.50	2.50	29.00	0.83	1.34	1.51	58.90	32.70	0.050	0.38	0.23	0.005	0.002	0.180	0.350
Mofor	MOF	29.50	4.50	54.00	9.00	266.69	17.52	30.00	2.30	ND	3.70	11.13	2.20	0.60	6.70	0.41	0.21	0.18	13.10	5.10	ND	0.05	0.22	0.001	0.001	0.020	0.150
FUPRE	FUP	29.22	3.60	260.00	7.81	13.91	11.00	146.00	5.70	ND	2.90	6.37	18.00	1.60	25.10	1.19	1.46	1.19	51.80	35.70	0.041	0.20	0.19	0.005	0.002	0.190	0.360
Otokutu	SHP	31.13	4.20	138.00	5.13	4.91	5.29	77.00	6.10	1.60	7.20	7.41	13.40	0.80	10.70	0.52	0.65	0.55	29.60	15.80	0.019	0.54	0.22	0.003	0.001	0.120	0.210
Robbinson Plaza	ROP	32.20	4.30	62.00	20.06	13.95	12.22	35.00	9.60	2.20	8.40	0.07	3.00	0.50	8.20	0.16	0.15	0.19	14.30	6.10	ND	0.10	0.22	0.002	0.001	0.090	0.200
Esisi Road	ESR	27.40	4.50	56.00	19.65	19.34	6.10	32.00	7.10	2.50	9.20	34.20	2.60	0.40	7.30	0.14	0.17	0.23	12.50	6.10	ND	0.15	0.22	0.001	0.001	0.020	0.060
Udu Road	ROR	31.50	3.90	286.00	20.01	13.49	13.00	160.00	2.00	ND	5.40	12.80	12.80	2.90	34.10	0.63	1.69	1.07	55.20	41.30	0.026	0.58	0.23	0.005	0.002	0.150	0.350
Pet. Training Inst.	PTR	29.91	3.90	77.00	0.05	20.39	23.09	43.00	8.70	ND	2.10	2.11	3.70	0.60	10.20	0.20	0.29	0.29	18.20	7.00	ND	0.19	0.22	0.005	0.002	0.140	0.330
Minimum Value	Min	22.20	3.40	46.00	0.00	3.72	0.00	26.00	1.90	0.70	0.30	0.00	1.50	0.10	4.10	0.11	0.14	0.01	12.30	3.10	0.00	0.04	0.19	0.00	0.00	0.01	0.01
Maximum Value	Max	32.20	5.90	678.00	35.77	336.29	46.92	380.00	9.60	2.50	9.20	36.54	30.50	4.20	90.20	2.40	8.08	4.12	147.10	82.30	0.06	0.91	0.26	0.01	0.00	0.19	0.36
Mean	Mean	27.47	4.49	186.68	6.27	55.53	11.17	104.52	4.29	1.59	3.92	11.58	10.34	1.74	21.42	0.59	1.20	1.06	39.41	21.92	0.02	0.28	0.22	0.00	0.00	0.07	0.15
Median	Median	27.19	4.50	130.00	3.16	14.18	10.38	72.50	3.20	1.60	4.05	8.94	8.00	1.35	14.05	0.48	0.64	0.69	27.35	14.80	0.02	0.17	0.22	0.00	0.00	0.05	0.15
Standard Deviation	SD	2.52	0.54	149.96	7.53	90.38	10.39	83.96	2.42	0.48	2.49	11.19	7.62	1.22	19.68	0.45	1.51	1.08	30.40	19.05	0.02	0.24	0.01	0.00	0.00	0.06	0.11
WHO Standard	WHO		6.5-8.5	-	5		30	500	5	5	40	0	-	-	75	-	400	50	250	100	-	5	0.1	0.003	-	-	0.01
NSDWQ Standard	NSDWQ		6.5-8.5	1000	5		-	500	-	-	-	10	200	-	-	0.2	100	50	250	-	-	-	0.3	0.003	0.05	1	0.01
EU Standard	EU		6.5-9.5	2500	-		-	-	-	-	-	10	200	-	-	-	250	50	250	-	0.5	-	0.2	0.005	0.05	0.2	0.01

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APPENDIX III
SEASONAL VARIATIONS

APPENDIX III(A): Results of seasonal groundwater quality parameters analyzed for dry and wet seasons

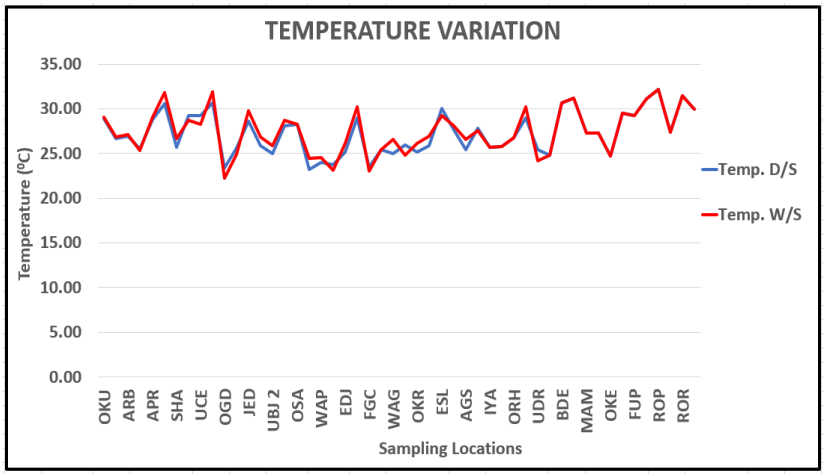
Sampling L.	Temp. (^{0}C)		pH		EC (µS/cm)		Turb. (NTU)		TH (mg/L)		TSS (mg/L)		TDS (mg/L)		DO (mg/L)		BOD (mg/L)	
SEASON	D	W	D	W	D	W	D	W	D	W	D	W	D	W	D	W	D	W
OKU	28.85	29.03	6.10	5.40	46.00	48.00	0.35	0.53	194.00	202.24	0.00	10.75	26.00	27.00	5.80	6.50	0.00	1.50
EFG	26.70	26.86	5.80	4.70	180.00	192.00	0.62	1.73	5.80	14.19	5.00	22.38	101.00	108.00	4.90	6.00	0.50	2.20
ARB	26.95	27.12	5.60	4.30	72.00	75.00	6.31	7.42	17.32	25.57	15.67	25.05	40.00	42.00	4.30	6.60	0.00	2.20
NCAT	25.50	25.32	4.80	4.10	100.00	105.00	2.11	3.23	4.79	13.05	16.01	27.84	56.00	59.00	5.40	8.80	0.00	1.80
APR	28.80	29.10	6.20	5.10	532.00	678.00	0.31	1.34	28.71	36.97	0.00	14.78	298.00	380.00	4.20	6.50	0.00	0.00
JKR	30.60	31.80	5.90	4.90	199.00	215.00	16.10	15.00	4.28	12.55	10.00	9.90	112.00	120.00	6.70	9.50	0.00	1.50
SHA	25.70	26.70	4.90	4.40	108.00	113.00	2.60	5.67	25.02	33.30	0.00	0.00	57.00	63.00	5.30	7.30	0.00	1.70
EKP	29.20	28.70	5.10	5.10	74.00	81.00	0.91	9.10	5.13	13.42	0.00	17.38	42.00	46.00	1.90	2.20	0.00	1.30
UCE	29.20	28.30	5.90	4.90	54.00	58.00	0.00	1.23	14.57	22.86	23.00	6.98	30.00	32.00	1.50	2.10	0.00	0.00
EFM	30.70	31.90	6.20	5.10	314.00	390.00	16.70	16.00	4.60	12.90	10.00	8.88	176.00	218.00	3.10	3.50	0.00	0.00
OGD	23.40	22.20	5.20	5.10	206.00	252.00	0.00	0.34	30.68	22.38	0.00	0.00	115.00	141.00	1.40	2.10	0.80	0.70
UGT	25.60	24.90	4.20	3.80	412.00	454.00	0.25	0.52	302.00	310.31	1.00	14.38	231.00	254.00	3.00	3.40	0.00	0.00
JED	28.60	29.80	4.70	4.20	378.00	405.00	12.60	12.55	5.84	14.16	12.00	12.01	212.00	227.00	2.10	2.50	0.00	0.00
UBJ 1	25.84	26.84	4.50	3.90	304.00	356.00	0.60	6.06	4.36	12.93	0.00	46.92	170.00	199.00	3.10	3.70	0.00	0.00
UBJ 2	24.95	25.85	5.10	4.20	106.00	125.00	14.20	14.52	3.75	12.09	0.00	11.74	59.00	70.00	2.20	2.40	0.00	0.00
OSM	28.07	28.67	4.60	4.60	53.00	57.00	37.53	35.77	16.32	24.67	32.67	0.02	30.00	32.00	2.00	2.30	0.00	1.90
OSA	28.28	28.28	4.60	4.10	434.00	520.00	2.07	3.09	4.54	12.90	1.20	0.01	243.00	291.00	3.20	3.80	0.00	0.00
OGB	23.21	24.41	5.80	4.10	362.00	411.00	3.40	3.88	22.87	31.24	0.00	11.00	203.00	230.00	3.60	4.40	0.00	0.00
WAP	24.00	24.50	5.20	3.80	83.00	93.00	13.40	15.00	4.21	4.16	11.00	0.00	47.00	52.00	1.50	2.30	0.00	0.00
OGU	23.70	23.10	6.10	4.90	156.00	179.00	0.00	0.02	5.75	14.13	0.00	10.84	87.00	100.00	1.00	1.90	0.00	0.00
EDJ	25.20	26.10	5.60	3.80	498.00	548.00	0.70	0.89	281.00	272.61	0.00	13.40	279.00	307.00	3.00	3.40	0.00	1.80
EDHE	29.00	30.20	6.70	4.20	115.00	131.00	13.90	14.00	4.82	13.20	10.00	11.75	65.00	73.00	3.00	3.90	0.50	0.80
FGC	23.50	23.00	5.40	4.50	108.00	130.00	0.00	0.03	28.04	36.41	0.00	0.11	61.00	72.00	2.90	3.10	0.90	1.20
AJA	25.40	25.40	6.30	4.90	74.00	79.00	1.80	2.65	4.42	12.79	3.00	3.50	42.00	44.00	2.00	2.50	0.00	0.00
WAG	25.00	26.60	5.90	4.80	57.00	59.00	1.20	2.45	26.25	34.61	6.00	23.38	32.00	33.00	2.50	2.90	0.00	0.00
OKL	26.00	24.80	5.30	4.40	40.00	46.00	0.00	0.03	12.97	21.32	0.00	1.23	22.00	26.00	5.30	8.90	0.00	1.70
OKR	25.20	26.10	6.30	5.50	189.00	254.00	0.40	0.78	30.28	38.62	1.00	8.05	106.00	142.00	6.40	8.70	0.00	1.30
MRQ	25.90	26.90	4.90	4.30	116.00	130.00	0.00	0.09	4.31	12.65	0.00	15.90	65.00	73.00	4.20	9.10	0.00	1.60
ESL	30.00	29.20	5.60	3.90	235.00	252.00	0.88	0.99	12.00	20.33	1.00	16.82	132.00	141.00	2.30	2.90	0.00	0.00
IGM	27.65	28.05	4.70	4.00	126.00	140.00	13.20	15.00	19.96	11.62	13.03	0.00	71.00	79.00	2.20	2.80	0.00	0.00
AGS	25.40	26.60	6.40	5.90	82.00	88.00	0.60	2.01	4.73	4.73	0.00	7.00	46.00	49.00	2.90	3.60	0.70	1.20
BOA	27.84	27.54	5.40	4.80	52.00	55.00	0.77	0.77	205.00	213.32	10.00	13.03	29.00	31.00	2.10	2.80	0.00	0.00
IYA	25.70	25.70	5.00	4.70	96.00	120.00	0.00	0.00	11.67	19.98	0.00	0.00	54.00	67.00	2.10	2.80	0.00	0.00
PEM	25.80	25.80	5.30	4.80	107.00	119.00	0.40	0.32	5.86	14.16	0.00	10.00	60.00	67.00	1.70	2.40	0.00	0.00
ORH	26.76	26.76	4.80	4.50	154.00	170.00	0.58	0.85	253.00	245.00	7.00	9.87	86.00	95.00	2.10	2.70	0.00	0.00
ENE	29.00	30.20	5.00	4.90	97.00	121.00	0.40	0.04	12.00	20.24	1.00	1.00	54.00	68.00	2.60	3.00	0.00	2.10
UDR	25.40	24.20	5.50	5.10	53.00	60.00	5.20	5.00	5.29	13.54	8.00	26.00	30.00	34.00	2.10	2.00	0.00	0.00
OTO	24.80	24.80	5.30	4.90	67.00	81.00	0.77	0.77	13.22	13.22	0.96	0.96	38.00	45.00	2.20	3.00	0.00	0.00
BDE	30.70	30.70	4.40	4.20	71.00	89.00	2.16	2.16	13.60	13.60	1.00	1.00	40.00	50.00	2.20	3.00	0.00	0.00
UPE	31.20	31.20	4.70	4.80	112.00	131.00	3.27	3.27	3.72	3.72	0.50	0.50	63.00	73.00	1.60	2.60	0.00	0.00
MAM	27.26	27.26	5.70	5.10	114.00	140.00	5.11	5.11	192.28	192.28	3.50	3.50	64.00	78.00	2.80	3.60	0.30	1.10
DST	27.30	27.30	5.70	3.40	329.00	370.00	15.34	15.34	336.29	336.29	42.47	42.47	184.00	207.00	2.40	3.30	0.00	1.10
OKE	24.70	24.70	6.10	3.60	237.00	281.00	6.13	6.13	13.74	13.74	10.00	10.00	133.00	158.00	1.70	2.20	0.00	0.00
MOF	29.50	29.50	4.80	4.50	45.00	54.00	9.00	9.00	266.69	266.69	17.52	17.52	25.00	30.00	1.70	2.30	0.00	0.00
FUP	29.22	29.22	5.10	3.60	236.00	260.00	7.81	7.81	13.91	13.91	11.00	11.00	132.00	146.00	4.80	5.70	0.00	0.00
SHP	31.13	31.13	5.70	4.20	127.00	138.00	5.13	5.13	4.91	4.91	5.29	5.29	71.00	77.00	5.30	6.10	0.00	1.60
ROP	32.20	32.20	6.10	4.30	55.00	62.00	20.06	20.06	13.95	13.95	12.22	12.22	31.00	35.00	7.70	9.60	0.00	2.20
ESR	27.40	27.40	5.90	4.50	52.00	56.00	19.65	19.65	19.34	19.34	6.10	6.10	29.00	32.00	6.00	7.10	0.00	2.50
ROR	31.50	31.50	4.40	3.90	250.00	286.00	20.01	20.01	13.49	13.49	13.00	13.00	140.00	160.00	1.30	2.00	0.00	0.00
PTR	29.91	29.91	5.90	3.90	70.00	77.00	0.05	0.05	20.39	20.39	23.09	23.09	39.00	43.00	5.70	8.70	0.00	0.00
Mean	29.38	29.47	6.00	4.65	58.00	62.50	0.20	0.29	107.20	111.32	11.55	16.92	32.50	35.00	5.75	7.60	0.00	0.75
Std. E.	0.106	0.088	0.020	0.150	2.400	2.900	0.030	0.048	17.361	18.185	2.309	1.234	1.300	1.600	0.010	0.220	0.000	0.150
Std. D.	0.750	0.622	0.141	1.061	16.971	20.506	0.212	0.339	122.761	128.587	16.327	8.726	9.192	11.314	0.071	1.556	0.000	1.061
T-test		0.051656		2.3E-13		5.67489E-08		0.009901		2.96E-07		0.009358		5.7E-08		1.09E-09		3.23303E-06

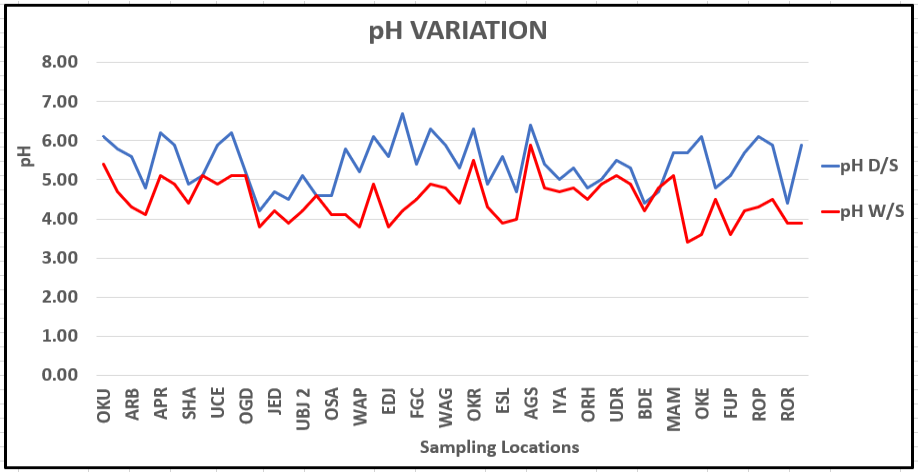
Sampling L.	COD (mg/L)		tal Coli. (MPN/10(		Na (mg/L)		K (mg/L)		Ca (mg/L)		Mg (mg/L)		SO_4 (mg/L)		NO_3 (mg/L)		Cl (mg/L)	
SEASON	D	W	D	W	D	W	D	W	D	W	D	W	D	W	D	W	D	W
OKU	3.60	5.30	32.12	27.35	3.20	3.40	0.50	0.60	5.20	5.30	0.20	0.18	0.15	0.15	0.14	0.14	12.00	12.30
EFG	5.50	7.50	0.00	0.09	9.20	9.90	1.90	2.50	20.80	21.70	0.80	0.83	1.48	1.78	1.20	1.26	35.40	36.40
ARB	8.90	7.40	11.00	15.77	4.60	4.80	0.70	0.80	7.80	8.00	0.20	0.26	0.33	0.35	0.27	0.28	14.80	15.20
NCAT	5.80	2.40	30.19	32.69	6.30	6.50	1.00	2.10	11.00	10.60	0.50	0.48	0.71	0.69	0.52	0.67	25.20	20.30
APR	4.90	5.20	0.00	9.85	27.30	30.50	1.00	1.20	69.00	90.20	1.90	2.40	5.92	8.08	1.95	4.12	117.00	147.10
JKR	3.80	5.70	0.00	4.13	20.90	22.20	1.90	2.60	14.60	15.60	0.80	0.93	1.28	1.11	0.82	0.96	43.50	46.50
SHA	5.70	4.40	0.00	4.13	5.20	5.50	0.40	0.40	12.50	13.50	0.40	0.47	0.44	0.45	0.11	0.11	24.00	26.60
EKP	1.70	0.50	13.00	6.24	8.30	9.20	1.90	2.70	4.00	4.10	0.60	0.58	0.43	0.62	0.02	0.04	18.00	19.20
UCE	2.50	0.60	0.00	0.06	3.40	3.50	0.40	0.40	5.90	6.70	0.10	0.13	0.19	0.20	0.15	0.16	12.40	13.00
EFM	3.50	4.00	5.02	0.08	9.20	11.20	2.40	3.30	42.20	53.90	0.70	1.07	2.19	2.88	1.94	2.64	58.20	72.80
OGD	3.80	7.40	0.00	0.02	18.00	20.90	2.50	3.50	17.90	19.60	0.30	0.80	1.41	1.81	1.28	1.72	38.40	47.00
UGT	7.70	5.10	0.00	3.11	20.00	21.50	3.90	4.00	49.00	56.20	1.20	1.31	3.40	3.62	3.27	3.96	87.00	93.80
JED	2.50	0.50	25.98	24.67	18.00	19.20	2.20	3.20	46.00	51.80	1.00	1.03	2.92	2.92	1.90	2.87	85.30	86.40
UBJ 1	4.80	1.40	4.80	7.60	11.00	11.30	3.10	3.50	38.70	46.90	0.60	1.13	2.57	3.02	1.74	2.83	58.90	68.90
UBJ 2	2.50	0.80	5.91	4.80	5.80	6.60	1.00	1.50	12.60	14.50	0.30	0.48	0.61	0.68	0.57	0.68	25.20	30.50
OSM	3.00	6.40	33.33	36.54	3.80	4.10	0.40	0.40	5.30	5.70	0.10	0.11	0.23	0.20	0.29	0.39	12.00	13.00
OSA	4.50	6.70	10.67	14.52	21.10	24.50	2.60	4.10	57.70	66.70	1.10	1.32	2.51	4.83	2.95	3.41	99.80	107.80
OGB	1.90	2.70	30.53	26.52	20.90	22.10	1.80	3.70	43.40	50.20	1.00	1.19	2.64	3.24	2.64	3.05	77.90	89.20
WAP	3.20	0.70	0.00	1.19	2.20	2.30	0.10	0.10	11.90	13.60	0.10	0.17	0.35	0.58	0.46	0.79	17.80	18.60
OGU	2.70	0.30	12.05	16.05	7.60	8.50	1.20	1.40	19.90	23.00	0.30	0.46	0.48	0.54	0.46	0.69	33.60	39.50
EDJ	8.40	6.10	6.97	10.36	23.30	25.00	2.50	4.20	59.00	68.20	1.20	1.35	3.44	4.21	2.68	3.10	91.30	98.60
EDHE	6.90	2.10	0.00	0.07	5.40	6.40	2.40	2.70	12.70	14.70	0.30	0.38	1.00	1.02	0.91	1.05	24.90	28.40
FGC	1.20	0.70	28.50	31.94	5.20	5.90	1.00	1.20	12.00	14.90	0.30	0.41	0.68	0.85	1.03	1.19	19.50	24.60
AJA	2.70	1.40	15.11	16.88	2.20	2.40	0.70	0.70	10.90	11.90	0.20	0.23	0.26	0.20	0.81	0.94	18.80	19.00
WAG	1.20	0.60	5.90	18.00	4.00	4.10	0.40	0.40	5.80	5.90	0.10	0.11	0.12	0.20	0.57	0.66	13.60	13.30
OKL	3.90	4.40	0.00	0.01	1.80	1.90	0.30	0.30	5.00	5.40	0.20	0.17	0.15	0.15	0.21	0.27	10.30	12.30
OKR	3.10	5.40	35.00	25.54	8.50	10.10	2.50	3.50	21.30	24.80	1.00	1.06	1.00	1.31	0.43	0.59	40.40	59.50
MRQ	5.90	6.40	11.00	13.55	6.30	7.50	1.80	2.10	12.40	14.70	0.50	0.68	0.43	0.56	0.55	0.75	26.50	28.30
ESL	4.80	4.10	5.40	9.65	19.00	20.00	1.70	2.90	22.50	24.10	0.30	0.38	1.17	1.15	0.98	1.30	55.50	57.10
IGM	6.30	5.70	0.00	4.00	13.60	14.80	1.90	2.30	7.50	8.60	0.30	0.64	0.78	0.88	0.72	0.95	24.00	26.10
AGS	4.70	4.00	30.70	33.97	3.10	3.50	0.50	0.80	10.60	12.20	0.20	0.20	0.20	0.24	0.10	0.18	16.60	23.50
BOA	7.10	4.40	11.50	11.55	1.50	1.50	0.20	0.30	7.50	7.80	0.20	0.18	0.37	0.16	0.30	0.13	11.70	12.40
IYA	3.90	2.00	4.80	3.90	6.60	8.70	1.00	1.30	9.50	11.00	0.20	0.42	0.33	0.35	0.05	0.08	18.20	25.20
PEM	5.50	5.90	31.22	26.45	5.10	5.60	0.70	0.90	13.20	15.30	0.30	0.30	0.21	0.28	0.02	0.02	21.50	24.10
ORH	3.20	2.40	0.00	0.02	11.80	12.70	1.90	2.10	13.70	14.60	0.30	0.68	0.98	1.00	0.95	1.26	32.20	34.80
ENE	6.60	7.10	12.23	0.09	10.20	12.50	0.90	1.40	7.00	8.10	0.50	0.43	0.54	0.54	0.58	0.68	21.80	28.10
UDR	5.40	3.70	6.12	0.02	2.50	2.90	0.60	0.60	7.00	7.20	0.10	0.11	0.12	0.14	0.31	0.41	12.10	14.10
OTO	5.30	1.40	0.57	0.57	3.60	5.30	0.20	0.80	8.50	8.90	0.10	0.25	0.22	0.22	0.09	0.01	16.40	19.30
BDE	7.10	2.10	15.67	15.67	6.20	6.80	1.00	1.20	6.20	9.00	0.20	0.30	0.18	0.18	0.24	0.24	17.70	22.70
UPE	3.90	4.70	8.23	8.23	9.60	10.80	0.90	1.30	9.50	10.10	0.40	0.55	0.90	0.91	1.20	1.26	20.50	23.60
MAM	2.40	6.10	25.90	25.90	3.30	3.90	0.90	1.20	15.60	19.60	0.60	0.72	0.38	0.52	0.41	0.69	28.70	35.10
DST	3.20	1.10	0.00	0.00	19.60	21.00	2.50	3.10	39.00	45.00	0.40	0.50	1.13	1.38	1.36	1.40	76.60	82.50
OKE	1.10	0.50	12.92	12.92	18.20	20.50	2.10	2.50	22.00	29.00	0.60	0.83	1.27	1.34	1.44	1.51	49.80	58.90
MOF	5.80	3.70	11.13	11.13	2.10	2.20	0.30	0.60	5.50	6.70	0.30	0.41	0.18	0.21	0.10	0.18	10.60	13.10
FUP	1.80	2.90	6.37	6.37	16.00	18.00	1.40	1.60	23.80	25.10	1.10	1.19	1.12	1.46	0.98	1.19	49.90	51.80
SHP	5.70	7.20	7.41	7.41	11.90	13.40	0.70	0.80	10.40	10.70	0.40	0.52	0.61	0.65	0.53	0.55	27.50	29.60
ROP	4.90	8.40	0.07	0.07	2.50	3.00	0.20	0.50	7.10	8.20	0.20	0.16	0.12	0.15	0.17	0.19	12.90	14.30
ESR	5.20	9.20	34.20	34.20	2.20	2.60	0.30	0.40	6.90	7.30	0.10	0.14	0.16	0.17	0.22	0.23	11.90	12.50
ROR	4.40	5.40	12.80	12.80	10.70	12.80	2.30	2.90	30.00	34.10	0.50	0.63	1.28	1.69	0.83	1.07	49.90	55.20
PTR	3.90	2.10	2.11	2.11	3.10	3.70	0.50	0.60	9.30	10.20	0.30	0.20	0.21	0.29	0.17	0.29	16.90	18.20
Mean	3.75	3.70	17.12	14.73	3.15	3.55	0.50	0.60	7.25	7.75	0.25	0.19	0.18	0.22	0.16	0.22	14.45	15.25
Std. E.	0.030	0.320	3.001	2.524	0.010	0.030	0.000	0.000	0.410	0.490	0.010	0.002	0.006	0.014	0.003	0.015	0.490	0.590
Std. D.	0.212	2.263	21.220	17.847	0.071	0.212	0.000	0.000	2.899	3.465	0.071	0.014	0.042	0.099	0.021	0.106	3.465	4.172
T-test		0.171093		0.449720		2.01299E-11		1.29E-08		3.06E-06		5.56E-07		0.002672		0.000063		5.08183E-07

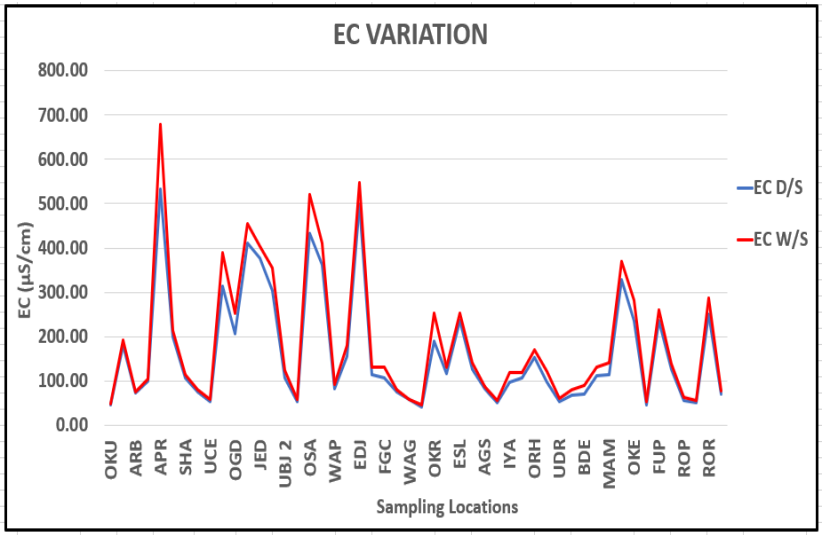
Sampling L.	HCO_3 (mg/L)		NH_4 (mg/L)		PO_4 (mg/L)		Fe (mg/L)		Cd (mg/L)		Cr (mg/L)		Cu (mg/L)		Pb (mg/L)	
SEASON	D	W	D	W	D	W	D	W	D	W	D	W	D	W	D	W
OKU	3.10	3.10	0.003	0.009	0.01	0.04	0.20	0.22	0.000	0.000	0.000	0.000	0.000	0.010	0.001	0.010
EFG	24.30	26.30	0.007	0.018	0.23	0.31	0.21	0.23	0.000	0.001	0.000	0.001	0.002	0.020	0.001	0.080
ARB	9.20	9.50	0.003	0.009	0.10	0.11	0.20	0.22	0.002	0.002	0.001	0.001	0.010	0.040	0.001	0.180
NCAT	7.80	13.60	0.000	0.012	0.06	0.06	0.20	0.22	0.005	0.003	0.004	0.002	0.310	0.120	0.040	0.210
APR	57.40	71.10	0.021	0.061	0.53	0.77	0.24	0.26	0.000	0.000	0.000	0.000	0.000	0.010	0.001	0.020
JKR	21.50	22.50	0.008	0.001	0.15	0.29	0.21	0.23	0.001	0.000	0.000	0.000	0.001	0.020	0.001	0.060
SHA	11.20	12.20	0.005	0.000	0.05	0.06	0.20	0.19	0.004	0.002	0.004	0.001	0.310	0.100	0.040	0.180
EKP	6.00	6.10	0.000	0.000	0.02	0.09	0.20	0.22	0.002	0.000	0.003	0.001	0.100	0.010	0.050	0.050
UCE	5.80	6.10	0.000	0.000	0.03	0.06	0.20	0.22	0.001	0.000	0.000	0.001	0.002	0.005	0.001	0.090
EFM	48.80	56.10	0.029	0.051	0.54	0.67	0.21	0.23	0.001	0.000	0.001	0.000	0.200	0.020	0.001	0.050
OGD	29.10	36.60	0.014	0.023	0.15	0.33	0.21	0.23	0.003	0.000	0.002	0.001	0.120	0.010	0.010	0.060
UGT	50.10	53.10	0.026	0.025	0.32	0.47	0.22	0.24	0.005	0.005	0.005	0.002	0.900	0.150	0.050	0.310
JED	42.40	44.40	0.020	0.036	0.28	0.59	0.22	0.24	0.005	0.002	0.003	0.001	0.420	0.070	0.060	0.250
UBJ 1	44.00	48.80	0.007	0.015	0.33	0.68	0.21	0.23	0.006	0.005	0.004	0.002	0.700	0.170	0.060	0.230
UBJ 2	10.00	10.50	0.000	0.001	0.10	0.12	0.20	0.22	0.003	0.002	0.003	0.002	0.090	0.060	0.030	0.150
OSM	5.80	6.10	0.000	0.000	0.00	0.09	0.20	0.22	0.006	0.001	0.004	0.001	0.700	0.010	0.060	0.050
OSA	41.60	59.60	0.008	0.015	0.79	0.91	0.22	0.24	0.006	0.004	0.004	0.002	0.600	0.100	0.050	0.240
OGB	40.90	42.50	0.005	0.011	0.52	0.83	0.22	0.24	0.001	0.003	0.001	0.002	0.010	0.110	0.001	0.220
WAP	11.00	12.60	0.000	0.005	0.10	0.18	0.20	0.22	0.003	0.005	0.002	0.002	0.100	0.150	0.010	0.350
OGU	18.80	19.50	0.008	0.000	0.09	0.12	0.21	0.20	0.001	0.001	0.000	0.001	0.000	0.010	0.010	0.080
EDJ	79.50	82.30	0.004	0.016	0.48	0.90	0.23	0.25	0.001	0.005	0.002	0.002	0.019	0.150	0.001	0.260
EDHE	13.30	14.00	0.001	0.010	0.24	0.39	0.20	0.22	0.000	0.002	0.000	0.001	0.000	0.060	0.001	0.190
FGC	17.60	18.30	0.000	0.008	0.19	0.22	0.20	0.22	0.002	0.001	0.001	0.001	0.060	0.070	0.020	0.150
AJA	5.40	6.10	0.000	0.003	0.10	0.13	0.20	0.22	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.110
WAG	5.30	6.10	0.000	0.000	0.14	0.16	0.20	0.22	0.001	0.001	0.000	0.000	0.001	0.040	0.001	0.060
OKL	3.10	3.70	0.000	0.000	0.06	0.12	0.20	0.22	0.002	0.001	0.002	0.001	0.100	0.100	0.001	0.160
OKR	25.00	32.00	0.009	0.017	0.34	0.47	0.21	0.23	0.001	0.000	0.000	0.000	0.000	0.020	0.001	0.030
MRQ	12.90	13.70	0.006	0.012	0.06	0.10	0.20	0.22	0.003	0.002	0.003	0.001	0.300	0.070	0.030	0.150
ESL	23.10	24.90	0.000	0.007	0.11	0.39	0.21	0.23	0.001	0.005	0.002	0.002	0.100	0.160	0.001	0.200
IGM	18.00	19.20	0.000	0.010	0.14	0.11	0.20	0.22	0.006	0.004	0.003	0.002	0.500	0.110	0.060	0.230
AGS	11.90	5.20	0.008	0.015	0.11	0.18	0.20	0.22	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.010
BOA	6.00	6.10	0.020	0.030	0.10	0.14	0.20	0.22	0.002	0.001	0.002	0.001	0.250	0.010	0.001	0.050
IYA	14.70	15.60	0.008	0.016	0.07	0.11	0.20	0.22	0.004	0.002	0.002	0.001	0.400	0.030	0.030	0.070
PEM	15.30	16.00	0.016	0.025	0.05	0.09	0.20	0.20	0.003	0.002	0.002	0.001	0.200	0.010	0.001	0.070
ORH	19.60	21.60	0.007	0.013	0.37	0.49	0.20	0.22	0.004	0.002	0.004	0.001	0.500	0.030	0.020	0.150
ENE	10.10	11.70	0.016	0.025	0.12	0.13	0.20	0.22	0.002	0.000	0.002	0.000	0.300	0.010	0.020	0.030
UDR	5.40	6.10	0.031	0.045	0.09	0.09	0.20	0.22	0.001	0.000	0.001	0.000	0.020	0.020	0.001	0.050
OTO	6.30	7.70	0.008	0.016	0.11	0.12	0.20	0.22	0.003	0.000	0.002	0.000	0.030	0.010	0.001	0.080
BDE	5.90	6.10	0.005	0.010	0.10	0.11	0.20	0.22	0.008	0.002	0.005	0.001	0.700	0.080	0.060	0.250
UPE	16.00	19.80	0.011	0.019	0.04	0.09	0.20	0.22	0.006	0.001	0.003	0.001	0.500	0.030	0.050	0.060
MAM	10.10	11.30	0.000	0.007	0.14	0.19	0.20	0.22	0.001	0.000	0.001	0.001	0.100	0.010	0.001	0.050
DST	33.20	38.60	0.039	0.053	0.22	0.29	0.22	0.24	0.001	0.005	0.001	0.002	0.080	0.190	0.001	0.350
OKE	29.70	32.70	0.035	0.050	0.29	0.38	0.21	0.23	0.000	0.005	0.001	0.002	0.000	0.180	0.001	0.350
MOF	4.90	5.10	0.000	0.000	0.05	0.05	0.20	0.22	0.005	0.001	0.002	0.001	0.400	0.020	0.030	0.150
FUP	30.50	35.70	0.091	0.041	0.17	0.20	0.21	0.19	0.005	0.005	0.003	0.002	0.100	0.190	0.020	0.360
SHP	14.80	15.80	0.008	0.019	0.45	0.54	0.20	0.22	0.001	0.003	0.001	0.001	0.010	0.120	0.006	0.210
ROP	5.80	6.10	0.000	0.000	0.09	0.10	0.20	0.22	0.001	0.002	0.000	0.001	0.100	0.090	0.001	0.200
ESR	5.50	6.10	0.000	0.000	0.10	0.15	0.20	0.22	0.001	0.001	0.000	0.001	0.001	0.020	0.001	0.060
ROR	36.60	41.30	0.007	0.026	0.31	0.58	0.21	0.23	0.007	0.005	0.005	0.002	0.700	0.150	0.070	0.350
PTR	6.50	7.00	0.000	0.000	0.10	0.19	0.20	0.22	0.000	0.005	0.000	0.002	0.000	0.140	0.001	0.330
Mean	4.80	5.05	0.00	0.00	0.06	0.12	0.20	0.22	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.17
Std. E.	0.340	0.390	0.000	0.001	0.009	0.015	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.013	0.000	0.032
Std. D.	2.404	2.758	0.002	0.006	0.064	0.106	0.000	0.000	0.000	0.004	0.000	0.001	0.000	0.092	0.000	0.226
T-test		0.000051		0.000585		5.03887E-08		0.000000		0.103		7.51E-05		0.00025		2.06E-12

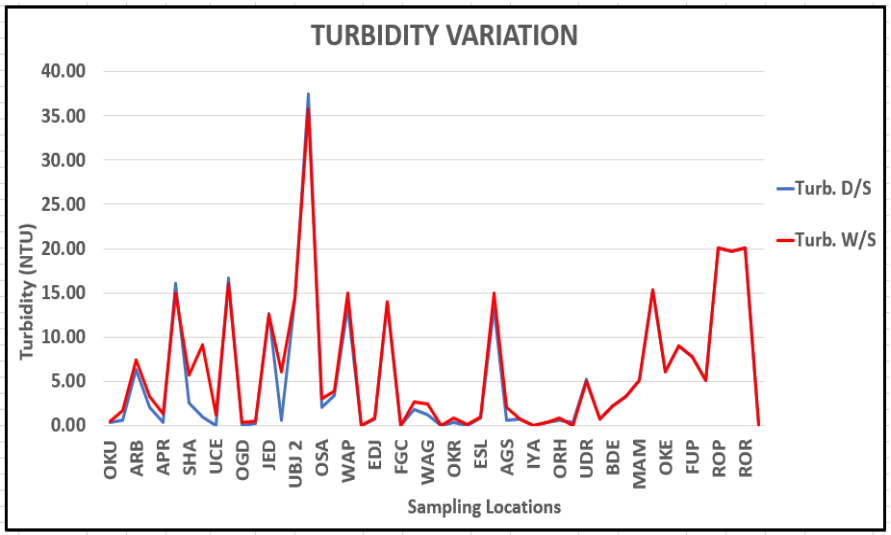
D = Dry season, W = Wet season

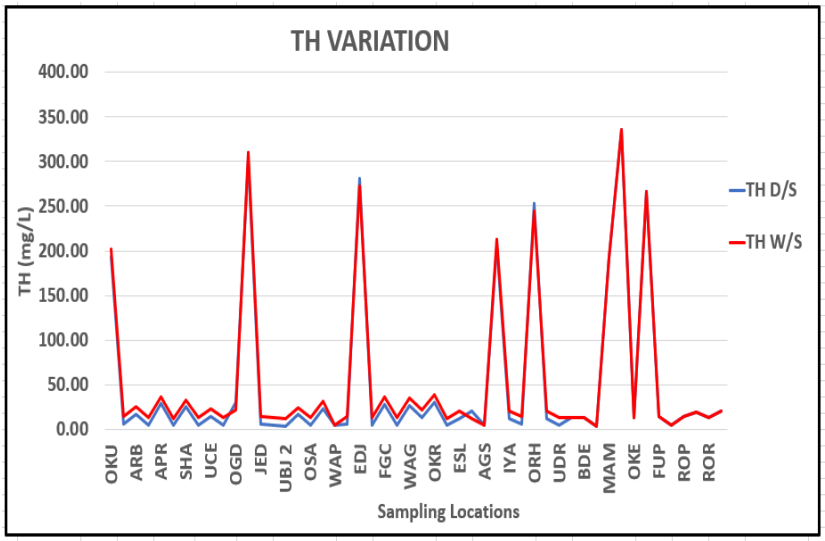
APPENDIX III(a): Graphical presentation for seasonal variation of groundwater quality parameters

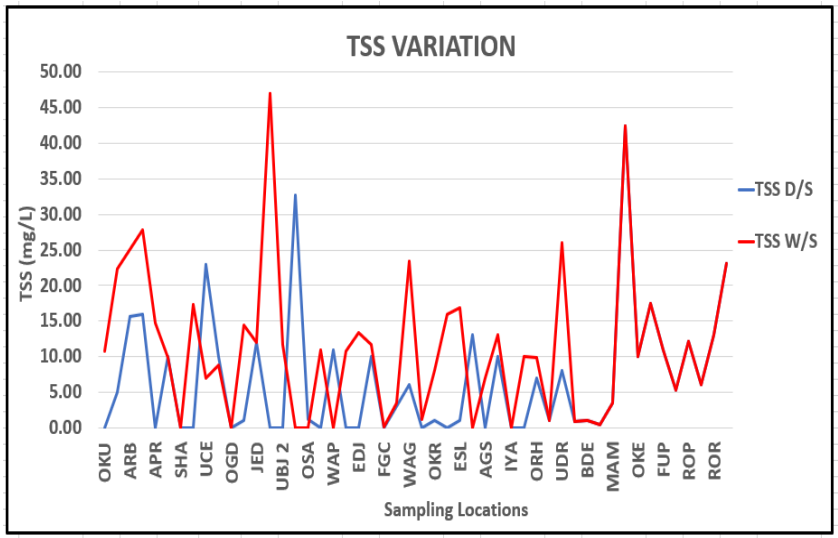


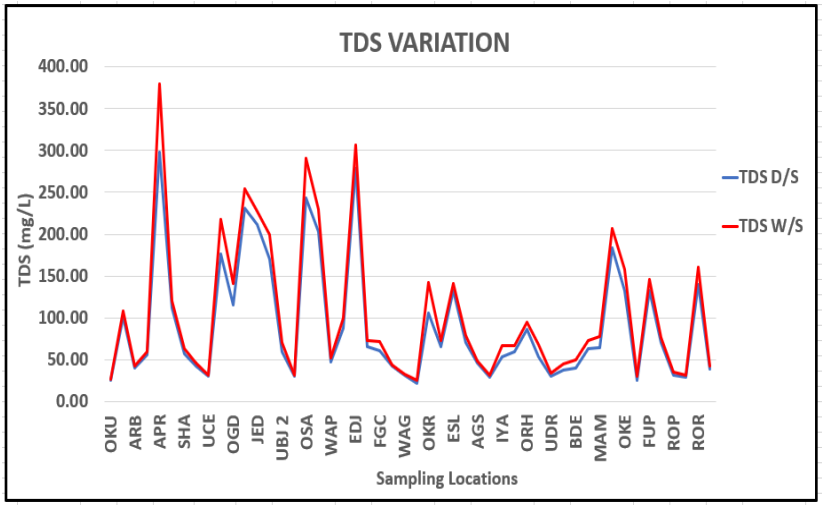


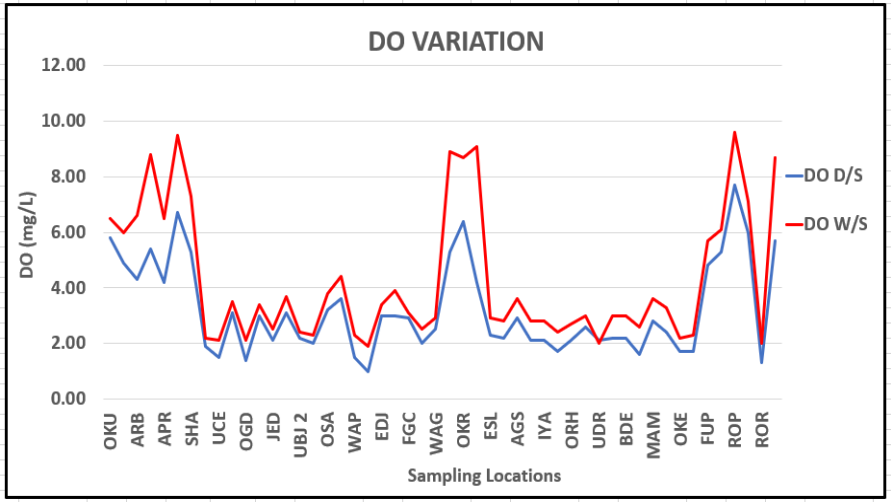


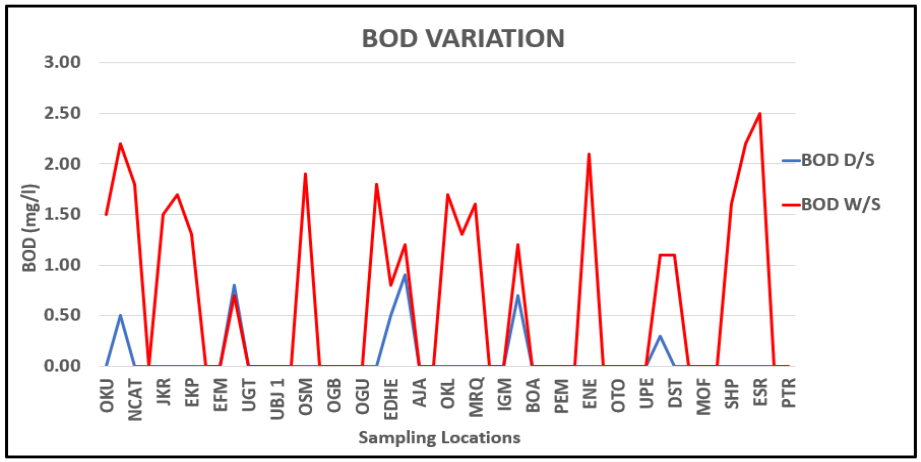


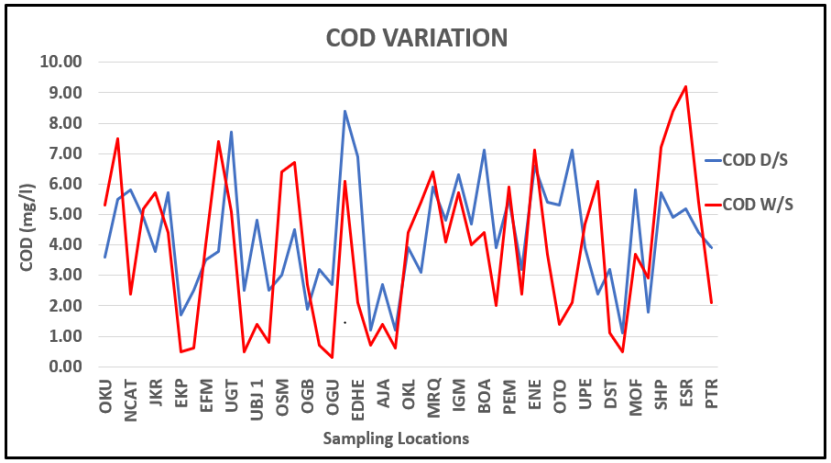

TH VARIATION
TH (mg/L)
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
OKU ARB APR SHA UCE OGD JED UBJ 2 OSA WAP EDJ FGC WAG OKR ESL AGS IYA ORH UDR BDE MAM OKE FUP ROP ROR
Sampling Locations
TH D/S
TH W/S

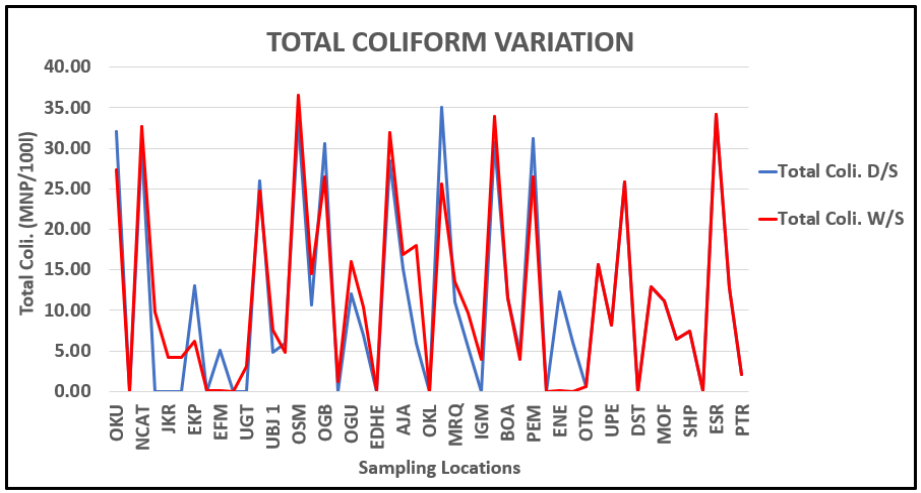

TSS VARIATION
TSS (mg/L)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
OKU ARB APR SHA UCE OGD JED UBJ 2 OSA WAP EDJ FGC WAG OKR ESL AGS IYA ORH UDR BDE MAM OKE FUP ROP ROR
Sampling Locations
TSS D/S
TSS W/S

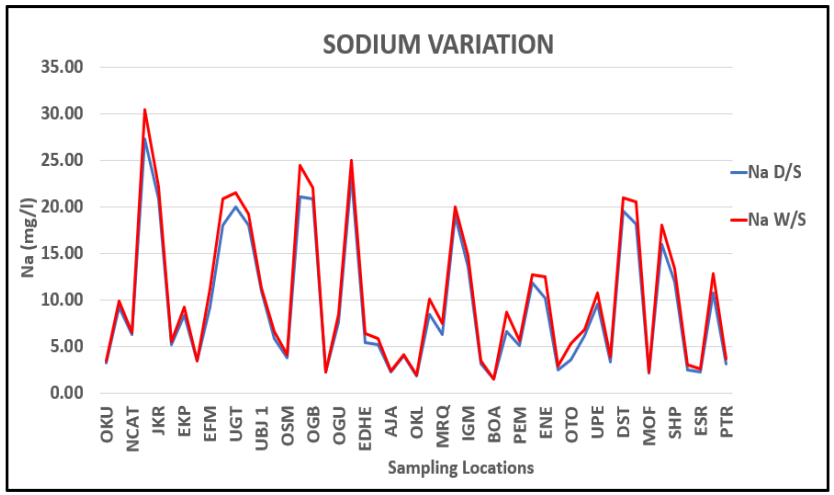

TDS VARIATION
TDS (mg/L)
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
OKU ARB APR SHA UCE OGD JED UBJ 2 OSA WAP EDJ FGC WAG OKR ESL AGS IYA ORH UDR BDE MAM OKE FUP ROP ROR
Sampling Locations
TDS D/S
TDS W/S

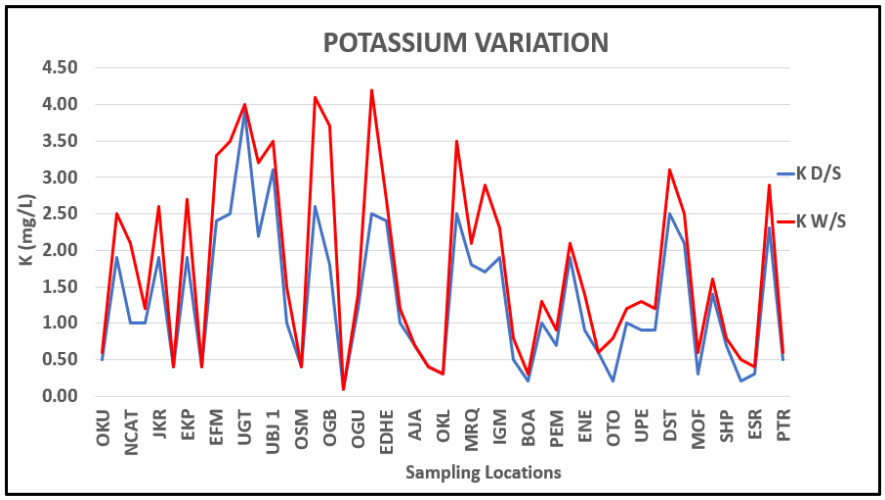

DO VARIATION
DO (mg/L)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
OKU ARB APR SHA UCE OGD JED UBJ 2 OSA WAP EDJ FGC WAG OKR ESL AGS IYA ORH UDR BDE MAM OKE FUP ROP ROR
Sampling Locations
DO D/S
DO W/S

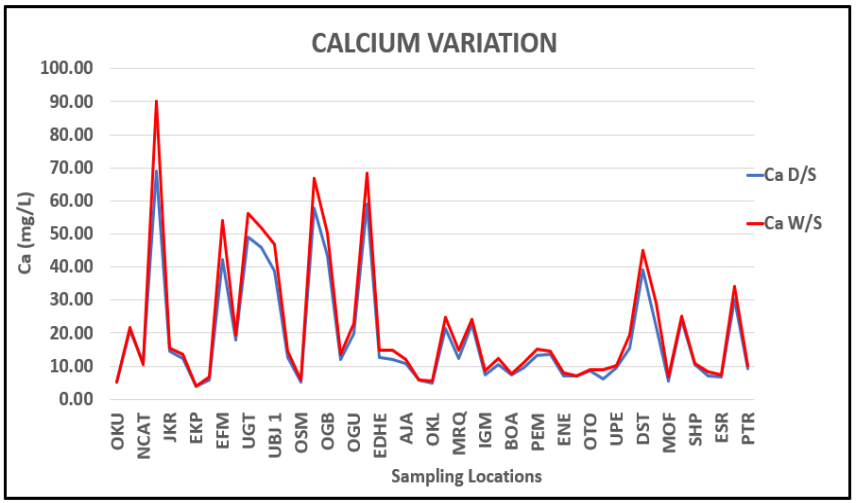

BOD VARIATION
BOD (mg/l)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
OKU NCAT JKR EKP EFM UGT UBJ 1 OSM OGB OGU EDHE AJA OKL MRQ IGM BOA PEM ENE OTO UPE DST MOF SHP ESR PTR
Sampling Locations
BOD D/S
BOD W/S

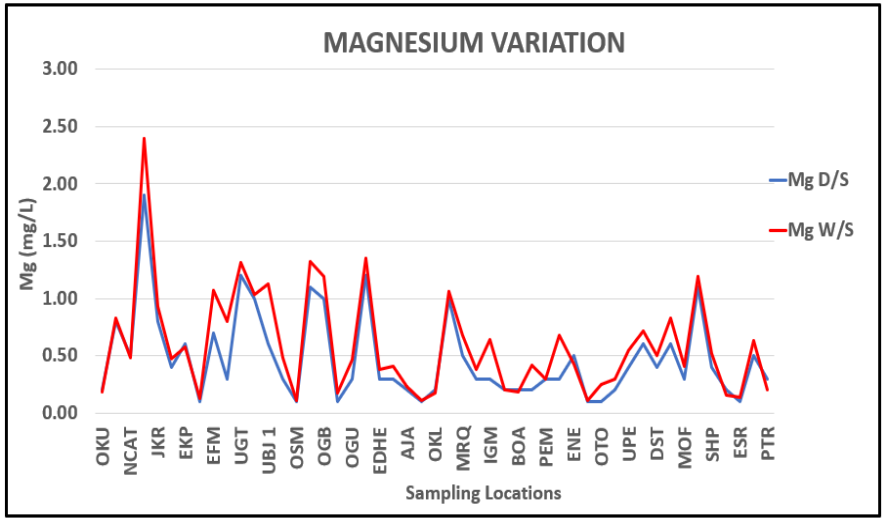

COD VARIATION
COD (mg/l)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
OKU NCAT JKR EKP EFM UGT UBJ 1 OSM OGB OGU EDHE AJA OKL MRQ IGM BOA PEM ENE OTO UPE DST MOF SHP ESR PTR
Sampling Locations
COD D/S
COD W/S

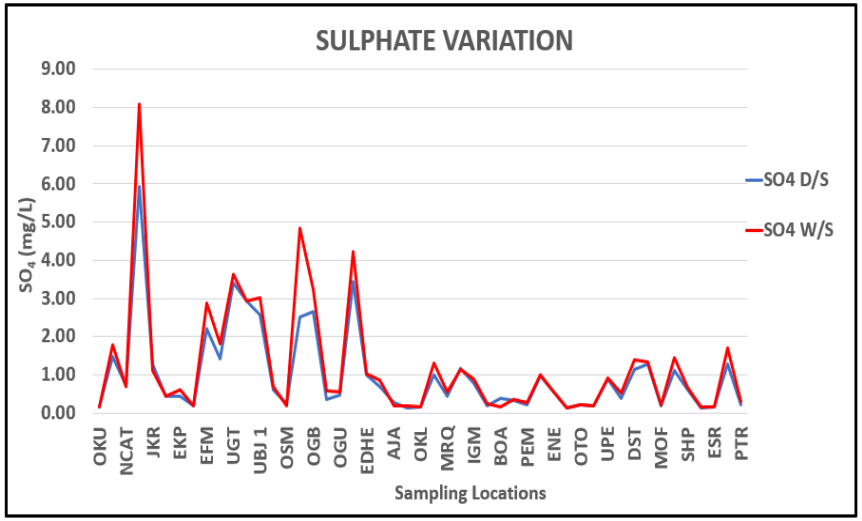

TOTAL COLIFORM VARIATION
Total Coli. (MNP/100l)
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
OKU NCAT JKR EKP EFM UGT UBJ 1 OSM OGB OGU EDHE AJA OKL MRQ IGM BOA PEM ENE OTO UPE DST MOF SHP ESR PTR
Sampling Locations
Total Coli. D/S
Total Coli. W/S

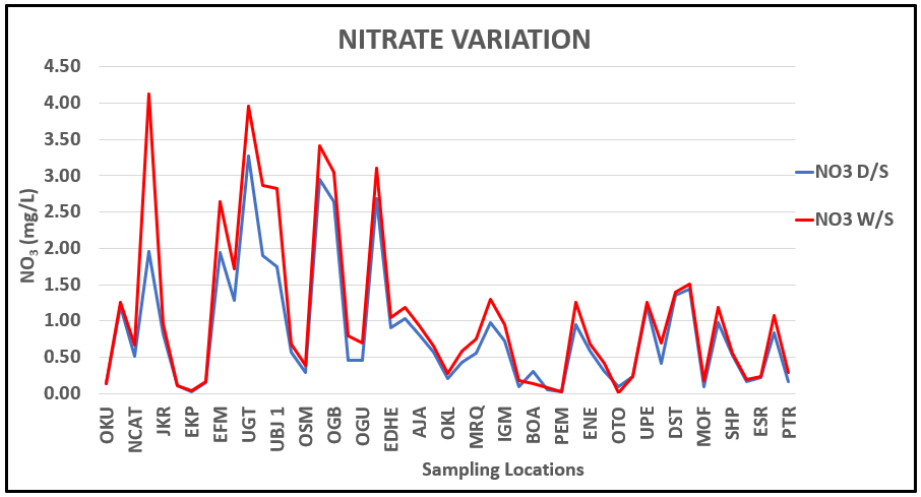

SODIUM VARIATION
Na (mg/l)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
OKU NCAT JKR EKP EFM UGT UBJ 1 OSM OGB OGU EDHE AJA OKL MRQ IGM BOA PEM ENE OTO UPE DST MOF SHP ESR PTR
Sampling Locations
Na D/S
Na W/S

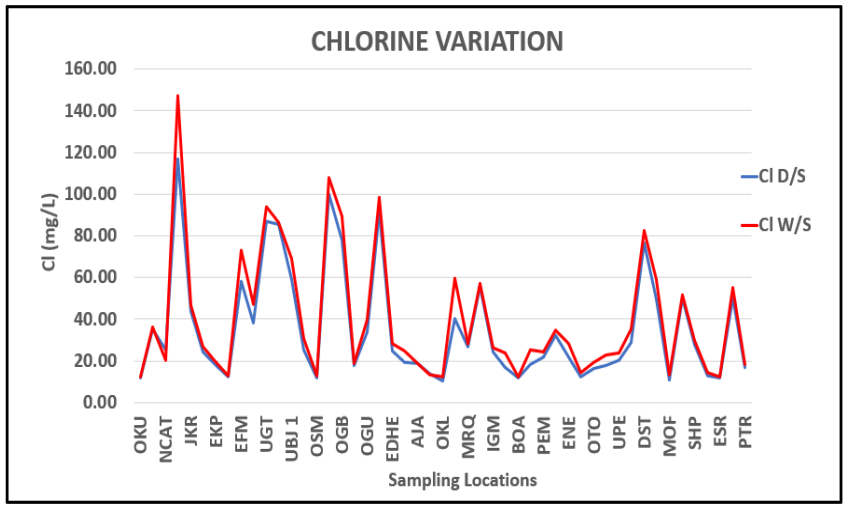

POTASSIUM VARIATION
K (mg/L)
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
OKU NCAT JKR EKP EFM UGT UBJ 1 OSM OGB OGU EDHE AJA OKL MRQ IGM BOA PEM ENE OTO UPE DST MOF SHP ESR PTR
Sampling Locations
K D/S
K W/S

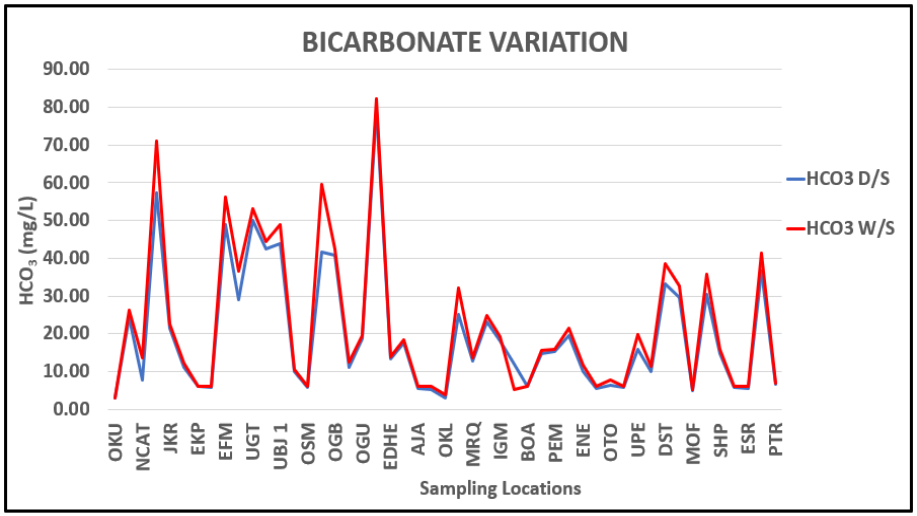

CALCIUM VARIATION
Ca (mg/L)
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
OKU NCAT JKR EKP EFM UGT UBJ 1 OSM OGB OGU EDHE AJA OKL MRQ IGM BOA PEM ENE OTO UPE DST MOF SHP ESR PTR
Sampling Locations
Ca D/S
Ca W/S

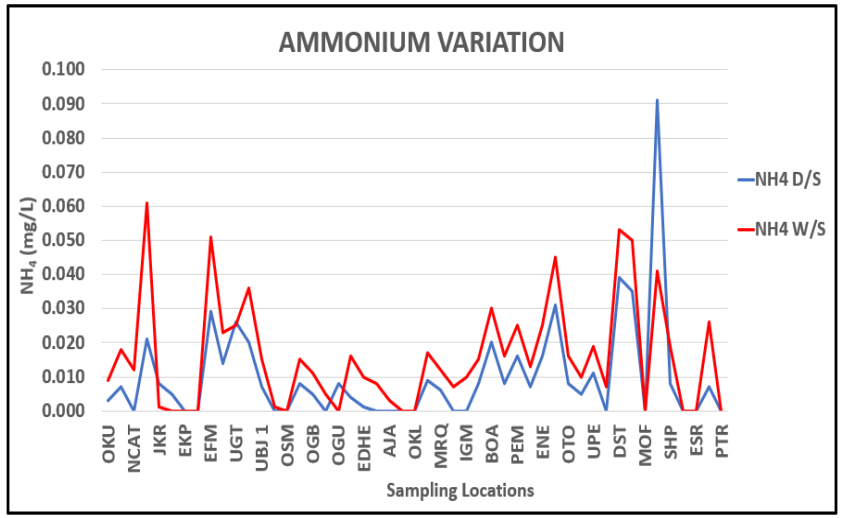

MAGNESIUM VARIATION
Mg (mg/L)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
OKU NCAT JKR EKP EFM UGT UBJ 1 OSM OGB OGU EDHE AJA OKL MRQ IGM BOA PEM ENE OTO UPE DST MOF SHP ESR PTR
Sampling Locations
Mg D/S
Mg W/S

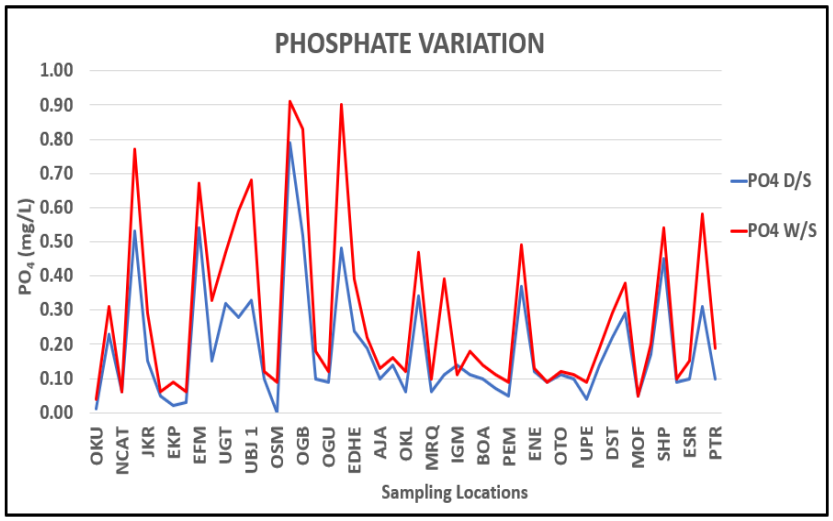

SULPHATE VARIATION
SO4 (mg/L)
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
OKU NCAT JKR EKP EFM UGT UBJ 1 OSM OGB OGU EDHE AJA OKL MRQ IGM BOA PEM ENE OTO UPE DST MOF SHP ESR PTR
Sampling Locations
SO4 D/S
SO4 W/S

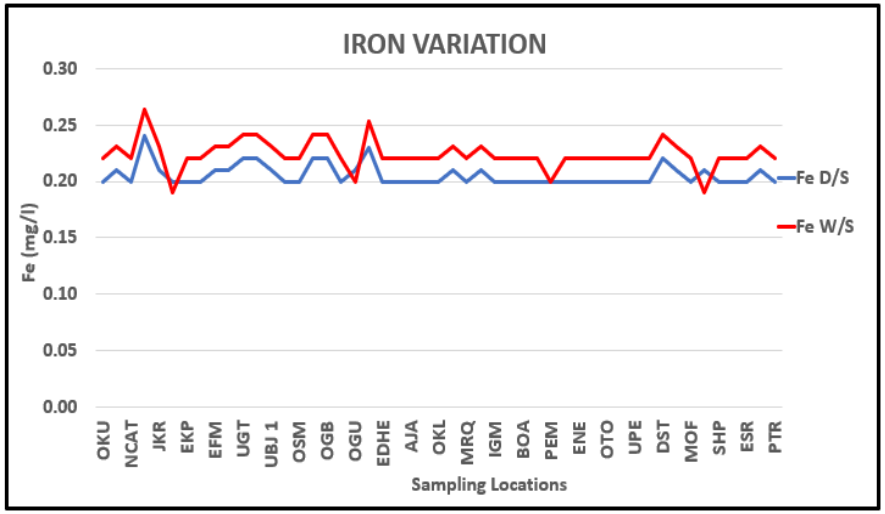

NITRATE VARIATION
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
NO3 (mg/L)
OKU NCAT JKR EKP EFM UGT UBJ 1 OSM OGB OGU EDHE AJA OKL MRQ IGM BOA PEM ENE OTO UPE DST MOF SHP ESR PTR
Sampling Locations
NO3 D/S
NO3 W/S

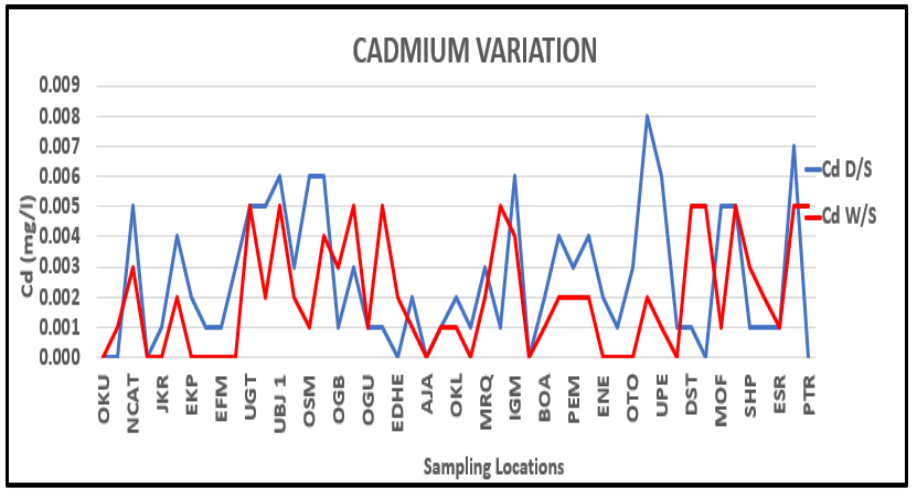

CHLORINE VARIATION
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Cl (mg/L)
OKU NCAT JKR EKP EFM UGT UBJ 1 OSM OGB OGU EDHE AJA OKL MRQ IGM BOA PEM ENE OTO UPE DST MOF SHP ESR PTR
Sampling Locations
Cl D/S
Cl W/S

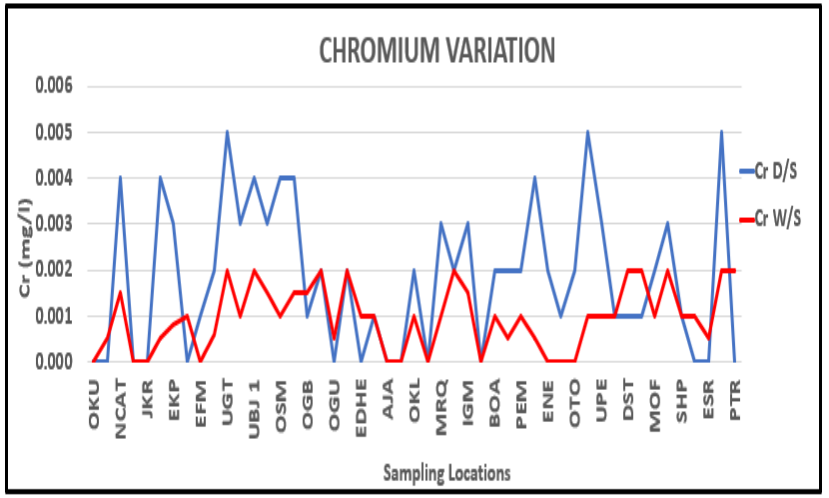

BICARBONATE VARIATION
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
HCO3 (mg/L)
OKU NCAT JKR EKP EFM UGT UBJ 1 OSM OGB OGU EDHE AJA OKL MRQ IGM BOA PEM ENE OTO UPE DST MOF SHP ESR PTR
Sampling Locations
HCO3 D/S
HCO3 W/S

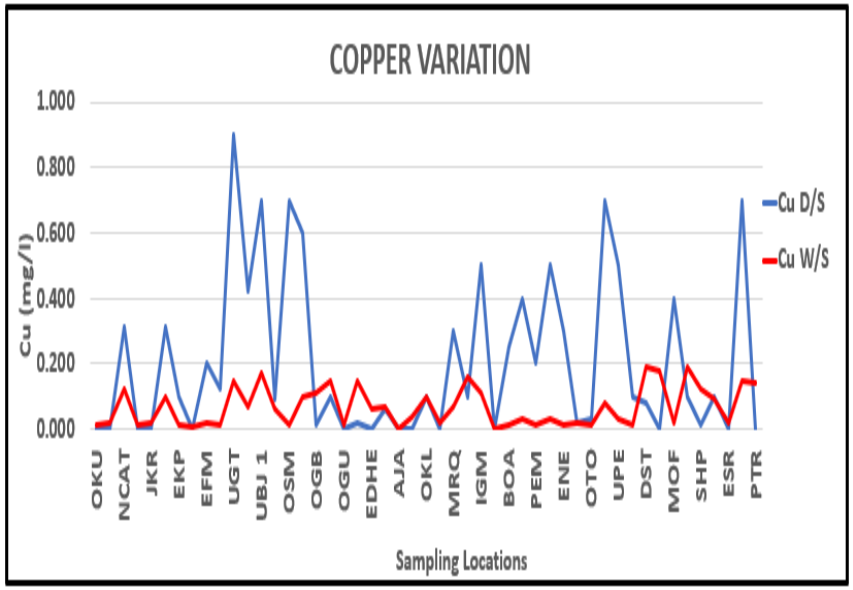

AMMONIUM VARIATION
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
NH4 (mg/L)
OKU NCAT JKR EKP EFM UGT UBJ 1 OSM OGB OGU EDHE AJA OKL MRQ IGM BOA PEM ENE OTO UPE DST MOF SHP ESR PTR
Sampling Locations
NH4 D/S
NH4 W/S

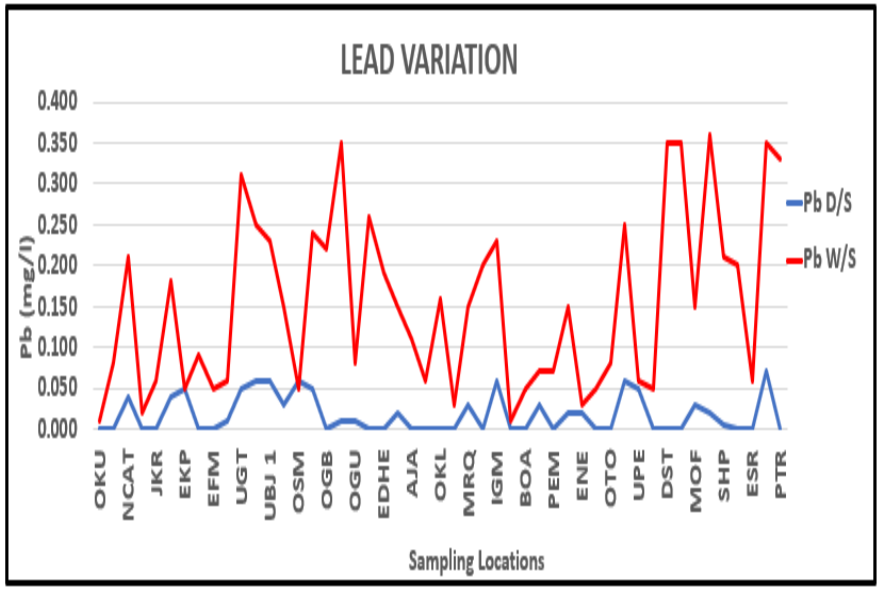

PHOSPHATE VARIATION
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
PO4 (mg/L)
PO4 D/S
PO4 W/S
OKU NCAT JKR EKP EFM UGT UBJ 1 OSM OGB OGU EDHE AJA OKL MRQ IGM BOA PEM ENE OTO UPE DST MOF SHP ESR PTR
Sampling Locations


IRON VARIATION
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Fe (mg/l)
Fe D/S
Fe W/S
OKU NCAT JKR EKP EFM UGT UBJ 1 OSM OGB OGU EDHE AJA OKL MRQ IGM BOA PEM ENE OTO UPE DST MOF SHP ESR PTR
Sampling Locations


CADMIUM VARIATION
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
Cd (mg/l)
Cd D/S
Cd W/S
OKU NCAT JKR EKP EFM UGT UBJ 1 OSM OGB OGU EDHE AJA OKL MRQ IGM BOA PEM ENE OTO UPE DST MOF SHP ESR PTR
Sampling Locations


CHROMIUM VARIATION
0.006
0.005
0.004
0.003
0.002
0.001
0.000
Cr (mg/l)
Cr D/S
Cr W/S
OKU NCAT JKR EKP EFM UGT UBJ 1 OSM OGB OGU EDHE AJA OKL MRQ IGM BOA PEM ENE OTO UPE DST MOF SHP ESR PTR
Sampling Locations


COPPER VARIATION
1.000
0.800
0.600
0.400
0.200
0.000
Cu (mg/l)
Cu D/S
Cu W/S
OKU NCAT JKR EKP EFM UGT UBJ 1 OSM OGB OGU EDHE AJA OKL MRQ IGM BOA PEM ENE OTO UPE DST MOF SHP ESR PTR
Sampling Locations


LEAD VARIATION
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
Pb (mg/l)
Pb D/S
Pb W/S
OKU NCAT JKR EKP EFM UGT UBJ 1 OSM OGB OGU EDHE AJA OKL MRQ IGM BOA PEM ENE OTO UPE DST MOF SHP ESR PTR
Sampling Locations

APPENDIX III(C): T-test paired two samples for means

Temp.	*D*	*W*
Mean	27.2684	27.467
Variance	5.7795	6.3326
Observations	50	50
Pearson Correlation	0.96008	
Hypothesized Mean Difference	0	
df	49	
t Stat	-1.99468	
P(T<=t) one-tail	0.02583	
t Critical one-tail	1.67655	
P(T<=t) two-tail	**0.05166**	
t Critical two-tail	2.00958	

K	*D*	*W*
Mean	1.304	1.744
Variance	0.8363	1.4927
Observations	50	50
Pearson Correlation	0.9489	
Hypothesized Mean Difference	0	
df	49	
t Stat	-6.813	
P(T<=t) one-tail	6E-09	
t Critical one-tail	1.6766	
P(T<=t) two-tail	**1E-08**	
t Critical two-tail	2.0096	

pH	*D*	*W*
Mean	5.408	4.492
Variance	0.38361	0.2938
Observations	50	50
Pearson Correlation	0.3783	
Hypothesized Mean Difference	0	
df	49	
t Stat	9.95403	
P(T<=t) one-tail	1.2E-13	
t Critical one-tail	1.67655	
P(T<=t) two-tail	**2.3E-13**	
t Critical two-tail	2.00958	

Ca	*D*	*W*
Mean	18.536	21.422
Variance	260.98	387.25
Observations	50	50
Pearson Correlation	0.9959	
Hypothesized Mean Difference	0	
df	49	
t Stat	-5.269	
P(T<=t) one-tail	2E-06	
t Critical one-tail	1.6766	
P(T<=t) two-tail	**3E-06**	
t Critical two-tail	2.0096	

EC	*D*	*W*
Mean	162.74	186.68
Variance	16222.3	22487
Observations	50	50
Pearson Correlation	0.99504	
Hypothesized Mean Difference	0	
df	49	
t Stat	-6.39834	
P(T<=t) one-tail	2.8E-08	
t Critical one-tail	1.67655	
P(T<=t) two-tail	**5.7E-08**	
t Critical two-tail	2.00958	

Mg	*D*	*W*
Mean	0.472	0.5892
Variance	0.1437	0.2032
Observations	50	50
Pearson Correlation	0.9544	
Hypothesized Mean Difference	0	
df	49	
t Stat	-5.755	
P(T<=t) one-tail	3E-07	
t Critical one-tail	1.6766	
P(T<=t) two-tail	**6E-07**	
t Critical two-tail	2.0096	

Turbidity	*D*	*W*
Mean	5.6916	6.2678
Variance	61.428	56.681
Observations	50	50
Pearson Correlation	0.98128	
Hypothesized Mean Difference	0	
df	49	
t Stat	-2.68376	
P(T<=t) one-tail	0.00495	
t Critical one-tail	1.67655	
P(T<=t) two-tail	**0.0099**	
t Critical two-tail	2.00958	

SO_4	*D*	*W*
Mean	0.9956	1.2032
Variance	1.2929	2.2777
Observations	50	50
Pearson Correlation	0.9776	
Hypothesized Mean Difference	0	
df	49	
t Stat	-3.164	
P(T<=t) one-tail	0.0013	
t Critical one-tail	1.6766	
P(T<=t) two-tail	**0.0027**	
t Critical two-tail	2.0096	

TH	*D*	*W*
Mean	51.0334	55.534
Variance	8453.68	8167.6
Observations	50	50
Pearson Correlation	0.99842	
Hypothesized Mean Difference	0	
df	49	
t Stat	-5.93395	
P(T<=t) one-tail	1.5E-07	
t Critical one-tail	1.67655	
P(T<=t) two-tail	**2.96E-07**	
t Critical two-tail	2.00958	

NO_3	*D*	*W*
Mean	0.8324	1.0628
Variance	0.6541	1.1596
Observations	50	50
Pearson Correlation	0.9617	
Hypothesized Mean Difference	0	
df	49	
t Stat	-4.375	
P(T<=t) one-tail	3E-05	
t Critical one-tail	1.6766	
P(T<=t) two-tail	**6E-05**	
t Critical two-tail	2.0096	

TSS	*D*	*W*
Mean	6.8846	11.171
Variance	81.924	107.94
Observations	50	50
Pearson Correlation	0.34215	
Hypothesized Mean Difference	0	
df	49	
t Stat	-2.70543	
P(T<=t) one-tail	0.00468	
t Critical one-tail	1.67655	
P(T<=t) two-tail	**0.00936**	
t Critical two-tail	2.00958	

Cl	*D*	*W*
Mean	34.892	39.406
Variance	712.14	923.98
Observations	50	50
Pearson Correlation	0.9897	
Hypothesized Mean Difference	0	
df	49	
t Stat	-5.781	
P(T<=t) one-tail	3E-07	
t Critical one-tail	1.6766	
P(T<=t) two-tail	**5E-07**	
t Critical two-tail	2.0096	

TDS	*D*	*W*
Mean	91.16	104.52
Variance	5092.38	7049
Observations	50	50
Pearson Correlation	0.99505	
Hypothesized Mean Difference	0	
df	49	
t Stat	-6.39723	
P(T<=t) one-tail	2.8E-08	
t Critical one-tail	1.67655	
P(T<=t) two-tail	**5.7E-08**	
t Critical two-tail	2.00958	

HCO_3	*D*	*W*
Mean	19.616	21.924
Variance	278.44	362.94
Observations	50	50
Pearson Correlation	0.9876	
Hypothesized Mean Difference	0	
df	49	
t Stat	-4.442	
P(T<=t) one-tail	3E-05	
t Critical one-tail	1.6766	
P(T<=t) two-tail	**5E-05**	
t Critical two-tail	2.0096	

DO	*D*	*W*
Mean	3.22	4.29
Variance	2.74776	5.8446
Observations	50	50
Pearson Correlation	0.94528	
Hypothesized Mean Difference	0	
df	49	
t Stat	-7.50616	
P(T<=t) one-tail	5.5E-10	
t Critical one-tail	1.67655	
P(T<=t) two-tail	**1.1E-09**	
t Critical two-tail	2.00958	

NH_4	*D*	*W*
Mean	0.0099	0.0157
Variance	0.0002	0.0003
Observations	50	50
Pearson Correlation	0.7432	
Hypothesized Mean Difference	0	
df	49	
t Stat	-3.677	
P(T<=t) one-tail	0.0003	
t Critical one-tail	1.6766	
P(T<=t) two-tail	**0.0006**	
t Critical two-tail	2.0096	

BOD	*D*	*W*
Mean	0.074	0.7
Variance	0.04604	0.7343
Observations	50	50
Pearson Correlation	0.1909	
Hypothesized Mean Difference	0	
df	49	
t Stat	-5.25281	
P(T<=t) one-tail	1.6E-06	
t Critical one-tail	1.67655	
P(T<=t) two-tail	**3.2E-06**	
t Critical two-tail	2.00958	

PO_4	*D*	*W*
Mean	0.1868	0.2798
Variance	0.0283	0.0593
Observations	50	50
Pearson Correlation	0.9415	
Hypothesized Mean Difference	0	
df	49	
t Stat	-6.432	
P(T<=t) one-tail	3E-08	
t Critical one-tail	1.6766	
P(T<=t) two-tail	**5E-08**	
t Critical two-tail	2.0096	

COD	*D*	*W*
Mean	4.36	3.924
Variance	3.57347	6.2223
Observations	50	50
Pearson Correlation	0.51636	
Hypothesized Mean Difference	0	
df	49	
t Stat	1.38907	
P(T<=t) one-tail	0.08555	
t Critical one-tail	1.67655	
P(T<=t) two-tail	**0.17109**	
t Critical two-tail	2.00958	

Fe	*D*	*W*
Mean	0.2056	0.2237
Variance	8E-05	0.0002
Observations	50	50
Pearson Correlation	0.7539	
Hypothesized Mean Difference	0	
df	49	
t Stat	-14.79	
P(T<=t) one-tail	5E-20	
t Critical one-tail	1.6766	
P(T<=t) two-tail	**1E-19**	
t Critical two-tail	2.0096	

Total Coliform	*D*	*W*
Mean	11.1286	11.576
Variance	134.046	125.21
Observations	50	50
Pearson Correlation	0.93411	
Hypothesized Mean Difference	0	
df	49	
t Stat	-0.76199	
P(T<=t) one-tail	0.22486	
t Critical one-tail	1.67655	
P(T<=t) two-tail	**0.44972**	
t Critical two-tail	2.00958	

Na	*D*	*W*
Mean	9.302	10.344
Variance	48.661	58.029
Observations	50	50
Pearson Correlation	0.997	
Hypothesized Mean Difference	0	
df	49	
t Stat	-8.644	
P(T<=t) one-tail	1E-11	
t Critical one-tail	1.6766	
P(T<=t) two-tail	**2E-11**	
t Critical two-tail	2.0096	

Cd	*D*	*W*
Mean	0.00254	0.00198
Variance	4.8E-06	3.4078E-06
Observations	50	50
Pearson Correlation	0.31476	
Hypothesized Mean Difference	0	
df	49	
t Stat	1.66149	
P(T<=t) one-tail	0.0515	
t Critical one-tail	1.67655	
P(T<=t) two-tail	**0.103**	
t Critical two-tail	2.00958	

Cr	*D*	*W*
Mean	0.0018	0.000958
Variance	2E-06	4.8698E-07
Observations	50	50
Pearson Correlation	0.4445	
Hypothesized Mean Difference	0	
df	49	
t Stat	4.3233	
P(T<=t) one-tail	4E-05	
t Critical one-tail	1.6766	
P(T<=t) two-tail	**8E-05**	
t Critical two-tail	2.0096	

Cu	*D*	*W*
Mean	0.20092	0.0663
Variance	0.06076	0.00363552
Observations	50	50
Pearson Correlation	0.21206	
Hypothesized Mean Difference	0	
df	49	
t Stat	3.94952	
P(T<=t) one-tail	0.00013	
t Critical one-tail	1.67655	
P(T<=t) two-tail	**0.00025**	
t Critical two-tail	2.00958	

Pb	*D*	*W*
Mean	0.0182	0.1528
Variance	0.0005	0.01129404
Observations	50	50
Pearson Correlation	0.2823	
Hypothesized Mean Difference	0	
df	49	
t Stat	-9.308	
P(T<=t) one-tail	1E-12	
t Critical one-tail	1.6766	
P(T<=t) two-tail	**2E-12**	
t Critical two-tail	2.0096	

APPENDIX IV

WATER QUALITY INDEX

APPENDIX IV(A):WQI Calculation (dry season)

Water Quality Parameters	pH	TDS	Cl	SO_4	HCO_3	NO_3	Ca	Mg	Na	QUALITY RATING (qi) qi = (ci/si)*100									Parameter Index (Si) = qi * Wi									WQI	Type of Water
WHO Standard	7.5	500	250	100	100	50	75	0.2	200																				
Relative Weight (Wi)	0.12	0.148	0.155	0.132	0.164	0.076	0.09	0.08	0.076																				
SAMPLE LOCATION CODE	MEASURED VALUES (Ci)									pH	TDS	Cl	SO_4	HCO_3	NO_3	Ca	Mg	Na	pH	TDS	Cl	SO_4	HCO_3	NO_3	Ca	Mg	Na		
OKU	6.92	112.00	2.67	0.13	2.92	0.32	3.21	0.67	1.74	92.27	22.40	1.07	0.13	2.92	0.64	4.28	335.00	0.87	11.26	3.32	0.17	0.02	0.48	0.05	0.39	25.46	0.07	41.20	Good
EFG	3.89	150.00	25.58	1.12	0.01	0.72	6.75	3.14	1.77	51.87	30.00	10.23	1.12	0.01	1.44	9.00	1570.00	0.89	6.33	4.44	1.59	0.15	0.00	0.11	0.83	119.32	0.07	132.83	Unfit for Drinking
ARB	6.84	10.11	18.78	8.36	3.12	10.34	13.94	14.33	4.36	91.20	2.02	7.51	8.36	3.12	20.68	18.59	7165.00	2.18	11.13	0.30	1.16	1.10	0.51	1.57	1.71	544.54	0.17	562.19	Unfit for Drinking
NCAT	5.74	10.07	8.17	7.89	1.94	10.16	13.16	8.42	4.73	76.53	2.01	3.27	7.89	1.94	20.32	17.55	4210.00	2.37	9.34	0.30	0.51	1.04	0.32	1.54	1.61	319.96	0.18	334.80	Unfit for Drinking
APR	7.05	32.00	26.41	31.57	3.16	2.13	4.99	1.32	0.45	94.00	6.40	10.56	31.57	3.16	4.26	6.65	660.00	0.23	11.47	0.95	1.64	4.17	0.52	0.32	0.61	50.16	0.02	69.85	Poor
JKR	6.00	227.00	12.01	8.44	35.00	2.38	1.18	0.09	0.08	80.00	45.40	4.80	8.44	35.00	4.76	1.57	45.00	0.04	9.76	6.72	0.74	1.11	5.74	0.36	0.14	3.42	0.00	28.01	Good
SHA	5.90	152.00	7.90	0.13	0.18	0.00	3.50	1.92	14.56	78.67	30.40	3.16	0.13	0.18	0.00	4.67	960.00	7.28	9.60	4.50	0.49	0.02	0.03	0.00	0.43	72.96	0.55	88.58	Poor
EKP	4.48	52.00	20.02	0.18	0.10	0.07	2.23	0.97	4.92	59.73	10.40	8.01	0.18	0.10	0.14	2.97	485.00	2.46	7.29	1.54	1.24	0.02	0.02	0.01	0.27	36.86	0.19	47.44	Good
UCE	5.72	84.75	6.06	0.14	3.55	0.48	1.04	1.24	1.99	76.27	16.95	2.42	0.14	3.55	0.97	1.38	620.00	1.00	9.30	2.51	0.38	0.02	0.58	0.07	0.13	47.12	0.08	60.19	Poor
EFM	6.40	306.00	25.03	14.94	32.00	1.98	1.61	0.12	0.09	85.33	61.20	10.01	14.94	32.00	3.96	2.15	60.00	0.05	10.41	9.06	1.55	1.97	5.25	0.30	0.20	4.56	0.00	33.30	Good
OGB	6.20	254.00	14.80	0.01	19.85	0.01	2.04	4.20	1.24	82.67	50.80	5.92	0.01	19.85	0.01	2.73	2100.00	0.62	10.09	7.52	0.92	0.00	3.26	0.00	0.25	159.60	0.05	181.68	Unfit for Drinking
UGT	6.10	17.00	6.50	1.65	7.32	0.75	4.85	3.31	2.79	81.33	3.40	2.60	1.65	7.32	1.50	6.47	1655.00	1.40	9.92	0.50	0.40	0.22	1.20	0.11	0.59	125.78	0.11	138.84	Unfit for Drinking
JED	6.40	79.60	4.50	2.52	3.00	12.46	2.13	0.14	0.05	85.33	15.92	1.80	2.52	3.00	24.92	2.84	70.00	0.03	10.41	2.36	0.28	0.33	0.49	1.89	0.26	5.32	0.00	21.35	Excellent
UBJ1	6.40	76.60	51.97	4.00	42.79	0.00	2.33	1.25	3.52	85.33	15.32	20.79	4.00	42.79	0.00	3.11	625.00	1.76	10.41	2.27	3.22	0.53	7.02	0.00	0.29	47.50	0.13	71.37	Poor
UBJ 2	4.10	63.78	4.50	2.52	18.00	12.49	2.13	0.14	0.05	54.67	12.76	1.80	2.52	18.00	24.98	2.84	70.00	0.03	6.67	1.89	0.28	0.33	2.95	1.90	0.26	5.32	0.00	19.60	Excellent
OSM	7.44	228.54	127.91	15.86	0.31	1.32	0.89	1.70	19.98	99.20	45.71	51.16	15.86	0.31	2.64	1.19	850.00	9.99	12.10	6.76	7.93	2.09	0.05	0.20	0.11	64.60	0.76	94.61	Very Poor
OSA	6.72	36.99	14.81	0.91	0.31	0.30	0.24	0.32	2.56	89.60	7.40	5.92	0.91	0.31	0.60	0.32	160.00	1.28	10.93	1.09	0.92	0.12	0.05	0.05	0.03	12.16	0.10	25.45	Excellent
OGW	7.00	14.90	1.70	0.00	4.56	0.02	1.42	0.12	1.63	93.33	2.98	0.68	0.00	4.56	0.03	1.90	60.00	0.82	11.39	0.44	0.11	0.00	0.75	0.00	0.17	4.56	0.06	17.48	Excellent
WAP	7.20	25.90	2.10	0.01	23.48	0.02	2.64	15.00	1.66	96.00	5.18	0.84	0.01	23.48	0.03	3.52	7500.00	0.83	11.71	0.77	0.13	0.00	3.85	0.00	0.32	570.00	0.06	586.85	Unfit for Drinking
OGU	5.90	171.10	16.10	0.06	0.08	0.01	3.20	2.13	13.76	78.67	34.22	6.44	0.06	0.08	0.01	4.27	1065.00	6.88	9.60	5.06	1.00	0.01	0.01	0.00	0.39	80.94	0.52	97.54	Very Poor
EDJ	7.00	15.00	1.40	0.01	20.02	0.00	2.11	0.56	0.34	93.33	3.00	0.56	0.01	20.02	0.00	2.81	280.00	0.17	11.39	0.44	0.09	0.00	3.28	0.00	0.26	21.28	0.01	36.75	Good
EDHE	7.60	122.00	6.51	2.66	18.00	10.72	2.40	0.43	0.06	101.33	24.40	2.60	2.66	18.00	21.44	3.20	215.00	0.03	12.36	3.61	0.40	0.35	2.95	1.63	0.29	16.34	0.00	37.95	Good
FGC	6.20	22.20	2.60	0.00	8.21	0.01	0.84	3.03	1.19	82.67	4.44	1.04	0.00	8.21	0.01	1.12	1515.00	0.60	10.09	0.66	0.16	0.00	1.35	0.00	0.10	115.14	0.05	127.54	Unfit for Drinking
AJA	6.00	87.00	4.60	0.09	5.00	0.00	1.58	9.31	1.20	80.00	17.40	1.84	0.09	5.00	0.00	2.11	4655.00	0.60	9.76	2.58	0.29	0.01	0.82	0.00	0.19	353.78	0.05	367.47	Unfit for Drinking
WAG	6.50	14.90	1.70	0.00	0.04	0.01	1.83	4.73	2.96	86.67	2.98	0.68	0.00	0.04	0.02	2.44	2365.00	1.48	10.57	0.44	0.11	0.00	0.01	0.00	0.22	179.74	0.11	191.21	Unfit for Drinking
OKL	5.40	146.00	10.90	0.25	24.53	0.02	2.00	1.21	4.67	72.00	29.20	4.36	0.25	24.53	0.04	2.67	605.00	2.34	8.78	4.32	0.68	0.03	4.02	0.00	0.25	45.98	0.18	64.24	Poor
OKR	5.00	112.00	10.80	0.00	0.09	0.00	0.97	0.44	4.23	66.67	22.40	4.32	0.00	0.09	0.00	1.29	220.00	2.12	8.13	3.32	0.67	0.00	0.01	0.00	0.12	16.72	0.16	29.13	Good
MRQ	5.30	79.00	6.40	0.00	19.01	1.00	1.92	1.62	0.37	70.67	15.80	2.56	0.00	19.01	2.00	2.56	810.00	0.19	8.62	2.34	0.40	0.00	3.12	0.15	0.24	61.56	0.01	76.44	Very Poor
ESL	4.47	239.45	15.18	1.75	0.00	30.00	8.00	4.00	0.23	59.60	47.89	6.07	1.75	0.00	60.00	10.67	2000.00	0.12	7.27	7.09	0.94	0.23	0.00	4.56	0.98	152.00	0.01	173.08	Unfit for Drinking
IGM	7.40	294.70	104.00	45.78	7.70	31.24	14.90	9.89	10.95	98.67	58.94	41.60	45.78	7.70	62.48	19.87	4945.00	5.48	12.04	8.72	6.45	6.04	1.26	4.75	1.83	375.82	0.42	417.33	Unfit for Drinking
AGS	6.70	250.00	11.50	0.32	6.54	0.01	2.11	0.15	1.57	89.33	50.00	4.60	0.32	6.54	0.01	2.81	75.00	0.79	10.90	7.40	0.71	0.04	1.07	0.00	0.26	5.70	0.06	26.15	Good
BOA	6.60	598.00	4.21	0.14	3.84	0.47	2.25	1.86	1.68	88.00	119.60	1.68	0.14	3.84	0.94	3.00	930.00	0.84	10.74	17.70	0.26	0.02	0.63	0.07	0.28	70.68	0.06	100.44	Unfit for Drinking
NYA	5.40	192.00	9.20	0.25	0.18	0.00	1.07	2.22	11.25	72.00	38.40	3.68	0.25	0.18	0.00	1.43	1110.00	5.63	8.78	5.68	0.57	0.03	0.03	0.00	0.13	84.36	0.43	100.02	Unfit for Drinking
PEM	6.20	58.00	5.50	0.01	2.90	0.00	1.34	2.31	4.32	82.67	11.60	2.20	0.01	2.90	0.00	1.79	1155.00	2.16	10.09	1.72	0.34	0.00	0.48	0.00	0.16	87.78	0.16	100.73	Unfit for Drinking
ORH	7.20	328.00	1.71	0.12	1.69	0.24	4.23	0.83	0.83	96.00	65.60	0.68	0.12	1.69	0.48	5.64	415.00	0.42	11.71	9.71	0.11	0.02	0.28	0.04	0.52	31.54	0.03	53.95	Poor
ENE	4.38	36.57	2.83	2.98	0.00	0.33	8.00	4.00	1.82	58.40	7.31	1.13	2.98	0.00	0.66	10.67	2000.00	0.91	7.12	1.08	0.18	0.39	0.00	0.05	0.98	152.00	0.07	161.88	Unfit for Drinking
UDR	6.30	154.50	9.60	0.20	0.15	0.00	2.06	0.94	2.45	84.00	30.90	3.84	0.20	0.15	0.00	2.75	470.00	1.23	10.25	4.57	0.60	0.03	0.02	0.00	0.25	35.72	0.09	51.53	Poor
OTO	6.10	15.10	1.40	0.01	2.81	0.00	2.56	5.12	20.70	81.33	3.02	0.56	0.01	2.81	0.00	3.42	2560.00	10.35	9.92	0.45	0.09	0.00	0.46	0.00	0.31	194.56	0.79	206.58	Unfit for Drinking

WQI Calculation dry season Contd:

Water Quality ParameterS	pH	TDS	Cl	SO_4	HCO_3	NO_3	Ca	Mg	Na	QUALITY RATING (qi)									Parameter Index (Si) = qi * Wi									WQI	Type of Water
WHO Standard Values (Si)	7.5	500	250	100	100	50	75	0.2	200	qi = (ci/si)*100																			
Relative Weight (Wi)	0.122	0.148	0.155	0.132	0.164	0.076	0.092	0.076	0.076																				
LOCATION CODE	MEASURED VALUES (Ci)									pH	TDS	Cl	SO_4	HCO_3	NO_3	Ca	Mg	Na	pH	TDS	Cl	SO_4	HCO_3	NO_3	Ca	Mg	Na		
BDE	4.42	87.63	67.50	2.13	0.00	0.07	8.00	4.00	1.50	58.93	17.53	27.00	2.13	0.00	0.14	10.67	2000.00	0.75	7.19	2.59	4.19	0.28	0.00	0.01	0.98	152.00	0.06	167.30	Unfit for Drinking
UPE	4.48	179.00	11.20	3.18	0.00	0.21	8.00	4.00	5.27	59.73	35.80	4.48	3.18	0.00	0.42	10.67	2000.00	2.64	7.29	5.30	0.69	0.42	0.00	0.03	0.98	152.00	0.20	166.91	Unfit for Drinking
MAM	6.80	510.00	2.54	0.13	2.96	0.24	3.00	0.69	1.96	90.67	102.00	1.02	0.13	2.96	0.49	4.00	345.00	0.98	11.06	15.10	0.16	0.02	0.49	0.04	0.37	26.22	0.07	53.52	Poor
DST	7.50	25.06	2.38	0.12	2.52	0.17	5.89	0.65	0.28	100.00	5.01	0.95	0.12	2.52	0.34	7.86	325.00	0.14	12.20	0.74	0.15	0.02	0.41	0.03	0.72	24.70	0.01	38.98	Good
OKE	5.50	282.50	9.40	0.39	0.11	0.00	1.77	3.87	6.19	73.33	56.50	3.76	0.39	0.11	0.00	2.37	1935.00	3.10	8.95	8.36	0.58	0.05	0.02	0.00	0.22	147.06	0.24	165.47	Unfit for Drinking
MOF	7.44	440.00	0.50	3.00	3.61	0.00	4.29	1.22	1.22	99.20	88.00	0.20	3.00	3.61	0.00	5.72	610.00	0.61	12.10	13.02	0.03	0.40	0.59	0.00	0.53	46.36	0.05	73.08	Very Poor
FUP	5.40	58.95	8.50	2.24	0.30	0.04	3.01	2.40	1.80	72.00	11.79	3.40	2.24	0.30	0.08	4.01	1200.00	0.90	8.78	1.74	0.53	0.30	0.05	0.01	0.37	91.20	0.07	103.04	Unfit for Drinking
SHP	5.60	184.00	3.12	0.94	2.16	0.36	0.54	0.85	2.33	74.67	36.80	1.25	0.94	2.16	0.72	0.72	425.00	1.17	9.11	5.45	0.19	0.12	0.35	0.05	0.07	32.30	0.09	47.74	Good
ROP	6.70	192.00	31.53	20.74	20.00	2.40	0.65	0.04	0.04	89.33	38.40	12.61	20.74	20.00	4.80	0.87	20.00	0.02	10.90	5.68	1.95	2.74	3.28	0.36	0.08	1.52	0.00	26.52	Good
ESR	6.61	172.00	12.90	2.11	15.00	0.13	3.06	0.28	0.03	88.13	34.40	5.16	2.11	15.00	0.26	4.08	140.00	0.02	10.75	5.09	0.80	0.28	2.46	0.02	0.38	10.64	0.00	30.42	Good
ROR	5.60	211.00	14.51	22.04	5.00	2.70	0.80	0.06	0.06	74.67	42.20	5.80	22.04	5.00	5.40	1.07	30.00	0.03	9.11	6.25	0.90	2.91	0.82	0.41	0.10	2.28	0.00	22.77	Excellent
PTR	4.12	285.20	14.80	0.01	0.00	0.01	2.04	12.87	14.29	54.93	57.04	5.92	0.01	0.00	0.01	2.73	6435.00	7.15	6.70	8.44	0.92	0.00	0.00	0.00	0.25	489.06	0.54	505.92	Unfit for Drinking

APPENDIX IV(B):WQI calculation for wet season

Water Quality Parameters	pH	TDS	Cl	SO_4	HCO_3	NO_3	Ca	Mg	Na	QUALITY RATING (qi) qi = (ci/si)*100									Parameter Index (Si) = qi * Wi									WQI	Type of Water
WHO Standard	7.5	500	250	100	100	50	75	0.2	200																				
Relative Weight (Wi)	0.122	0.148	0.155	0.132	0.164	0.076	0.092	0.076	0.076																				
SAMPLE LOCATION CODE	MEASURED VALUES (Ci)									pH	TDS	Cl	SO_4	HCO_3	NO_3	Ca	Mg	Na	pH	TDS	Cl	SO_4	HCO_3	NO_3	Ca	Mg	Na		
OKU	7.02	130.00	4.76	0.26	7.72	0.24	1.52	1.09	0.54	93.60	26.00	1.90	0.26	7.72	0.48	2.03	545.00	0.27	11.42	3.85	0.30	0.03	1.27	0.04	0.19	41.42	0.02	58.53	Poor
EFG	4.49	160.22	29.85	0.73	0.41	0.64	5.06	1.38	0.51	59.87	32.04	11.94	0.73	0.41	1.28	6.75	690.00	0.26	7.30	4.74	1.85	0.10	0.07	0.10	0.62	52.44	0.02	67.24	Poor
ARB	7.34	21.33	20.78	5.91	7.92	9.85	6.97	6.83	2.08	97.87	4.27	8.31	5.91	7.92	19.70	9.29	3415.00	1.04	11.94	0.63	1.29	0.78	1.30	1.50	0.85	259.54	0.08	277.91	Unfit for Drinking
NCAT	6.34	28.07	19.92	5.44	2.34	9.67	6.19	6.66	2.45	84.53	5.61	7.97	5.44	2.34	19.34	8.25	3330.00	1.23	10.31	0.83	1.24	0.72	0.38	1.47	0.76	253.08	0.09	268.88	Unfit for Drinking
APR	6.95	42.50	38.16	29.21	3.56	2.05	3.30	0.44	1.83	92.67	8.50	15.26	29.21	3.56	4.10	4.40	220.00	0.92	11.31	1.26	2.37	3.86	0.58	0.31	0.40	16.72	0.07	36.87	Good
JKR	6.06	239.56	10.10	5.99	39.80	2.30	0.51	0.09	2.20	80.80	47.91	4.04	5.99	39.80	4.60	0.68	45.00	1.10	9.86	7.09	0.63	0.79	6.53	0.35	0.06	3.42	0.08	28.81	Good
SHA	6.00	167.45	5.09	0.62	0.58	0.00	1.81	0.56	9.52	80.00	33.49	2.04	0.62	0.58	0.00	2.41	280.00	4.76	9.76	4.96	0.32	0.08	0.10	0.00	0.22	21.28	0.36	37.07	Good
EKP	4.78	70.00	31.77	0.12	0.50	0.05	0.54	0.79	2.64	63.73	14.00	12.71	0.12	0.50	0.10	0.72	395.00	1.32	7.78	2.07	1.97	0.02	0.08	0.01	0.07	30.02	0.10	42.11	Good
UCE	5.92	74.57	8.55	0.12	8.35	0.40	0.65	0.52	1.22	78.93	14.91	3.42	0.12	8.35	0.80	0.87	260.00	0.61	9.63	2.21	0.53	0.02	1.37	0.06	0.08	19.76	0.05	33.70	Good
EFM	6.70	306.56	23.30	12.49	36.80	1.90	0.08	1.88	2.19	89.33	61.31	9.32	12.49	36.80	3.80	0.11	940.00	1.10	10.90	9.07	1.44	1.65	6.04	0.29	0.01	71.44	0.08	100.92	Unfit for Drinking
OGD	5.70	236.00	16.08	0.01	24.65	0.01	0.35	2.44	1.04	76.00	47.20	6.43	0.01	24.65	0.01	0.47	1220.00	0.52	9.27	6.99	1.00	0.00	4.04	0.00	0.04	92.72	0.04	114.10	Unfit for Drinking
UGT	6.20	29.60	8.05	1.26	7.72	0.67	3.16	1.55	0.51	82.67	5.92	3.22	1.26	7.72	1.34	4.21	775.00	0.26	10.09	0.88	0.50	0.17	1.27	0.10	0.39	58.90	0.02	72.30	Poor
JED	7.00	81.10	6.09	0.07	3.40	11.97	0.44	1.32	2.23	93.33	16.22	2.44	0.07	3.40	23.94	0.59	660.00	1.12	11.39	2.40	0.38	0.01	0.56	1.82	0.05	50.16	0.08	66.85	Poor
UBJ 1	6.90	92.09	63.72	3.61	47.59	0.01	0.64	0.51	1.24	92.00	18.42	25.49	3.61	47.59	0.02	0.85	255.00	0.62	11.22	2.73	3.95	0.48	7.80	0.00	0.08	19.38	0.05	45.69	Good
UBJ 2	4.70	73.87	6.50	0.07	22.80	12.00	4.84	1.62	2.23	62.67	14.77	2.60	0.07	22.80	24.00	6.45	810.00	1.12	7.65	2.19	0.40	0.01	3.74	1.82	0.59	61.56	0.08	78.05	Very Poor
OSM	4.20	241.06	125.19	13.41	0.71	1.24	0.80	0.06	14.94	56.00	48.21	50.08	13.41	0.71	2.48	1.07	30.00	7.47	6.83	7.14	7.76	1.77	0.12	0.19	0.10	2.28	0.57	26.75	Good
OSA	7.12	48.54	16.17	0.52	0.71	0.03	6.73	0.44	0.28	94.93	9.71	6.47	0.52	0.71	0.06	8.97	220.00	0.14	11.58	1.44	1.00	0.07	0.12	0.00	0.83	16.72	0.01	31.77	Good
OGB	7.10	27.54	0.32	0.00	9.36	0.01	0.27	0.64	0.65	94.67	5.51	0.13	0.00	9.36	0.02	0.36	320.00	0.33	11.55	0.82	0.02	0.00	1.54	0.00	0.03	24.32	0.02	38.30	Good
WAP	7.20	25.00	0.03	0.01	28.28	0.02	0.95	7.50	0.62	96.00	5.00	0.01	0.01	28.28	0.03	1.27	3750.00	0.31	11.71	0.74	0.00	0.00	4.64	0.00	0.12	285.00	0.02	302.24	Unfit for Drinking
OGU	6.30	153.50	18.01	0.33	4.88	0.02	1.51	0.37	8.72	84.00	30.70	7.20	0.33	4.88	0.04	2.01	185.00	4.36	10.25	4.54	1.12	0.04	0.80	0.00	0.19	14.06	0.33	31.33	Good
EDJ	7.30	33.00	3.04	0.01	24.82	0.01	0.42	0.20	1.94	97.33	6.60	1.22	0.01	24.82	0.02	0.56	100.00	0.97	11.87	0.98	0.19	0.00	4.07	0.00	0.05	7.60	0.07	24.84	Excellent
EDHE	7.80	136.60	8.15	2.27	22.80	10.27	0.71	0.27	2.22	104.00	27.32	3.26	2.27	22.80	20.54	0.95	135.00	1.11	12.69	4.04	0.51	0.30	3.74	1.56	0.09	10.26	0.08	33.27	Good
FGC	5.90	37.00	4.06	0.39	13.01	0.01	0.85	1.36	1.09	78.67	7.40	1.62	0.39	13.01	0.01	1.13	680.00	0.55	9.60	1.10	0.25	0.05	2.13	0.00	0.10	51.68	0.04	64.96	Poor
AJA	5.60	100.50	6.40	0.09	5.40	0.01	5.39	7.55	1.08	74.67	20.10	2.56	0.09	5.40	0.02	7.19	3775.00	0.54	9.11	2.97	0.40	0.01	0.89	0.00	0.66	286.90	0.04	300.98	Unfit for Drinking
WAG	7.10	29.80	3.07	0.00	5.44	0.04	0.14	2.97	0.68	94.67	5.96	1.23	0.00	5.44	0.08	0.19	1485.00	0.34	11.55	0.88	0.19	0.00	0.89	0.01	0.02	112.86	0.03	126.42	Unfit for Drinking
OKL	5.90	128.00	14.09	0.14	29.33	0.02	0.31	0.55	2.39	78.67	25.60	5.64	0.14	29.33	0.04	0.41	275.00	1.20	9.60	3.79	0.87	0.02	4.81	0.00	0.04	20.90	0.09	40.12	Good
OKR	5.40	129.50	12.08	0.00	4.89	0.00	0.72	1.32	1.95	72.00	25.90	4.83	0.00	4.89	0.00	0.96	660.00	0.98	8.78	3.83	0.75	0.00	0.80	0.00	0.09	50.16	0.07	64.49	Poor
MRQ	5.40	88.00	8.04	0.00	23.81	0.51	1.23	0.56	1.91	72.00	17.60	3.22	0.00	23.81	1.02	1.64	280.00	0.96	8.78	2.60	0.50	0.00	3.90	0.08	0.15	21.28	0.07	37.37	Good
ESL	4.77	257.35	17.18	1.61	0.01	29.51	1.03	2.24	2.05	63.60	51.47	6.87	1.61	0.01	59.02	1.37	1120.00	1.03	7.76	7.62	1.07	0.21	0.00	4.49	0.13	85.12	0.08	106.47	Unfit for Drinking
IGM	6.90	304.70	106.11	43.33	12.50	29.28	13.21	8.13	5.91	92.00	60.94	42.44	43.33	12.50	58.56	17.61	4065.00	2.96	11.22	9.02	6.58	5.72	2.05	4.45	1.62	308.94	0.22	349.83	Unfit for Drinking
AGS	6.30	232.41	13.05	0.07	11.34	0.01	0.42	0.14	0.71	84.00	46.48	5.22	0.07	11.34	0.01	0.56	70.00	0.36	10.25	6.88	0.81	0.01	1.86	0.00	0.05	5.32	0.03	25.20	Good
BOA	6.60	581.60	6.12	0.13	8.64	0.23	0.35	0.10	1.53	88.00	116.32	2.45	0.13	8.64	0.46	0.47	50.00	0.77	10.74	17.22	0.38	0.02	1.42	0.03	0.04	3.80	0.06	33.70	Good
IYA	6.00	185.50	11.02	0.14	0.58	0.00	0.62	0.46	6.21	80.00	37.10	4.41	0.14	0.58	0.00	0.83	230.00	3.11	9.76	5.49	0.68	0.02	0.10	0.00	0.08	17.48	0.24	33.84	Good
PEM	6.80	76.00	7.05	0.01	3.30	0.00	0.35	0.55	2.04	90.67	15.20	2.82	0.01	3.30	0.00	0.47	275.00	1.02	11.06	2.25	0.44	0.00	0.54	0.00	0.04	20.90	0.08	35.31	Good
ORH	7.70	335.40	2.17	0.27	2.09	0.16	2.54	0.39	1.48	102.67	67.08	0.87	0.27	2.09	0.32	3.39	195.00	0.74	12.53	9.93	0.13	0.04	0.34	0.02	0.31	14.82	0.06	38.18	Good
ENE	4.88	37.07	4.38	2.59	0.01	0.23	1.03	2.24	0.46	65.07	7.41	1.75	2.59	0.01	0.46	1.37	1120.00	0.23	7.94	1.10	0.27	0.34	0.00	0.03	0.13	85.12	0.02	94.95	Very Poor
UDR	6.90	137.50	11.90	0.19	0.55	0.02	0.37	0.82	0.17	92.00	27.50	4.76	0.19	0.55	0.04	0.49	410.00	0.09	11.22	4.07	0.74	0.03	0.09	0.00	0.05	31.16	0.01	47.36	Good
OTO	6.50	30.20	3.04	0.01	7.61	0.00	0.87	3.36	15.66	86.67	6.04	1.22	0.01	7.61	0.00	1.16	1680.00	7.83	10.57	0.89	0.19	0.00	1.25	0.00	0.11	127.68	0.60	141.29	Unfit for Drinking

WQI Calculation wet seasonContd:

Water Quality	pH	TDS	Cl	SO_4	HCO_3	NO_3	Ca	Mg	Na	QUALITY RATING (qi)									Parameter Index (Si) = qi * Wi									WQI	Type of Water
WHO Standard Values (Si)	7.5	500	250	100	100	50	75	0.2	200	qi = (ci*si)*100																			
Relative Weight (Wi)	0.122	0.148	0.155	0.132	0.164	0.076	0.092	0.076	0.076																				
SAMPLE LOCATION CODE	MEASURED VALUES (Ci)									pH	TDS	Cl	SO_4	HCO_3	NO_3	Ca	Mg	Na	pH	TDS	Cl	SO_4	HCO_3	NO_3	Ca	Mg	Na		
BDE	5.02	93.23	69.05	1.74	0.01	0.03	1.03	3.50	0.78	66.93	18.65	27.62	1.74	0.01	0.06	1.37	1750.00	0.39	8.17	2.76	4.28	0.23	0.00	0.00	0.13	133.00	0.03	148.60	Unfit for Drinking
UPE	4.78	183.30	13.02	2.79	0.01	0.12	0.03	2.42	2.99	63.73	36.66	5.21	2.79	0.01	0.24	0.04	1210.00	1.50	7.78	5.43	0.81	0.37	0.00	0.02	0.00	91.96	0.11	106.47	Unfit for Drinking
MAM	6.30	513.50	4.44	0.13	3.36	0.16	1.31	0.58	1.25	84.00	102.70	1.78	0.13	3.36	0.32	1.75	290.00	0.63	10.25	15.20	0.28	0.02	0.55	0.02	0.16	22.04	0.05	48.56	Poor
DST	8.10	38.79	4.92	0.12	7.32	0.09	1.08	0.56	2.00	108.00	7.76	1.97	0.12	7.32	0.18	1.44	280.00	1.00	13.18	1.15	0.31	0.02	1.20	0.01	0.13	21.28	0.08	37.35	Good
OKE	6.00	294.80	11.05	0.00	0.51	0.04	0.08	3.78	3.91	80.00	58.96	4.42	0.00	0.51	0.08	0.11	1890.00	1.96	9.76	8.73	0.69	0.00	0.08	0.01	0.01	143.64	0.15	163.06	Unfit for Drinking
MOF	7.04	450.00	2.25	2.61	8.41	0.08	2.68	0.22	1.06	93.87	90.00	0.90	2.61	8.41	0.16	3.57	110.00	0.53	11.45	13.32	0.14	0.34	1.38	0.01	0.33	8.36	0.04	35.38	Good
FUP	6.00	75.95	10.05	1.85	5.10	0.04	1.32	2.04	1.41	80.00	15.19	4.02	1.85	5.10	0.08	1.76	1020.00	0.71	9.76	2.25	0.62	0.24	0.84	0.01	0.16	77.52	0.05	91.45	Very Poor
SHP	5.30	170.00	5.21	0.55	6.96	0.13	1.15	0.58	0.05	70.67	34.00	2.08	0.55	6.96	0.26	1.53	290.00	0.03	8.62	5.03	0.32	0.07	1.14	0.02	0.14	22.04	0.00	37.39	Good
ROP	7.30	202.02	33.36	18.29	24.80	1.91	0.04	0.04	2.24	97.33	40.40	13.34	18.29	24.80	3.82	0.05	20.00	1.12	11.87	5.98	2.07	2.41	4.07	0.29	0.00	1.52	0.09	28.30	Good
ESR	6.91	155.60	14.09	1.72	19.80	0.05	3.06	0.48	1.25	92.13	31.12	5.64	1.72	19.80	0.10	4.08	240.00	0.63	11.24	4.61	0.87	0.23	3.25	0.01	0.38	18.24	0.05	38.86	Good
ROR	5.60	214.47	16.15	19.59	5.40	2.62	0.89	0.06	1.22	74.67	42.89	6.46	19.59	5.40	5.24	1.19	30.00	0.61	9.11	6.35	1.00	2.59	0.89	0.40	0.11	2.28	0.05	22.76	Excellent
PTR	4.72	299.30	16.20	0.01	4.81	0.01	0.35	5.37	9.25	62.93	59.86	6.48	0.01	4.81	0.01	0.47	2685.00	4.63	7.68	8.86	1.00	0.00	0.79	0.00	0.04	204.06	0.35	222.79	Unfit for Drinking

APPENDIX V
Summary Output of Regression Statistic Model of Water Quality Parameters for Dry and Wet Season

APPENDIX V(A): DRY SEASON

Regression Statistics of Sodium (Na^{+}) for Dry Season

Multiple R	0.8887
R Square	0.7898
Adjusted R Square	0.7809
Standard Error	3.2655
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.0000	1883.1922	941.5961	88.2985	0.0000
Residual	47.0000	501.1976	10.6638		
Total	49.0000	2384.3898			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**1.3990**	0.7542	1.8551	0.0699	-0.1182	2.9162	-0.1182	2.9162
EC	**-0.2430**	0.4494	-0.5407	0.5913	-1.1470	0.6611	-1.1470	0.6611
TDS	**0.5204**	0.8021	0.6489	0.5196	-1.0931	2.1340	-1.0931	2.1340

Regression Statistics of Calcium (Ca^{2+}) for Dry Season

Multiple R	0.9824
R Square	0.9652
Adjusted R Square	0.9637
Standard Error	3.0788
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.0000	12342.4650	6171.2325	651.0467	0.0000
Residual	47.0000	445.5102	9.4789		
Total	49.0000	12787.9752			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**-1.7477**	0.7110	-2.4580	0.0177	-3.1781	-0.3173	-3.1781	-0.3173
EC	**0.4032**	0.4237	0.9518	0.3461	-0.4491	1.2556	-0.4491	1.2556
TDS	**-0.4974**	0.7562	-0.6577	0.5139	-2.0187	1.0239	-2.0187	1.0239

Regression Statistics of Potassium (K^+) for Dry Season

Multiple R	0.7318
R Square	0.5356
Adjusted R Square	0.5158
Standard Error	0.6363
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.0000	21.9475	10.9737	27.1003	0.0000
Residual	47.0000	19.0317	0.4049		
Total	49.0000	40.9792			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**0.4638**	0.1470	3.1558	0.0028	0.1681	0.7594	0.1681	0.7594
EC	**-0.1012**	0.0876	-1.1558	0.2536	-0.2774	0.0750	-0.2774	0.0750
TDS	**0.1899**	0.1563	1.2150	0.2304	-0.1245	0.5043	-0.1245	0.5043

Regression Statistics of Magnesium (Mg^{2+}) for Dry Season

Multiple R	0.8574
R Square	0.7351
Adjusted R Square	0.7238
Standard Error	0.1992
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.0000	5.1758	2.5879	65.2164	0.0000
Residual	47.0000	1.8650	0.0397		
Total	49.0000	7.0408			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**0.0568**	0.0460	1.2339	0.2234	-0.0358	0.1493	-0.0358	0.1493
EC	**0.0016**	0.0274	0.0579	0.9541	-0.0536	0.0567	-0.0536	0.0567
TDS	**0.0017**	0.0489	0.0352	0.9721	-0.0967	0.1002	-0.0967	0.1002

Regression Statistics of Sulphate (SO_4) for Dry Season

Multiple R	0.9362
R Square	0.8765
Adjusted R Square	0.8712
Standard Error	0.4081
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.0000	55.5258	27.7629	166.7103	0.0000
Residual	47.0000	7.8271	0.1665		
Total	49.0000	63.3528			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**-0.3626**	0.0942	-3.8479	0.0004	-0.5522	-0.1730	-0.5522	-0.1730
EC	**-0.0276**	0.0562	-0.4911	0.6256	-0.1406	0.0854	-0.1406	0.0854
TDS	**0.0641**	0.1002	0.6399	0.5254	-0.1375	0.2658	-0.1375	0.2658

Regression Statistics of Nitrate (NO_3) for Dry Season

Multiple R	0.9040
R Square	0.8172
Adjusted R Square	0.8094
Standard Error	0.3531
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.0000	26.1895	13.0948	105.0335	0.0000
Residual	47.0000	5.8596	0.1247		
Total	49.0000	32.0491			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**-0.0938**	0.0815	-1.1497	0.2561	-0.2578	0.0703	-0.2578	0.0703
EC	**-0.0717**	0.0486	-1.4755	0.1468	-0.1694	0.0261	-0.1694	0.0261
TDS	**0.1381**	0.0867	1.5929	0.1179	-0.0363	0.3126	-0.0363	0.3126

Regression Statistics of Chloride (Cl^-) for Dry Season

Multiple R	0.9906
R Square	0.9814
Adjusted R Square	0.9806
Standard Error	3.7182
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.0000	34244.8480	17122.4240	1238.4854	0.0000
Residual	47.0000	649.7888	13.8253		
Total	49.0000	34894.6368			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**1.1129**	0.8587	1.2960	0.2013	-0.6146	2.8403	-0.6146	2.8403
EC	**0.2378**	0.5117	0.4647	0.6443	-0.7916	1.2672	-0.7916	1.2672
TDS	**-0.0540**	0.9133	-0.0591	0.9531	-1.8912	1.7833	-1.8912	1.7833

Regression Statistics of Phosphate (PO_4) for Dry Season

Multiple R	0.8083
R Square	0.6533
Adjusted R Square	0.6386
Standard Error	0.1011
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.0000	0.9058	0.4529	44.2883	0.0000
Residual	47.0000	0.4807	0.0102		
Total	49.0000	1.3865			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**0.0135**	0.0234	0.5787	0.5656	-0.0335	0.0605	-0.0335	0.0605
EC	**-0.0058**	0.0139	-0.4145	0.6804	-0.0338	0.0222	-0.0338	0.0222
TDS	**0.0122**	0.0248	0.4911	0.6256	-0.0378	0.0622	-0.0378	0.0622

Regression Statistics of HCO_3 for Dry Season

Multiple R	0.9622
R Square	0.9259
Adjusted R Square	0.9227
Standard Error	4.6392
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.0000	12631.9748	6315.9874	293.4670	0.0000
Residual	47.0000	1011.5324	21.5220		
Total	49.0000	13643.5072			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**-0.8940**	1.0714	-0.8344	0.4083	-3.0493	1.2614	-3.0493	1.2614
EC	**-0.0183**	0.6384	-0.0286	0.9773	-1.3026	1.2661	-1.3026	1.2661
TDS	**0.2576**	1.1395	0.2261	0.8221	-2.0347	2.5499	-2.0347	2.5499

Regression Statistics of NH_4 for Dry Season

Multiple R	0.3568
R Square	0.1273
Adjusted R Square	0.0902
Standard Error	0.0147
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.0000	0.0015	0.0007	3.4281	0.0408
Residual	47.0000	0.0101	0.0002		
Total	49.0000	0.0116			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**0.0029**	0.0034	0.8629	0.3926	-0.0039	0.0097	-0.0039	0.0097
EC	**0.0008**	0.0020	0.3794	0.7061	-0.0033	0.0048	-0.0033	0.0048
TDS	**-0.0013**	0.0036	-0.3583	0.7217	-0.0085	0.0060	-0.0085	0.0060

Regression Statistics of Fe for Dry Season

Multiple R	0.9542
R Square	0.9105
Adjusted R Square	0.9067
Standard Error	0.0028
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.0000	0.0037	0.0018	239.0547	0.0000
Residual	47.0000	0.0004	0.0000		
Total	49.0000	0.0040			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**0.1945**	0.0006	304.0051	0.0000	0.1933	0.1958	0.1933	0.1958
EC	**-0.0001**	0.0004	-0.1755	0.8615	-0.0008	0.0007	-0.0008	0.0007
TDS	**0.0002**	0.0007	0.3537	0.7252	-0.0011	0.0016	-0.0011	0.0016

Regression Statistics of Cd for Dry Season

Multiple R	0.9138
R Square	0.8350
Adjusted R Square	0.8316
Standard Error	0.0009
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1.0000	0.0002	0.0002	242.9367	0.0000
Residual	48.0000	0.0000	0.0000		
Total	49.0000	0.0002			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**0.0201**	0.0011	17.7317	0.0000	0.0178	0.0223	0.0178	0.0223
pH	**-0.0032**	0.0002	-15.5864	0.0000	-0.0037	-0.0028	-0.0037	-0.0028

Regression Statistics of Cr for Dry Season

Multiple R	0.9280
R Square	0.8612
Adjusted R Square	0.8584
Standard Error	0.0006
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1.0000	0.0001	0.0001	297.9261	0.0000
Residual	48.0000	0.0000	0.0000		
Total	49.0000	0.0001			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**0.0146**	0.0007	19.5982	0.0000	0.0131	0.0161	0.0131	0.0161
pH	**-0.0024**	0.0001	-17.2605	0.0000	-0.0026	-0.0021	-0.0026	-0.0021

Regression Statistics of Cu for Dry Season

Multiple R	0.8525
R Square	0.7268
Adjusted R Square	0.7211
Standard Error	0.1302
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1.0000	2.1636	2.1636	127.6661	0.0000
Residual	48.0000	0.8135	0.0169		
Total	49.0000	2.9771			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**2.0357**	0.1634	12.4564	0.0000	1.7071	2.3643	1.7071	2.3643
pH	**-0.3393**	0.0300	-11.2989	0.0000	-0.3996	-0.2789	-0.3996	-0.2789

Regression Statistics of Pb for Dry Season

Multiple R	0.8477
R Square	0.7186
Adjusted R Square	0.7127
Standard Error	0.0121
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1.0000	0.0181	0.0181	122.5759	0.0000
Residual	48.0000	0.0071	0.0001		
Total	49.0000	0.0252			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**0.1859**	0.0152	12.1918	0.0000	0.1553	0.2166	0.1553	0.2166
pH	**-0.0310**	0.0028	-11.0714	0.0000	-0.0367	-0.0254	-0.0367	-0.0254

APPENDIX V(B): WET SEASON

Regression Statistics of Sodium (Na^+) for Wet Season

Multiple R	0.8856
R Square	0.7842
Adjusted R Square	0.7751
Standard Error	3.6129
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.0000	2229.9486	1114.9743	85.4185	0.0000
Residual	47.0000	613.4946	13.0531		
Total	49.0000	2843.4432			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**1.9928**	0.8209	2.4276	0.0191	0.3414	3.6443	0.3414	3.6443
EC	**-1.2177**	0.8703	-1.3991	0.1683	-2.9686	0.5332	-2.9686	0.5332
TDS	**2.2548**	1.5545	1.4505	0.1536	-0.8725	5.3821	-0.8725	5.3821

Regression Statistics of Calcium (Ca^{2+}) for Wet Season

Multiple R	0.9817
R Square	0.9638
Adjusted R Square	0.9623
Standard Error	3.8220
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.0000	18288.6529	9144.3264	625.9835	0.0000
Residual	47.0000	686.5729	14.6079		
Total	49.0000	18975.2258			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**-2.6207**	0.8684	-3.0178	0.0041	-4.3678	-0.8737	-4.3678	-0.8737
EC	**0.7937**	0.9207	0.8620	0.3931	-1.0586	2.6459	-1.0586	2.6459
TDS	**-1.1875**	1.6445	-0.7221	0.4738	-4.4958	2.1208	-4.4958	2.1208

Regression Statistics of Potassium (K+) for Wet Season

Multiple R	0.7471
R Square	0.5582
Adjusted R Square	0.5394
Standard Error	0.8292
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.0000	40.8286	20.4143	29.6917	0.0000
Residual	47.0000	32.3146	0.6875		
Total	49.0000	73.1432			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**0.6094**	0.1884	3.2345	0.0022	0.2304	0.9884	0.2304	0.9884
EC	**0.0836**	0.1997	0.4187	0.6773	-0.3182	0.4855	-0.3182	0.4855
TDS	**-0.1385**	0.3568	-0.3883	0.6995	-0.8563	0.5792	-0.8563	0.5792

Regression Statistics of Magnesium (Mg^{2+}) for Wet Season

Multiple R	0.9106
R Square	0.8292
Adjusted R Square	0.8219
Standard Error	0.1902
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.0000	8.2561	4.1281	114.0729	0.0000
Residual	47.0000	1.7008	0.0362		
Total	49.0000	9.9570			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**0.0796**	0.0432	1.8405	0.0720	-0.0074	0.1665	-0.0074	0.1665
EC	**-0.0514**	0.0458	-1.1218	0.2677	-0.1436	0.0408	-0.1436	0.0408
TDS	**0.0967**	0.0819	1.1813	0.2434	-0.0680	0.2614	-0.0680	0.2614

Regression Statistics of Sulphate (SO_4) for Wet Season

Multiple R	0.9473
R Square	0.8973
Adjusted R Square	0.8929
Standard Error	0.4939
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.0000	100.1460	50.0730	205.2985	0.0000
Residual	47.0000	11.4635	0.2439		
Total	49.0000	111.6095			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**-0.5743**	0.1122	-5.1179	0.0000	-0.8001	-0.3486	-0.8001	-0.3486
EC	**-0.1237**	0.1190	-1.0398	0.3038	-0.3630	0.1156	-0.3630	0.1156
TDS	**0.2379**	0.2125	1.1198	0.2685	-0.1895	0.6654	-0.1895	0.6654

Regression Statistics of Nitrate (NO_3) for Wet Season

Multiple R	0.9315
R Square	0.8676
Adjusted R Square	0.8620
Standard Error	0.4001
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.0000	49.2997	24.6498	154.0174	0.0000
Residual	47.0000	7.5221	0.1600		
Total	49.0000	56.8218			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**-0.1840**	0.0909	-2.0239	0.0487	-0.3668	-0.0011	-0.3668	-0.0011
EC	**0.0917**	0.0964	0.9516	0.3462	-0.1022	0.2856	-0.1022	0.2856
TDS	**-0.1519**	0.1721	-0.8823	0.3821	-0.4982	0.1944	-0.4982	0.1944

Regression Statistics of Chloride (Cl^-) for Wet Season

Multiple R	0.9923
R Square	0.9847
Adjusted R Square	0.9840
Standard Error	3.8422
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.0000	44581.3264	22290.6632	1509.9423	0.0000
Residual	47.0000	693.8418	14.7626		
Total	49.0000	45275.1682			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**1.8571**	0.8730	2.1272	0.0387	0.1008	3.6134	0.1008	3.6134
EC	**0.3682**	0.9256	0.3978	0.6926	-1.4938	2.2302	-1.4938	2.2302
TDS	**-0.2984**	1.6532	-0.1805	0.8575	-3.6242	3.0274	-3.6242	3.0274

Regression Statistics of Phosphate (PO_4) for Wet Season

Multiple R	0.8854
R Square	0.7839
Adjusted R Square	0.7747
Standard Error	0.1156
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.0000	2.2772	1.1386	85.2607	0.0000
Residual	47.0000	0.6277	0.0134		
Total	49.0000	2.9049			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**0.0140**	0.0263	0.5318	0.5974	-0.0389	0.0668	-0.0389	0.0668
EC	**0.0494**	0.0278	1.7736	0.0826	-0.0066	0.1054	-0.0066	0.1054
TDS	**-0.0856**	0.0497	-1.7224	0.0916	-0.1857	0.0144	-0.1857	0.0144

Regression Statistics of HCO_3 for Wet Season

Multiple R	0.9727
R Square	0.9462
Adjusted R Square	0.9439
Standard Error	4.5138
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.0000	16826.2526	8413.1263	412.9342	0.0000
Residual	47.0000	957.5786	20.3740		
Total	49.0000	17783.8312			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**-1.1427**	1.0256	-1.1142	0.2709	-3.2060	0.9205	-3.2060	0.9205
EC	**0.4042**	1.0874	0.3718	0.7117	-1.7832	2.5917	-1.7832	2.5917
TDS	**-0.5013**	1.9421	-0.2581	0.7974	-4.4083	3.4057	-4.4083	3.4057

Regression Statistics of NH_4 for Wet Season

Multiple R	0.6223
R Square	0.3873
Adjusted R Square	0.3612
Standard Error	0.0125
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.0000	0.0046	0.0023	14.8541	0.0000
Residual	47.0000	0.0073	0.0002		
Total	49.0000	0.0120			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**0.0048**	0.0028	1.6762	0.1003	-0.0010	0.0105	-0.0010	0.0105
EC	**-0.0064**	0.0030	-2.1180	0.0395	-0.0124	-0.0003	-0.0124	-0.0003
TDS	**0.0115**	0.0054	2.1379	0.0378	0.0007	0.0223	0.0007	0.0223

Regression Statistics of Fe for Wet Season

Multiple R	0.8016
R Square	0.6425
Adjusted R Square	0.6273
Standard Error	0.0080
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.0000	0.0054	0.0027	42.2405	0.0000
Residual	47.0000	0.0030	0.0001		
Total	49.0000	0.0084			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**0.2117**	0.0019	114.3950	0.0000	0.2080	0.2154	0.2080	0.2154
EC	**-0.0043**	0.0011	-3.8570	0.0003	-0.0065	-0.0020	-0.0065	-0.0020
TDS	**0.0077**	0.0020	3.9248	0.0003	0.0038	0.0117	0.0038	0.0117

Regression Statistics of Cd for Wet Season

Multiple R	0.9138
R Square	0.8350
Adjusted R Square	0.8316
Standard Error	0.0009
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1.0000	0.0002	0.0002	242.9367	0.0000
Residual	48.0000	0.0000	0.0000		
Total	49.0000	0.0002			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**0.0201**	0.0011	17.7317	0.0000	0.0178	0.0223	0.0178	0.0223
pH	**-0.0032**	0.0002	-15.5864	0.0000	-0.0037	-0.0028	-0.0037	-0.0028

Regression Statistics of Cr for Wet Season

Multiple R	0.9280
R Square	0.8612
Adjusted R Square	0.8584
Standard Error	0.0006
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1.0000	0.0001	0.0001	297.9261	0.0000
Residual	48.0000	0.0000	0.0000		
Total	49.0000	0.0001			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**0.0146**	0.0007	19.5982	0.0000	0.0131	0.0161	0.0131	0.0161
pH	**-0.0024**	0.0001	-17.2605	0.0000	-0.0026	-0.0021	-0.0026	-0.0021

Regression Statistics of Cu for Wet Season

Multiple R	0.8525
R Square	0.7268
Adjusted R Square	0.7211
Standard Error	0.1302
Observations	50.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1.0000	2.1636	2.1636	127.6661	0.0000
Residual	48.0000	0.8135	0.0169		
Total	49.0000	2.9771			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**2.0357**	0.1634	12.4564	0.0000	1.7071	2.3643	1.7071	2.3643
pH	**-0.3393**	0.0300	-11.2989	0.0000	-0.3996	-0.2789	-0.3996	-0.2789

Regression Statistics of Pb for Wet Season

Multiple R	0.8477
R Square	0.7186
Adjusted R Square	0.7127
Standard Error	0.0121
Observations	50.0000

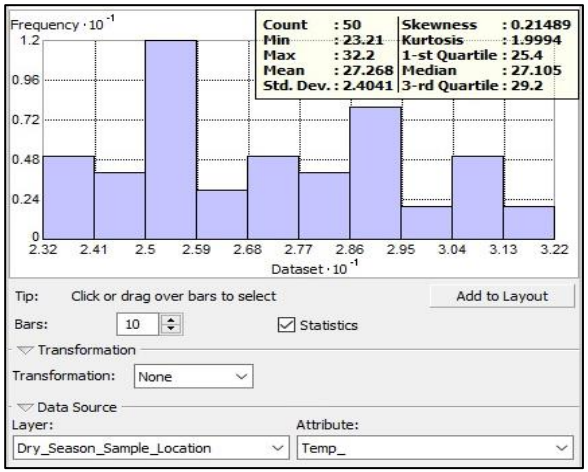
ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1.0000	0.0181	0.0181	122.5759	0.0000
Residual	48.0000	0.0071	0.0001		
Total	49.0000	0.0252			

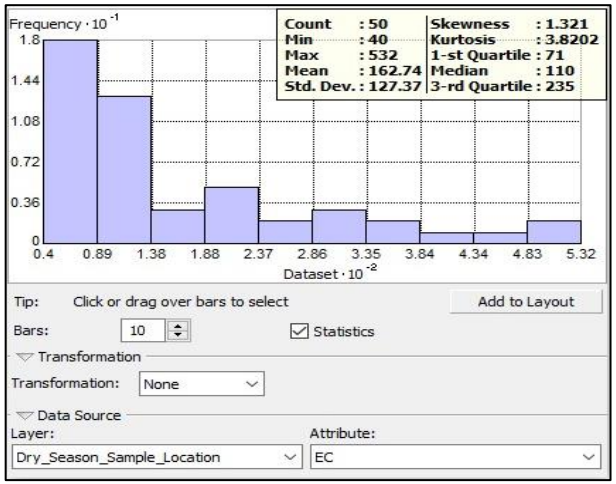
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	**0.1859**	0.0152	12.1918	0.0000	0.1553	0.2166	0.1553	0.2166
pH	**-0.0310**	0.0028	-11.0714	0.0000	-0.0367	-0.0254	-0.0367	-0.0254

APPENDIX VI
HISTOGRAM OF WATER QUALITY PARAMETERS AND THEIR TRANSFORMATION FOR BOTH DRY AND WET SEASONS

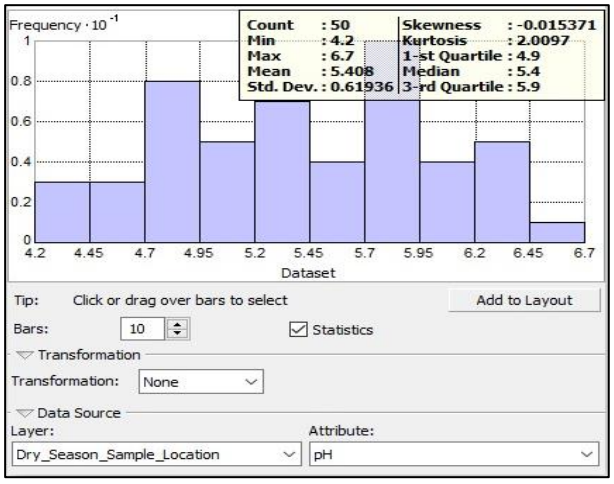
APPENDIX VI(A): Dry Season



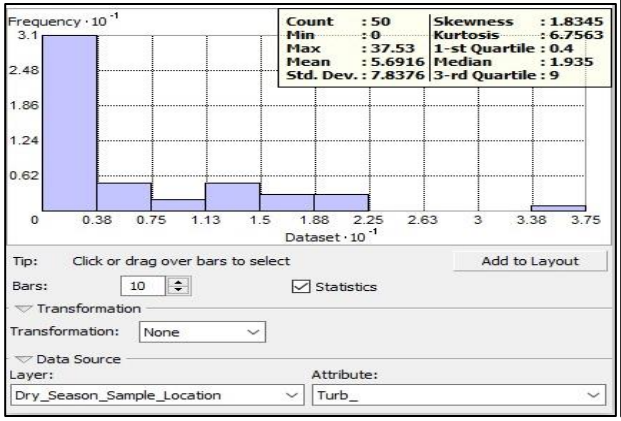
(a) Temperature (No transformation)



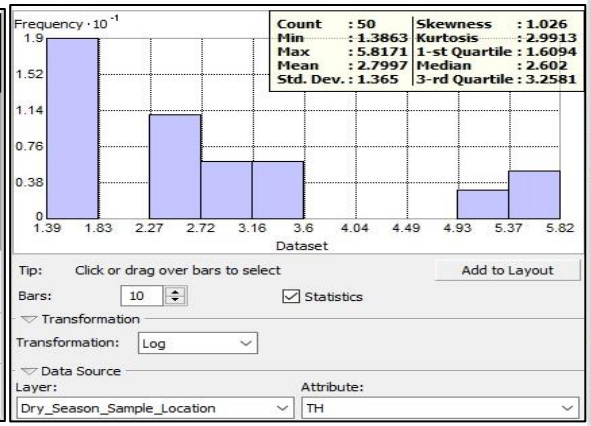
(b) pH level (No transformation)



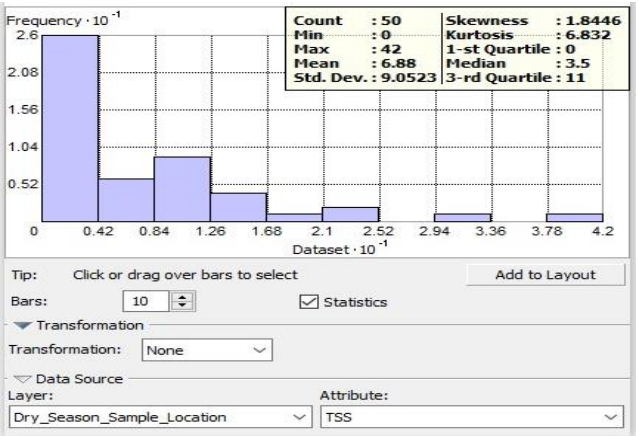
(c)Electrical Conductivity (No transformation)



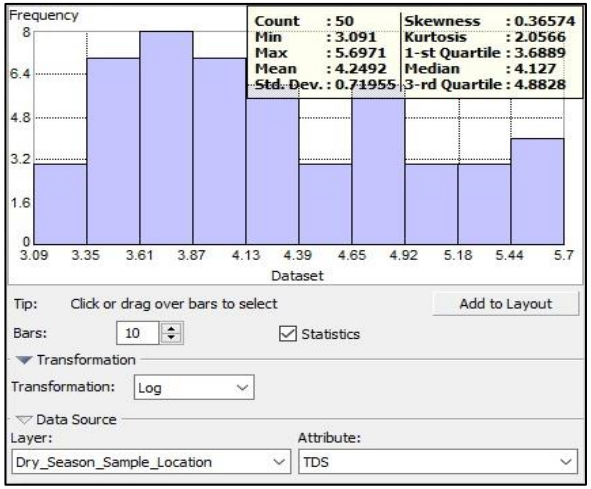
(d) Turbidity (No transformation)



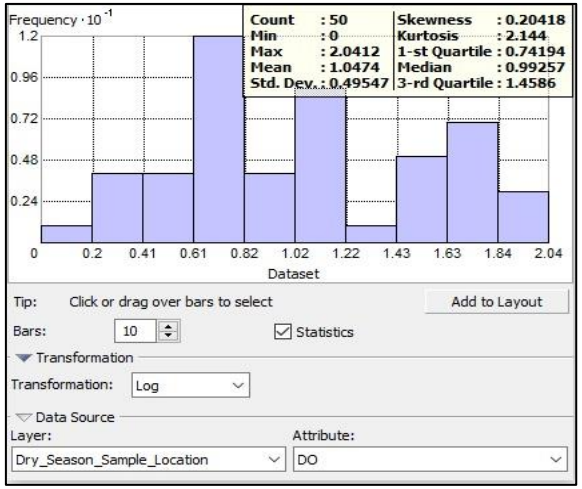
(e) Total Hardness (Log. transformation)



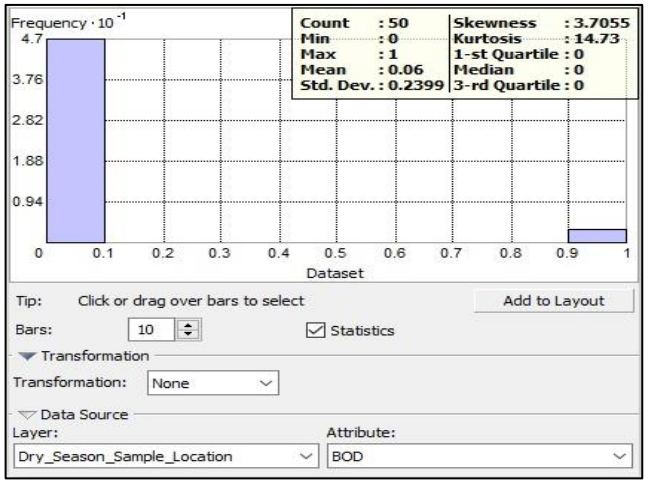
(f) Total Suspended Solid (No transformation)



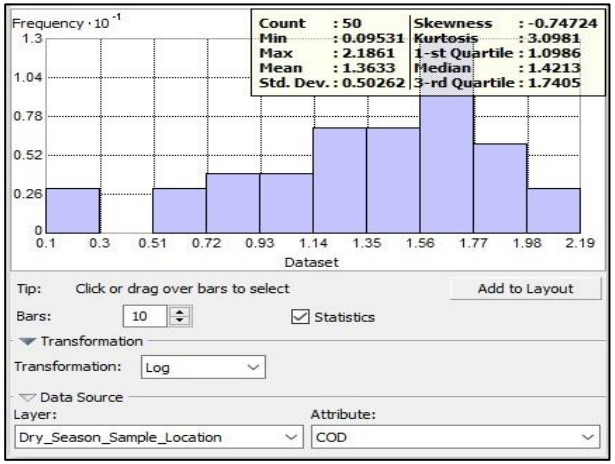
(g) TDS (Log. transformation)



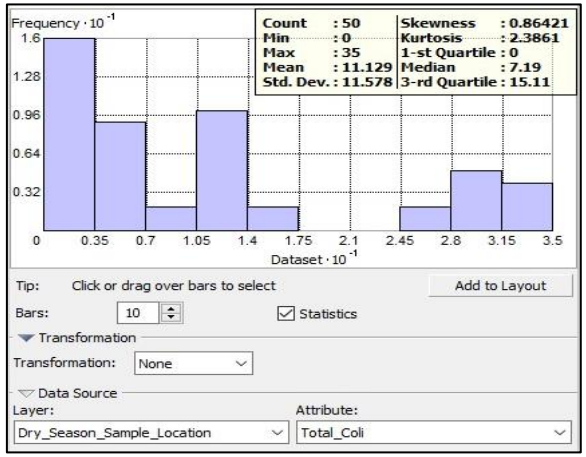
(h) Dissolved Oxygen (Log. transformation)



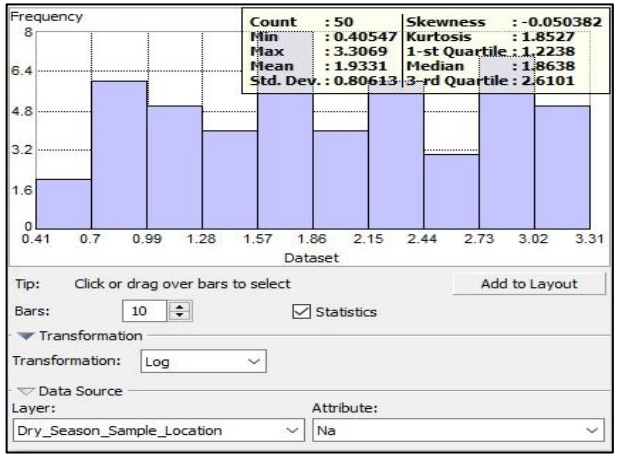
(i) BOD (No transformation)



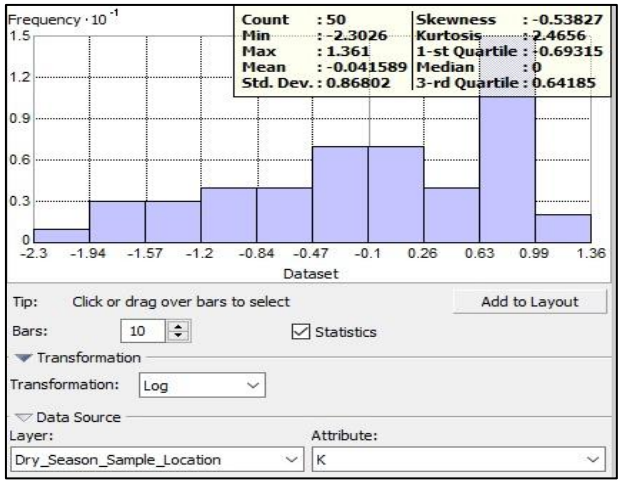
(j) COD (Log. transformation)



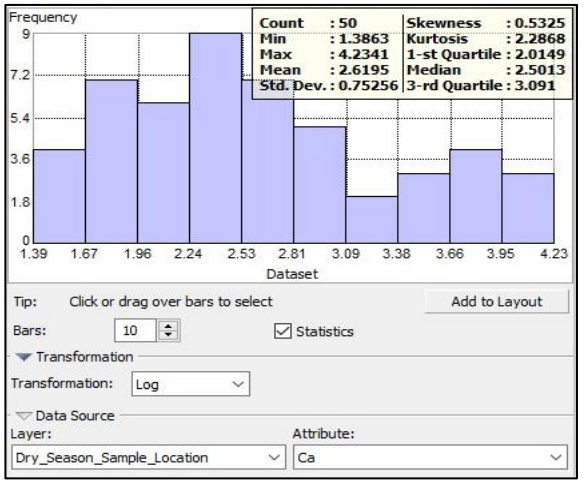
(k) Total Coliform (No transformation)



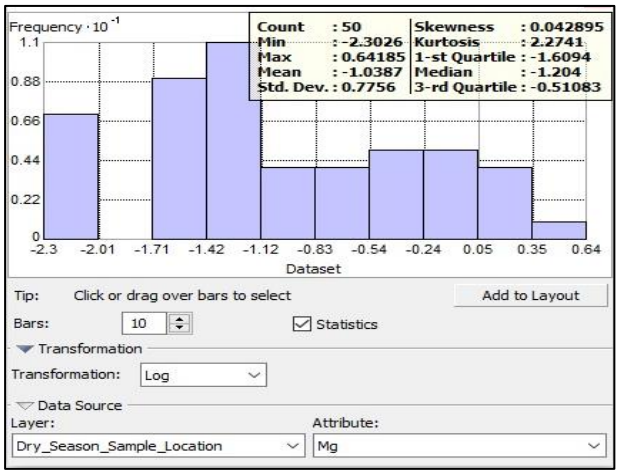
(l) Sodium (Log. transformation)



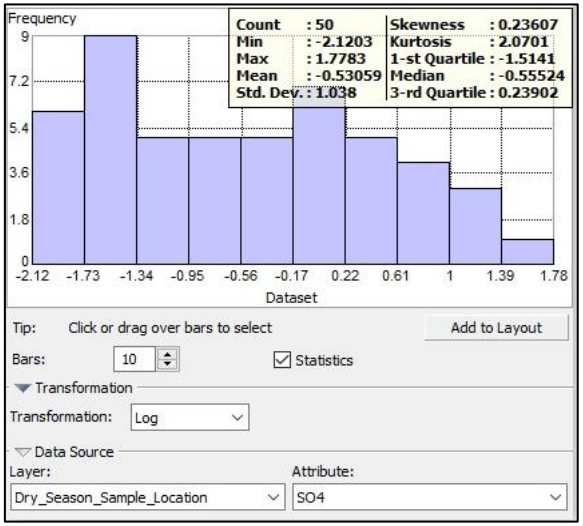
(m) Potassium (Log. transformation)



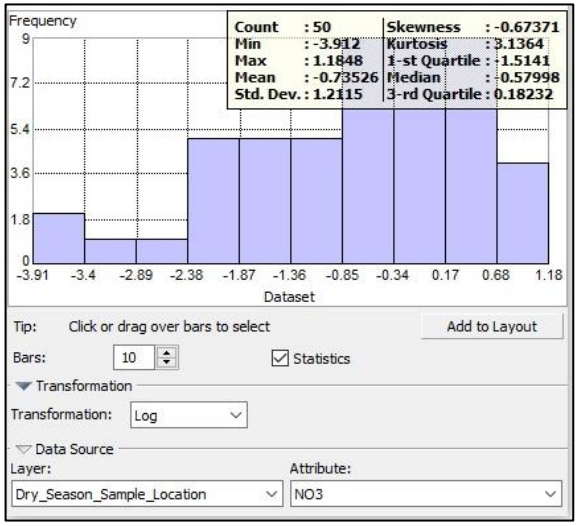
(n) Calcium (Log. transformation)



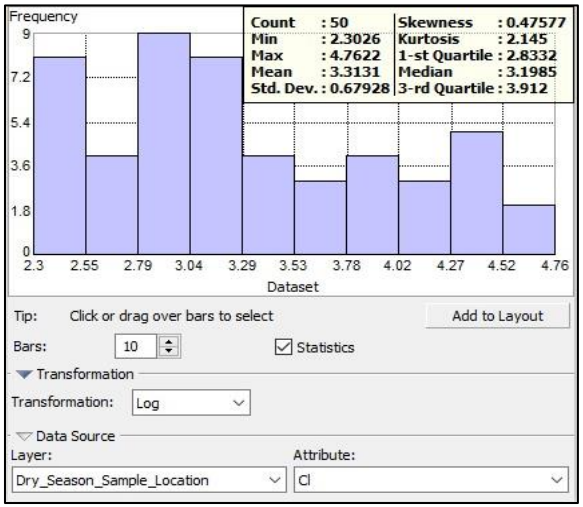
(o) Magnessium (Log. transformation)



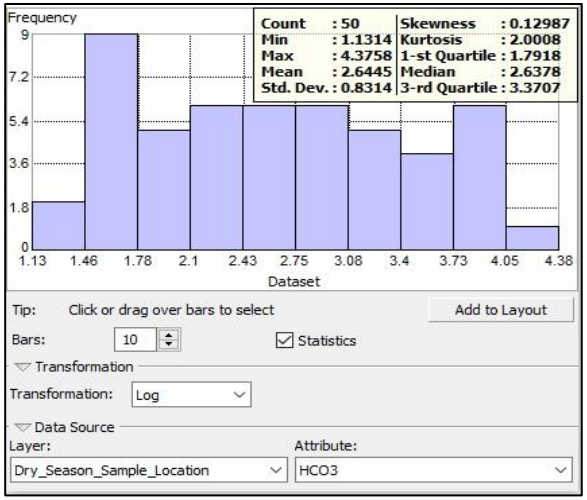
(p) Sulphate (Log. transformation)



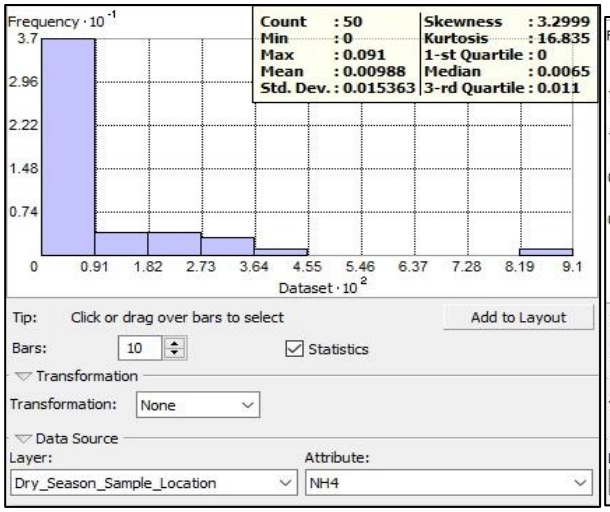
(q) Nitrate (Log. transformation)



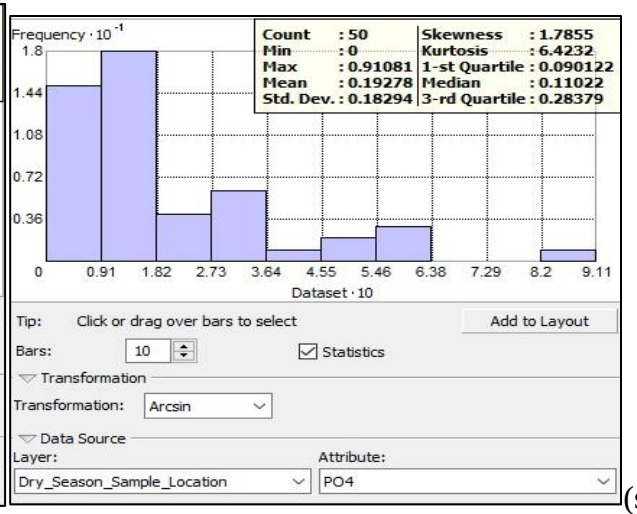
(r) Chloride (Log. transformation)



Bicarbonate (Log. transformation)

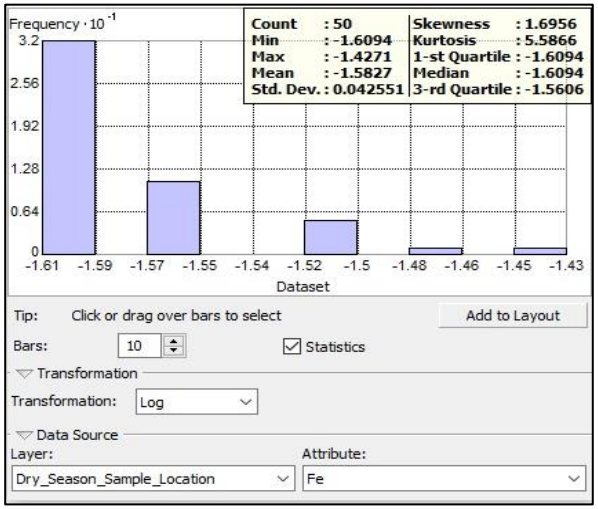


(t) Ammonium (No transformation)

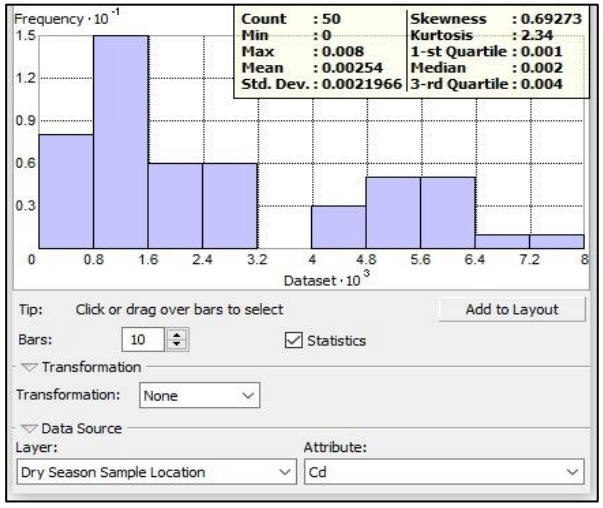


(s)

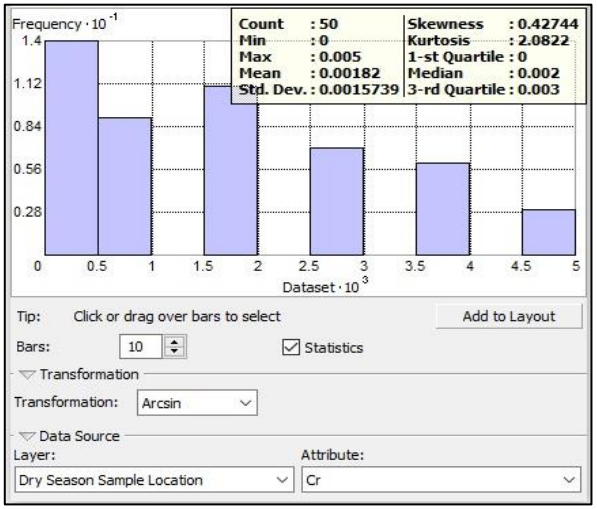
(u) Phosphate (Arcsine transformation)



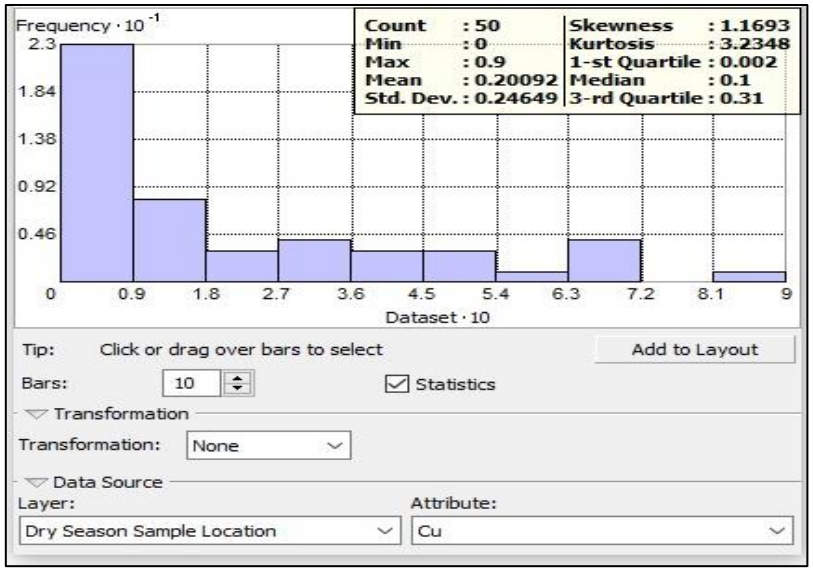
(v) Iron (Log. transformation)



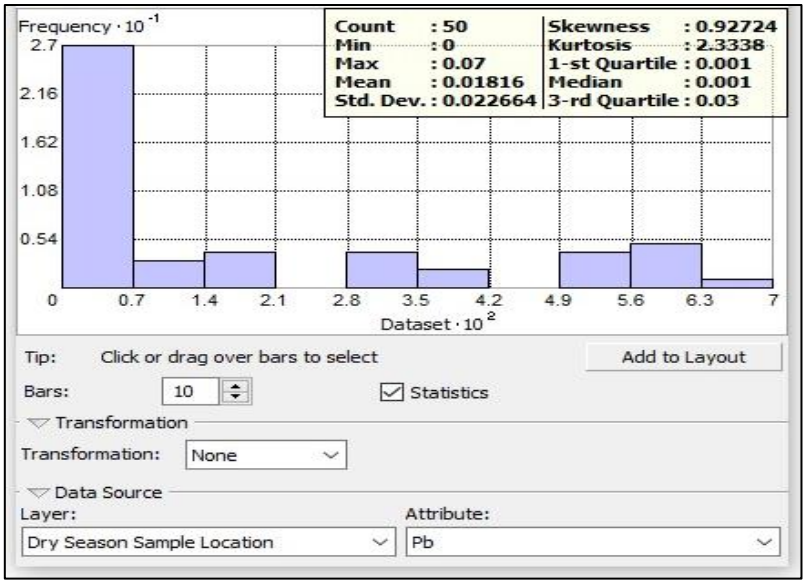
(w) Cadmium (None transformation)



(x) Chromium (Arcsine transformation)

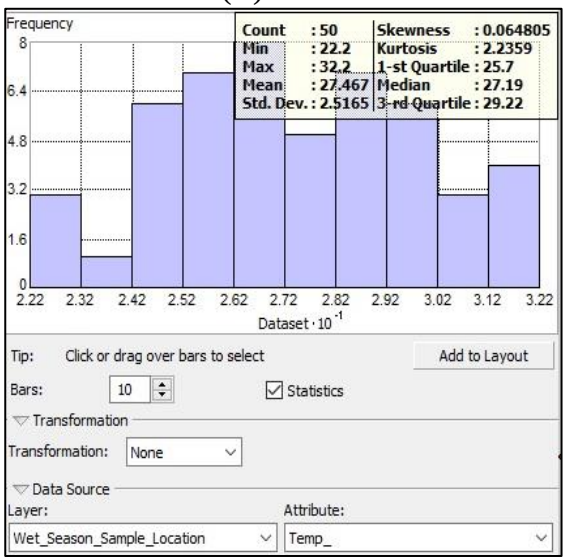


(y) Copper (None transformation)

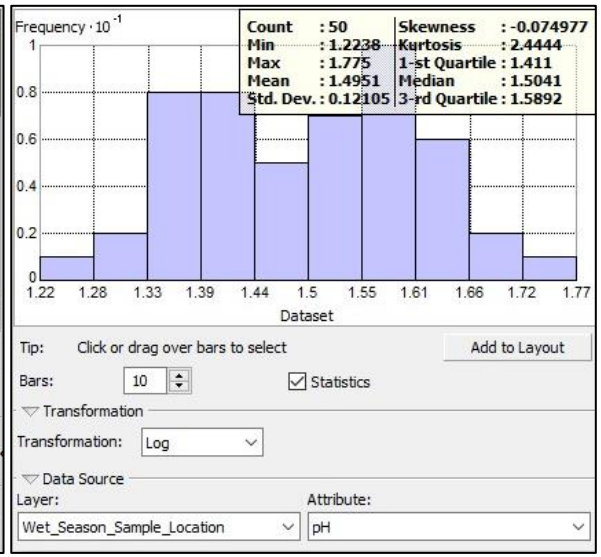


(z) Lead (None transformation)

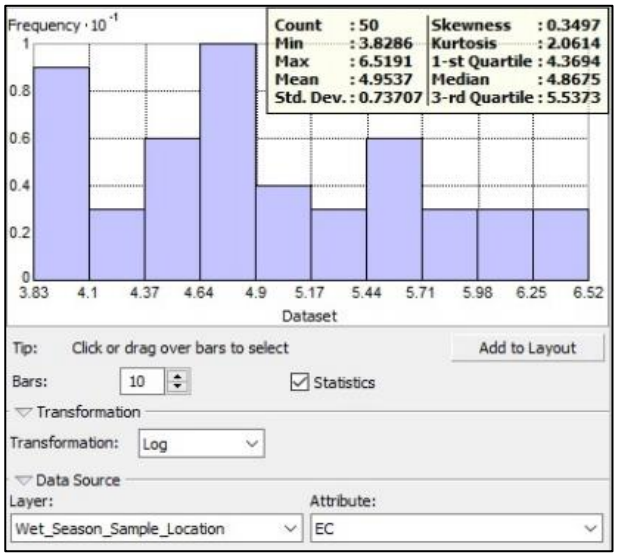
APPENDIX VI(B): Wet Season



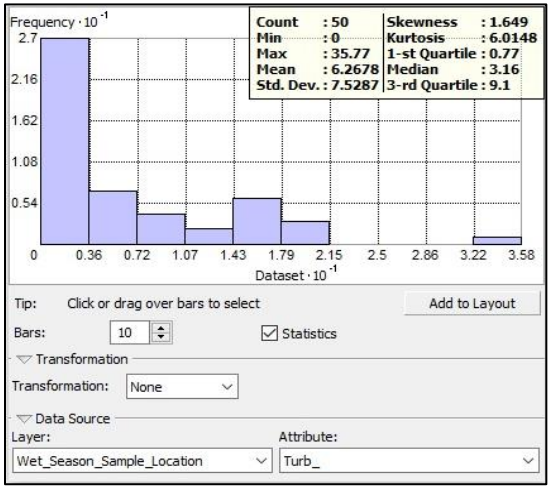
(a)Temperature(No transformation)



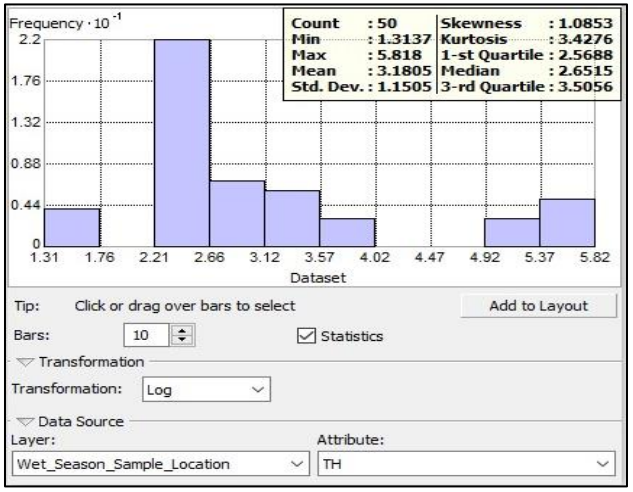
(b) pH level (Log. transformation)



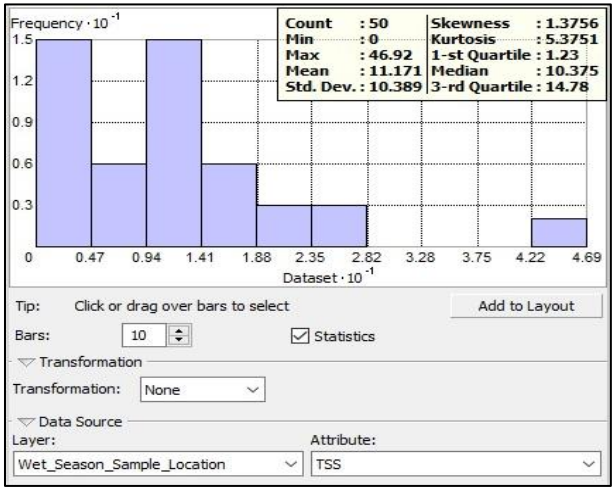
(c)Elect. Conductivity (Log. transformation)



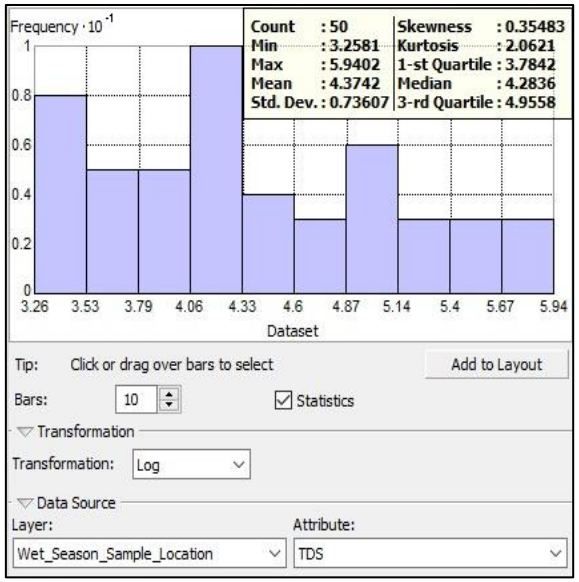
(d) Turbidity(None transformation)



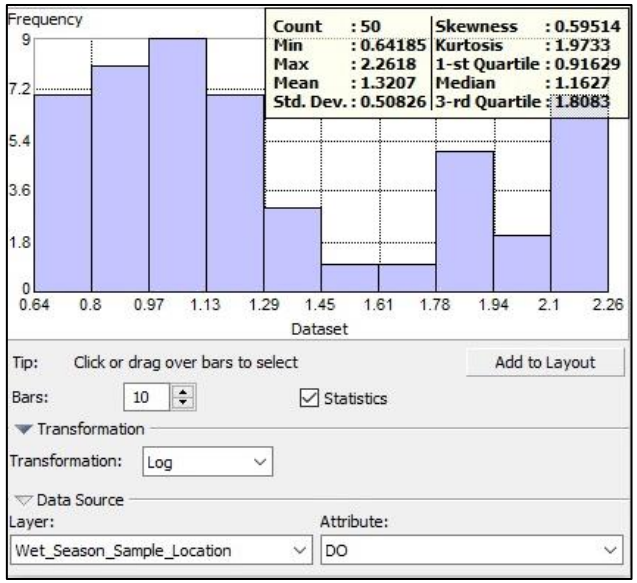
(e) Total Hardness(Log. transformation)



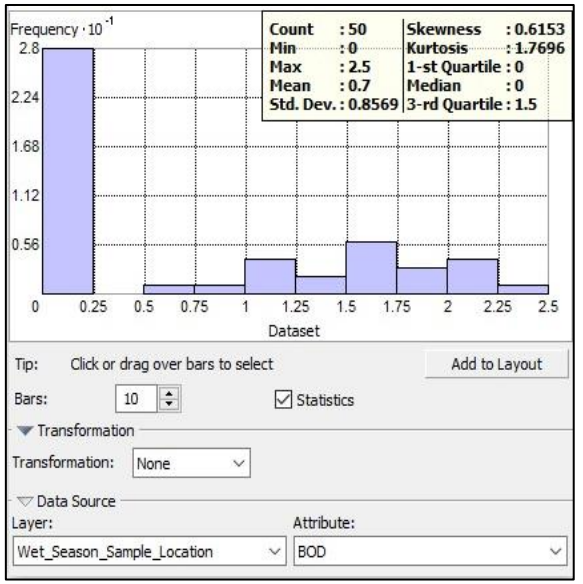
(f) TSS (No transformation)



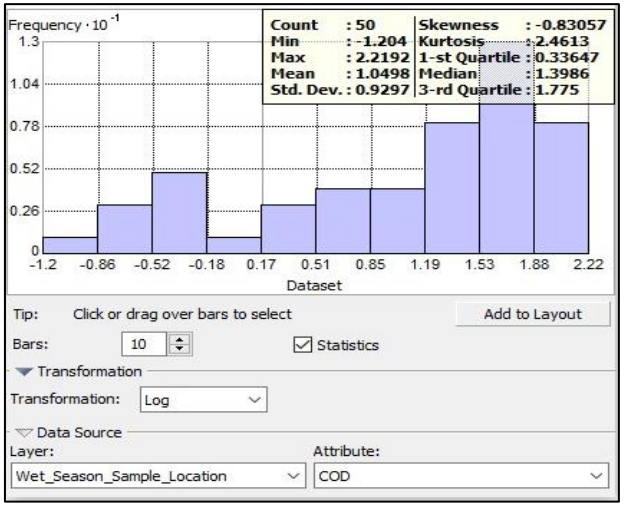
(g) TDS(Log.transformation)



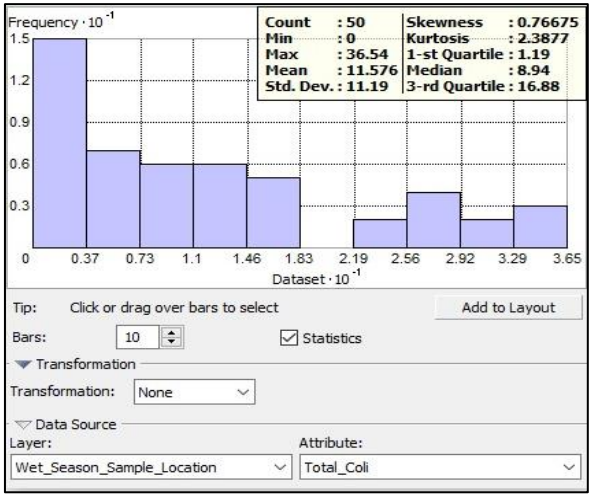
(h) Dissolved Oxygen(Log. transformation)



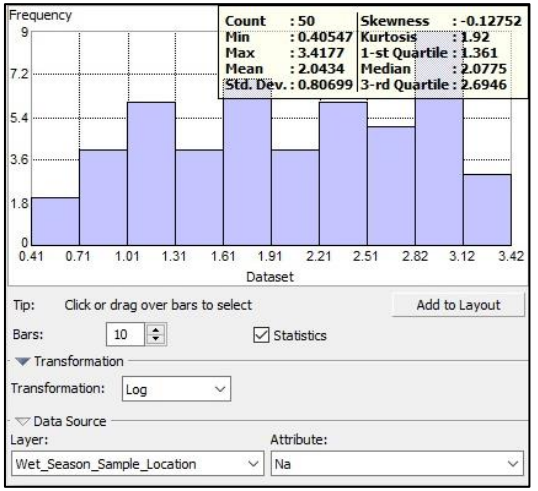
(i) BOD (No transformation)



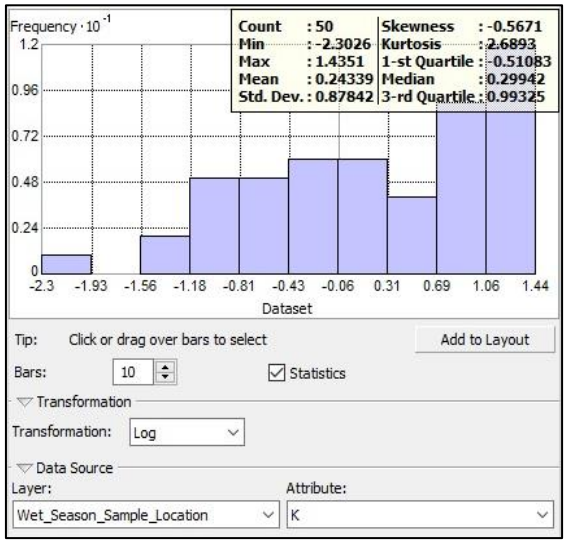
(j) COD (Log. transformation)



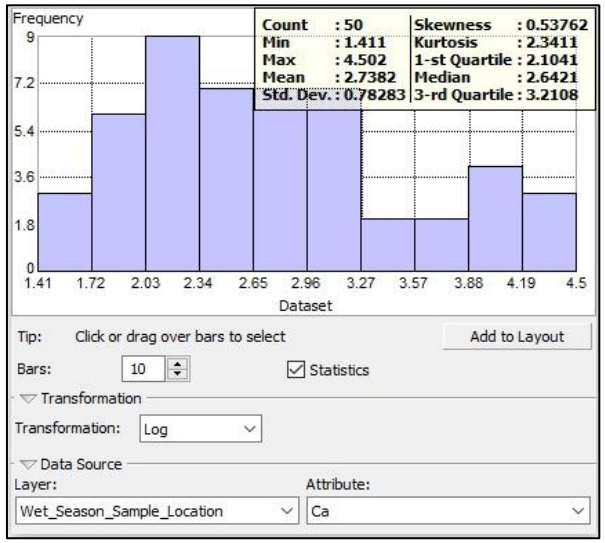
(k) Total Coliform (No transformation)



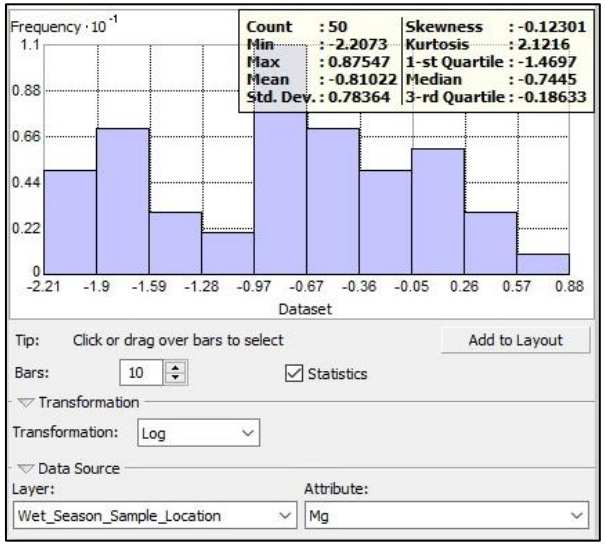
(l) Sodium (Log. transformation)



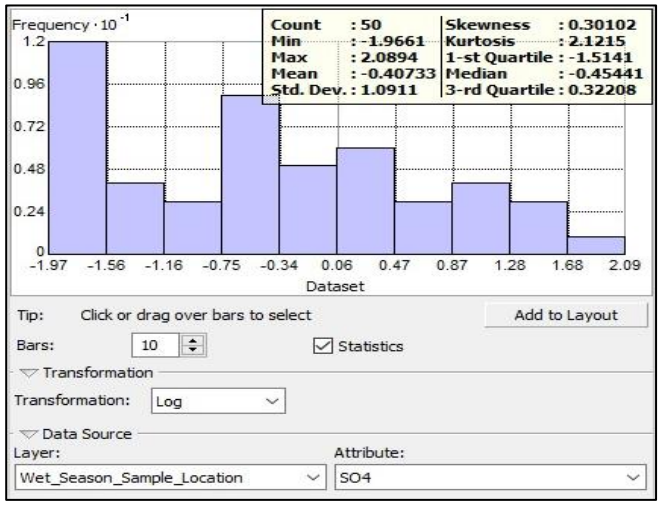
(m) Potassium (Log. transformation)



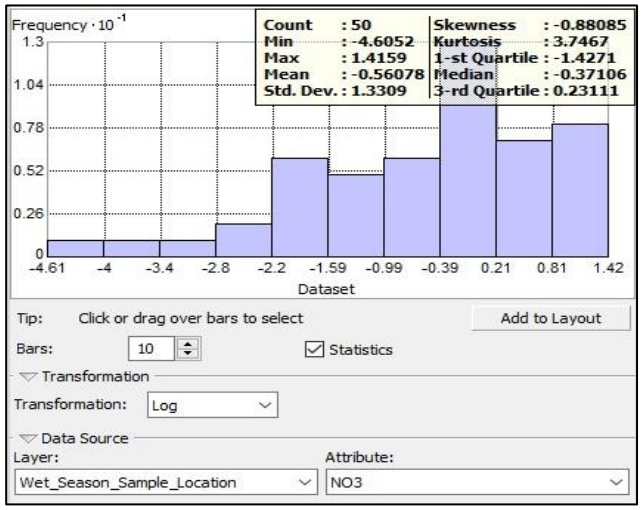
(n) Calcium (Log. transformation)



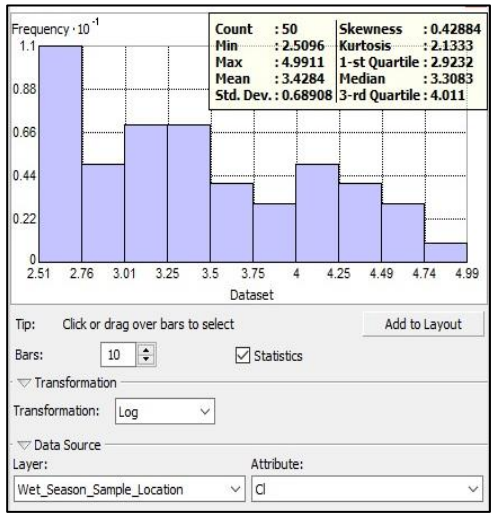
(o) Magnessium(Log. transformation)



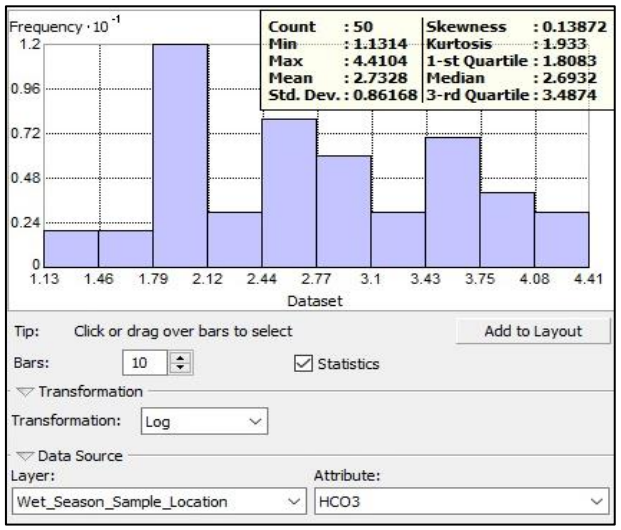
(p) Sulphate (Log. transformation)



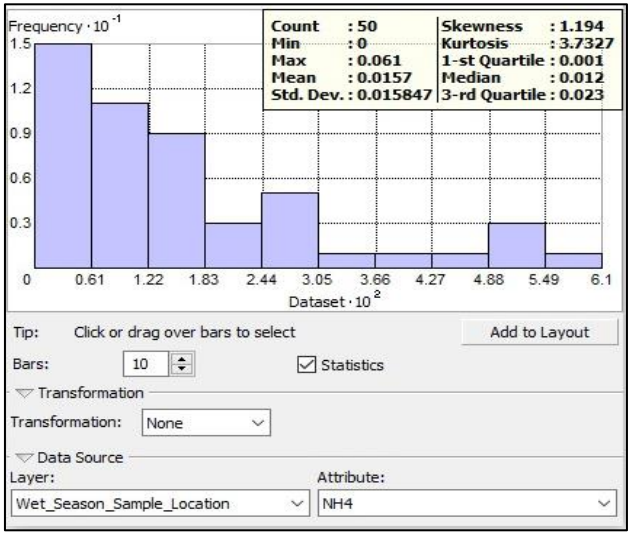
(q) Nitrate (Log. transformation)



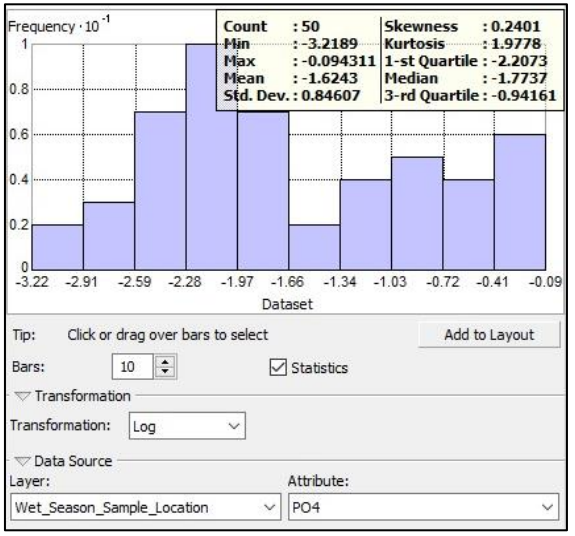
(r) Chloride (Log. transformation)



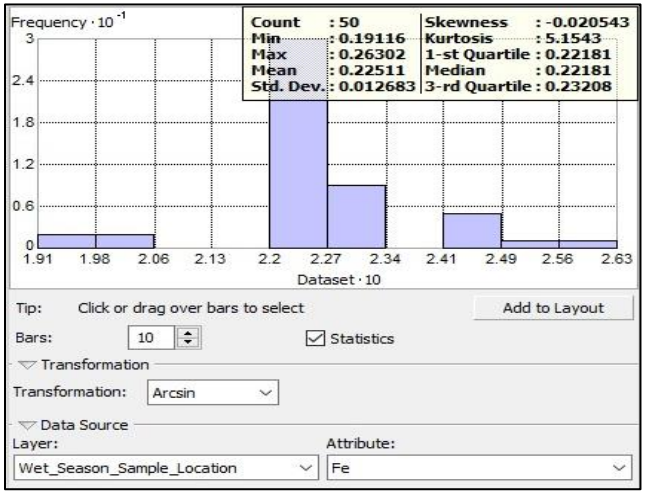
(s) Bicarbonate (Log. transformation)



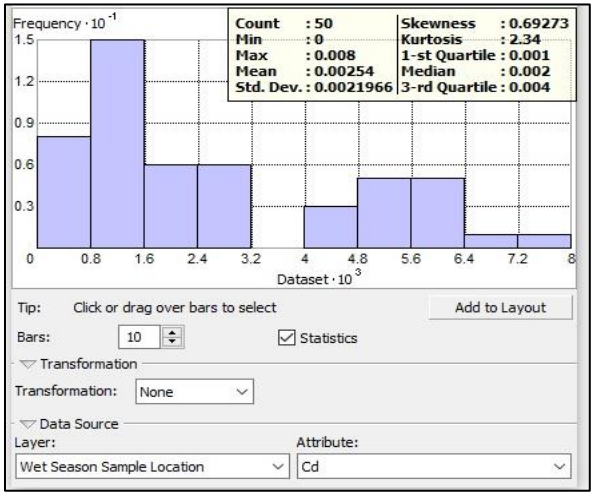
(t) Ammonium (No transformation)



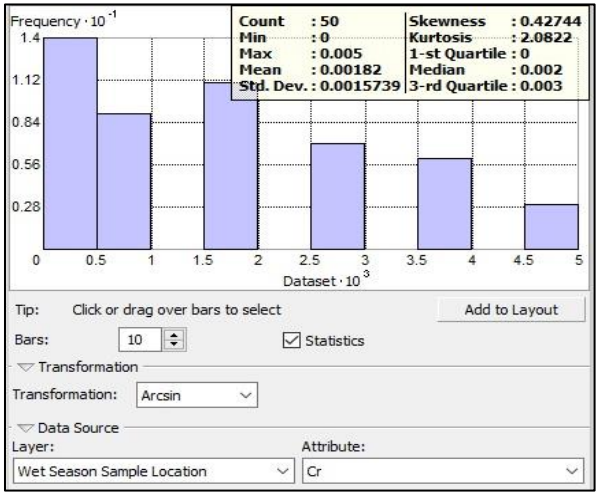
(u) Phosphate (Log. transformation)



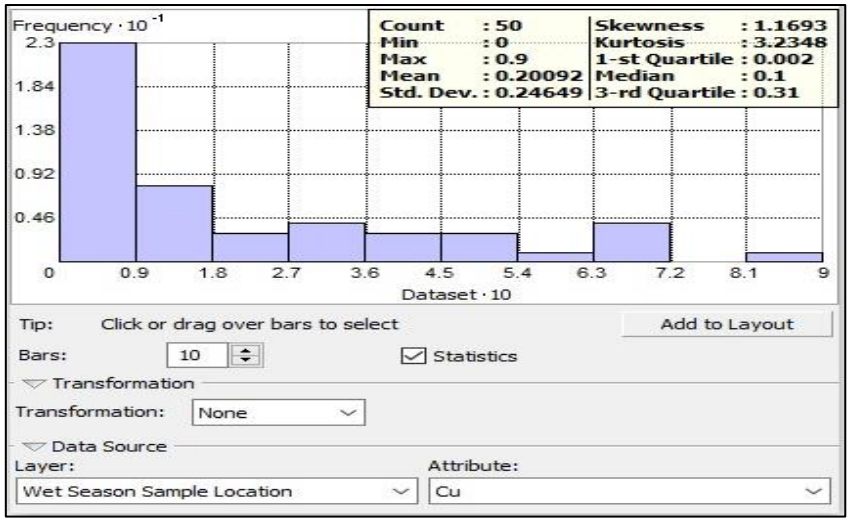
(v) Iron (Arcsine Transformation)



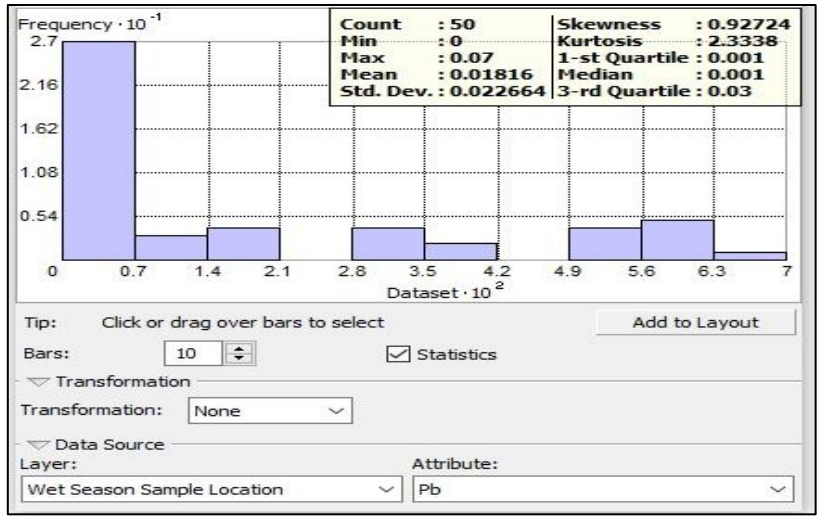
(w) Cadmium (None transformation)



(x) Chromium (Arcsine transformation)

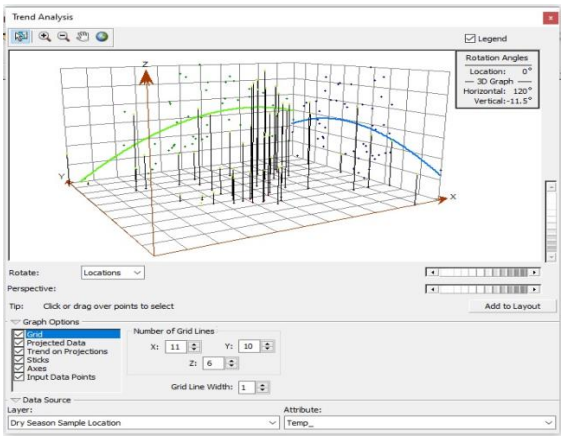


(y) Copper (None transformation)

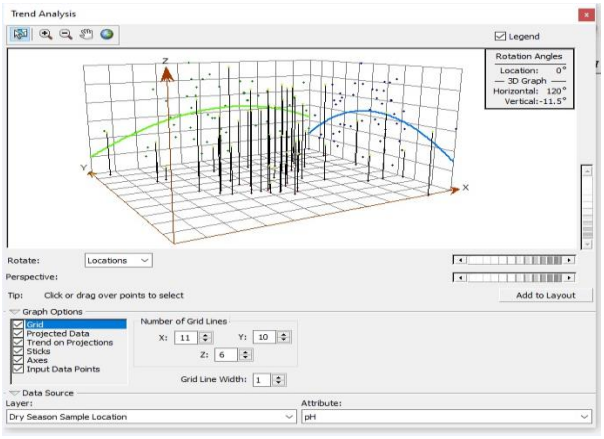


(z) Lead (None transformation)

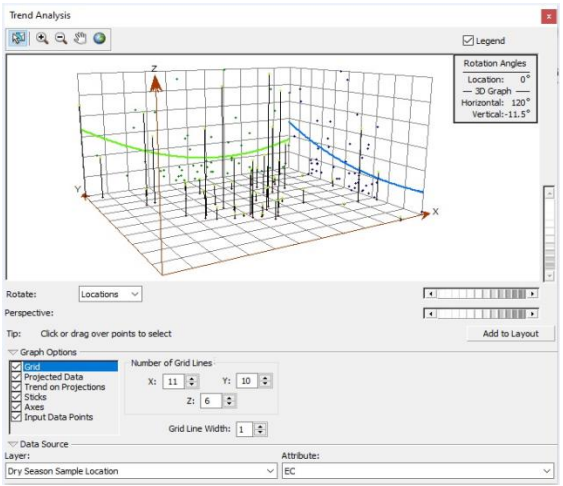
APPENDIX VII
TREND ANALYSIS FOR GROUNDWATER QUALITY PARAMETERS
APPENDIX VII(A): Dry Season



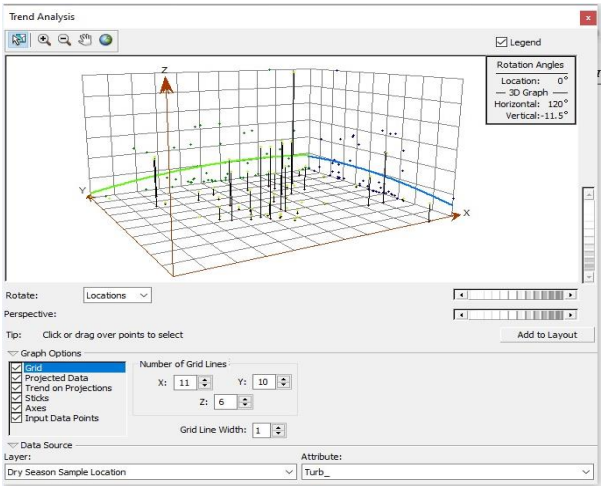
i. Trend Analysis for Temperature



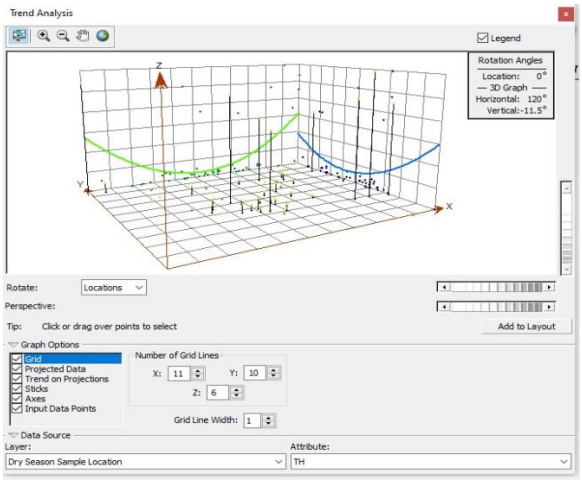
ii. Trend Analysis for pH



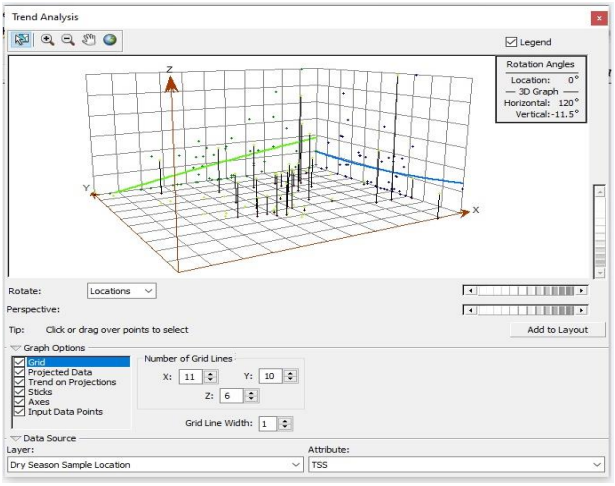
iii. Trend Analysis for EC



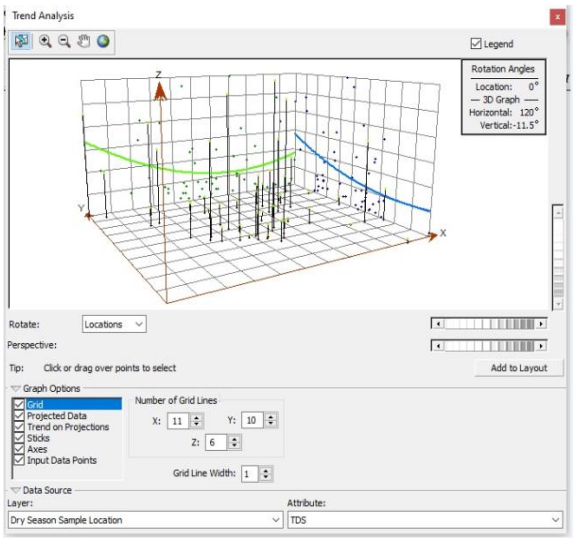
iv. Trend Analysis for Turbidity



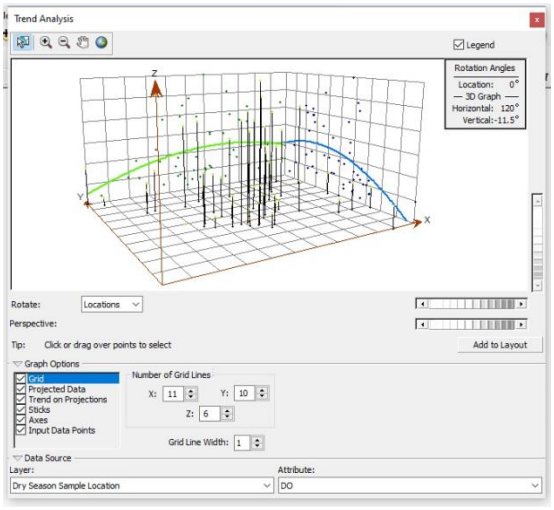
v. Trend Analysis for TH



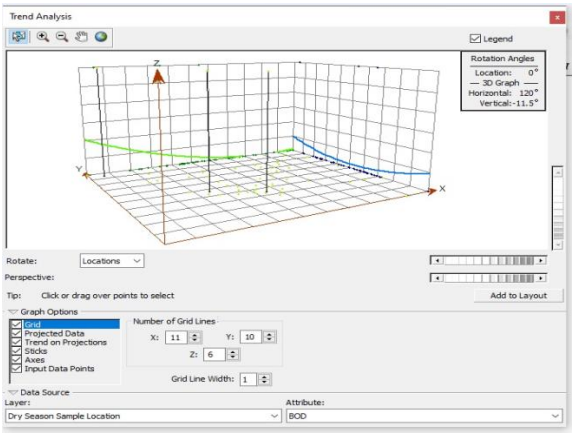
vi. Trend Analysis for TSS



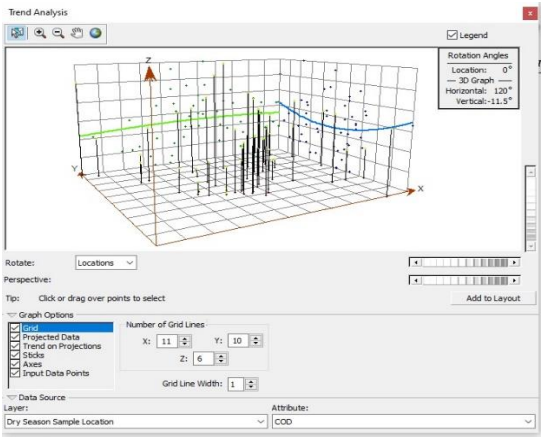
vii. Trend Analysis for TDS



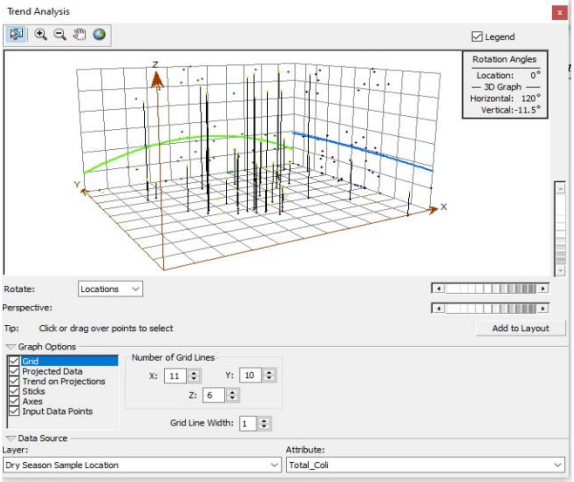
viii. Trend Analysis for DO



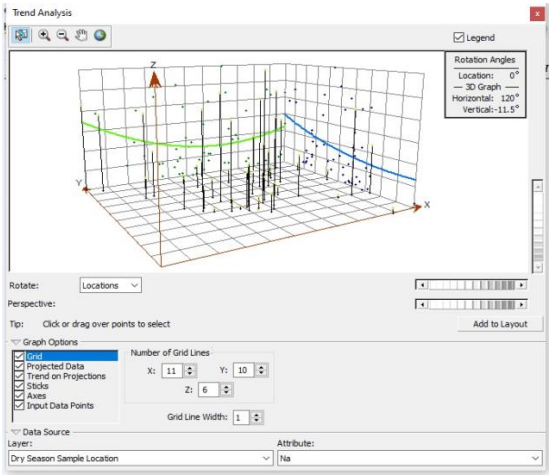
ix. Trend Analysis for BOD



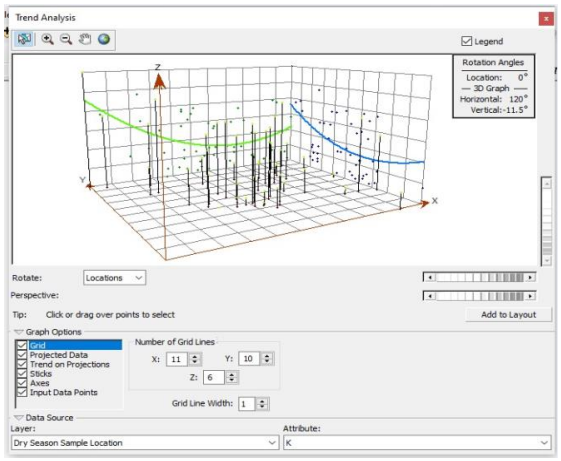
x. Trend Analysis for COD



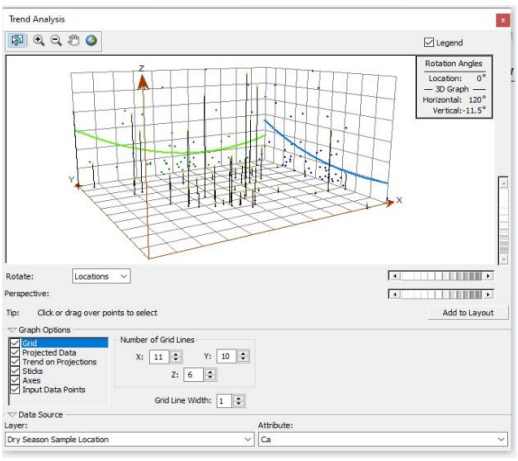
xi. Trend Analysis for Total Coli.



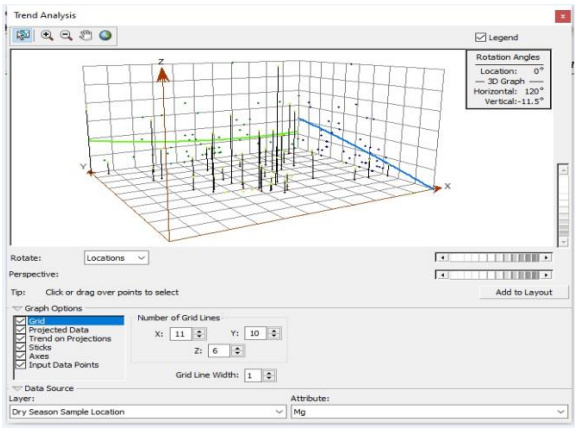
Xii. Trend Analysis for Na



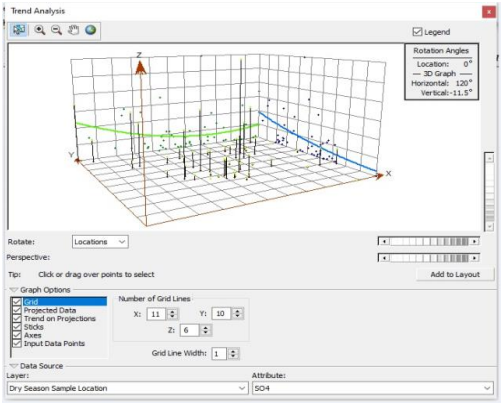
xiii. Trend Analysis for K



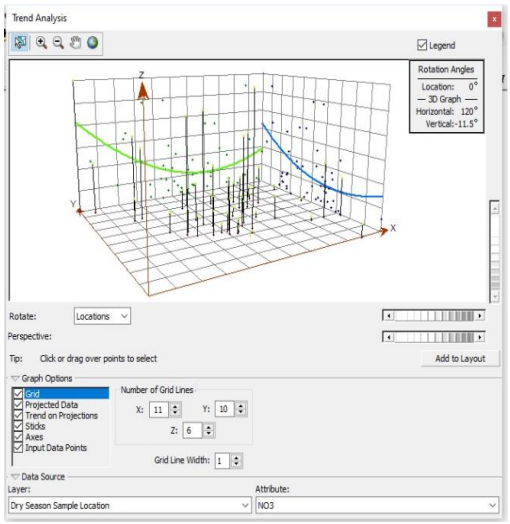
xiv. Trend Analysis for Ca



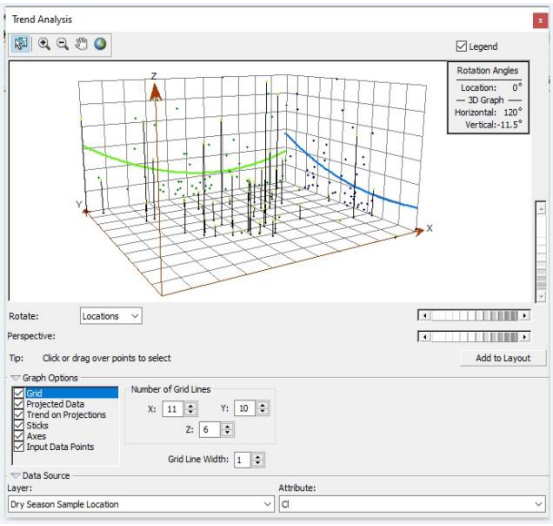
xv. Trend Analysis for Mg



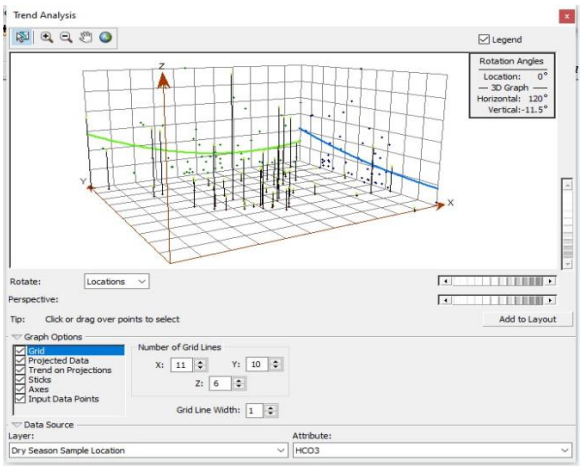
xvi. Trend Analysis for SO_4



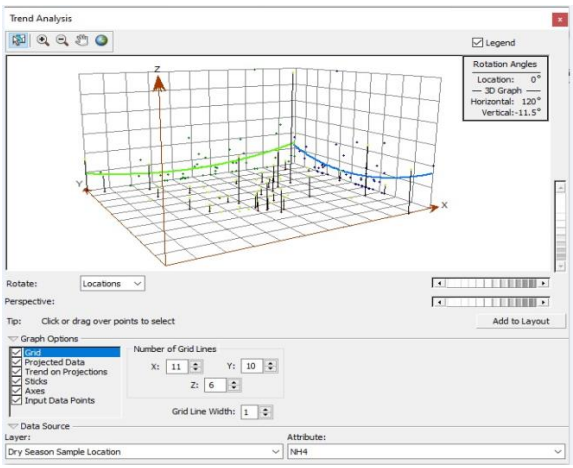
xvii. Trend Analysis for NO_3



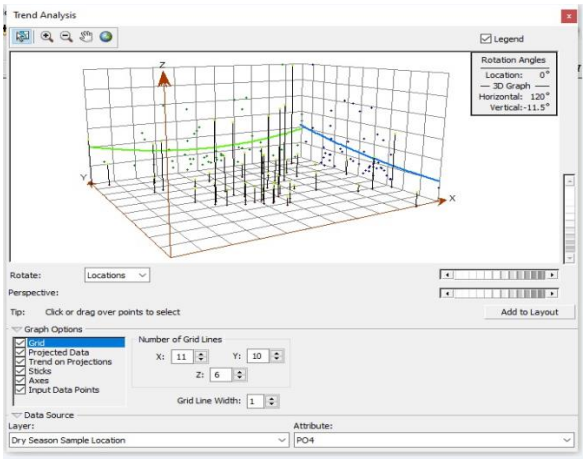
xviii. Trend Analysis for Cl



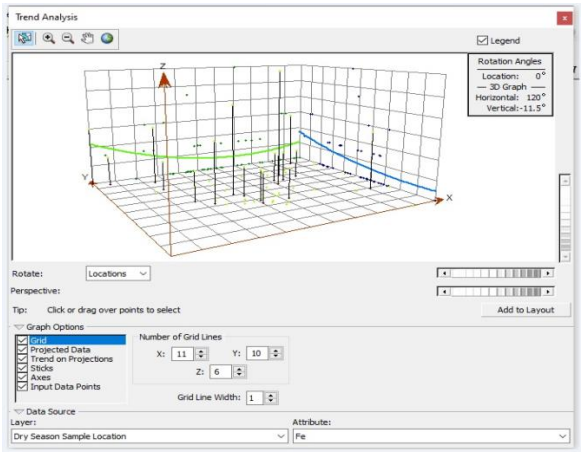
xix. Trend Analysis for HCO_3



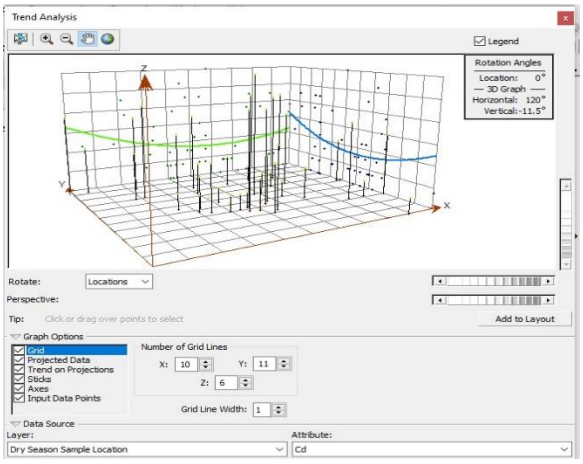
xx. Trend Analysis for NH_4



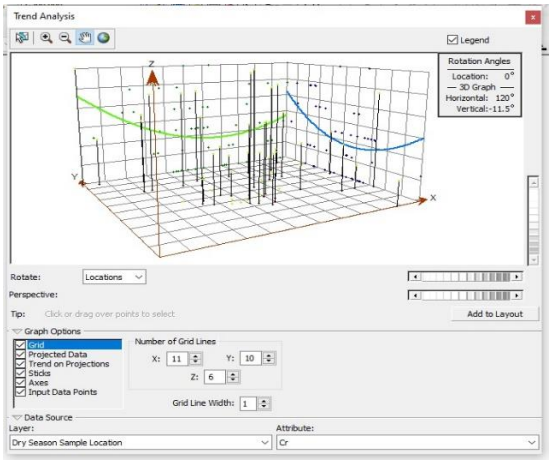
xxi. Trend Analysis for PO_4



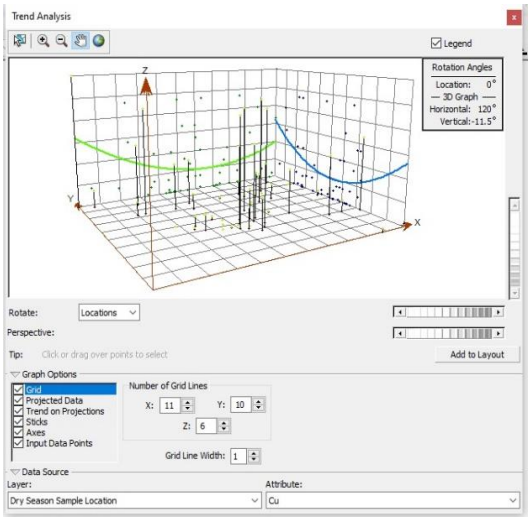
xxii. Trend Analysis for Fe



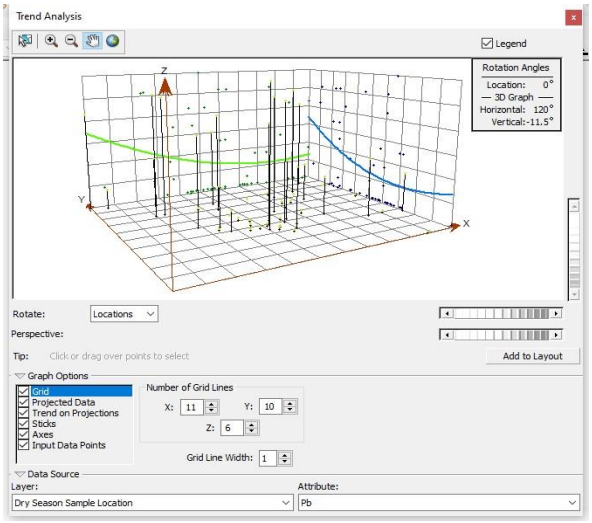
xxiii. Trend Analysis for Cd



xxiv. Trend Analysis for Cr

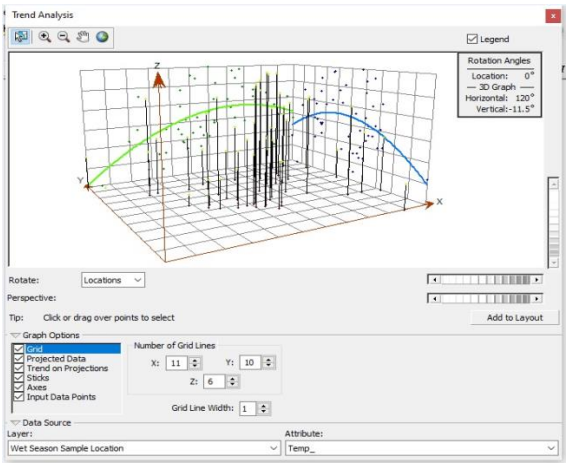


xxv. Trend Analysis for Cu

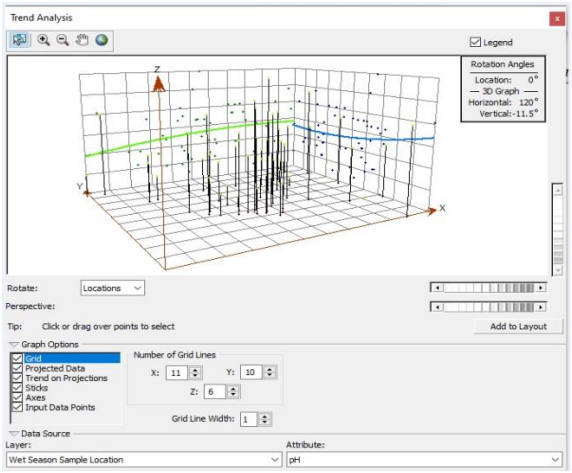


xxvi. Trend Analysis for Pb

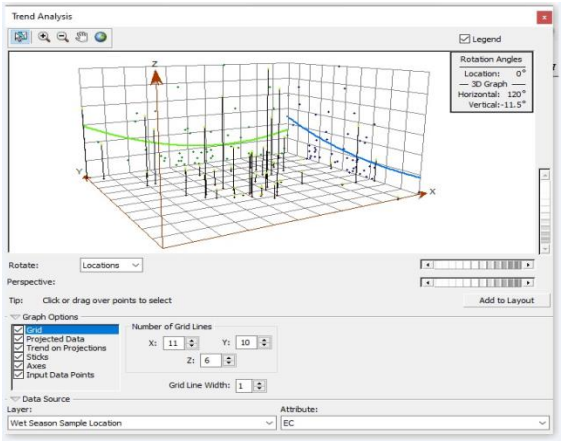
APPENDIX VII(B): Wet Season



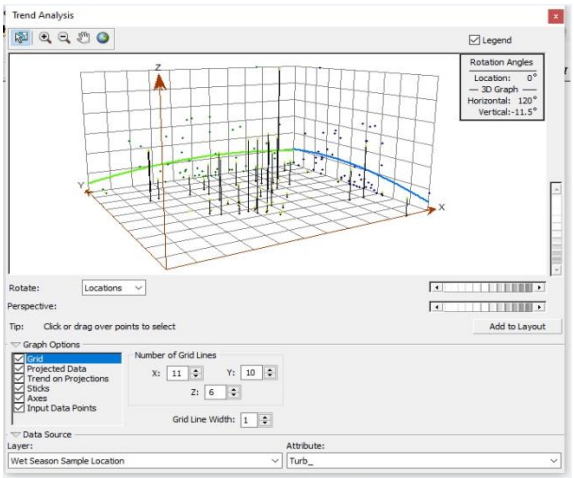
i. Trend Analysis for Temperature



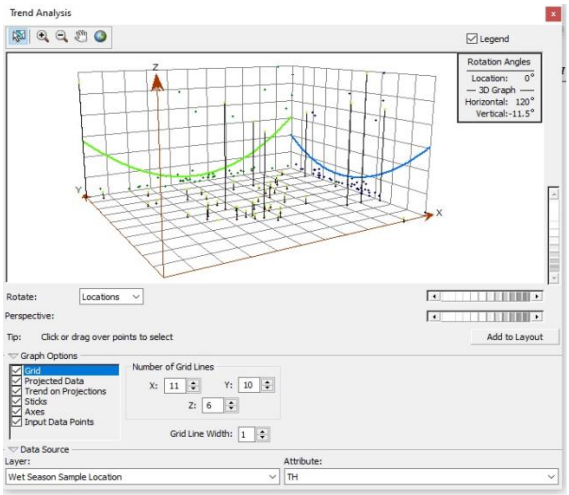
ii. Trend Analysis for pH



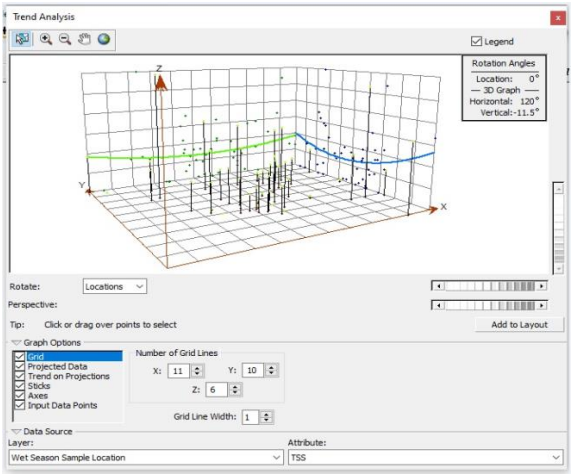
iii. Trend Analysis for EC



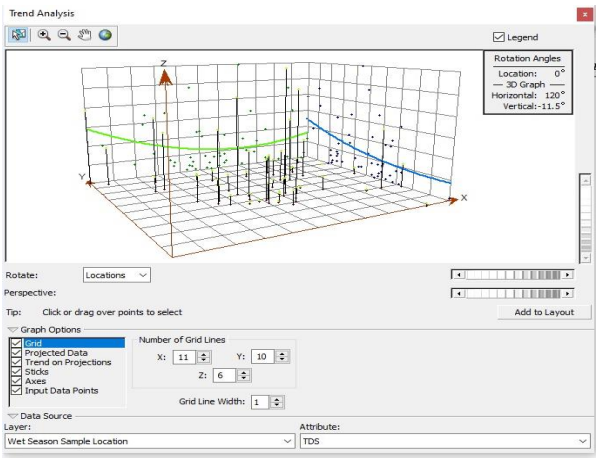
iv. Trend Analysis for Turbidity



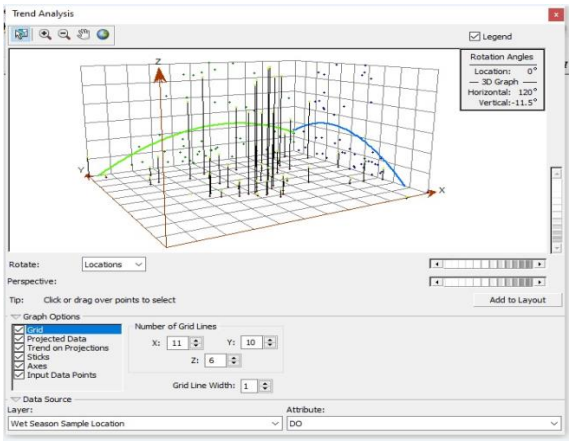
v. Trend Analysis for TH



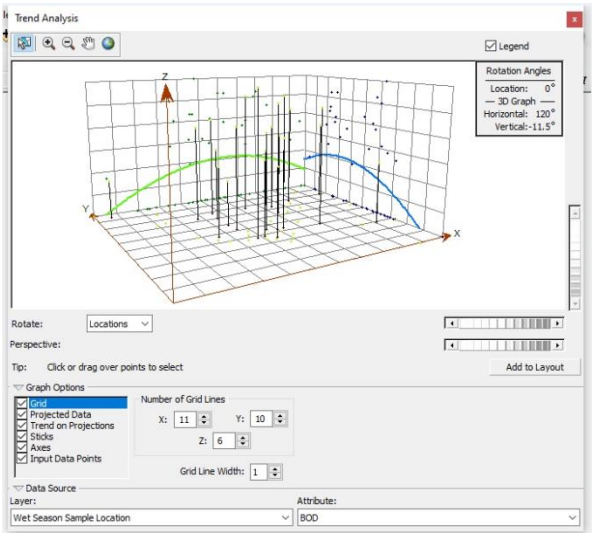
vi. Trend Analysis for TSS



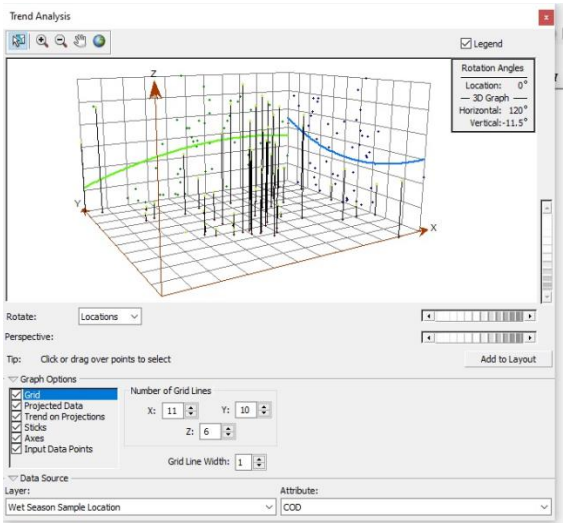
vii. Trend Analysis for TDS



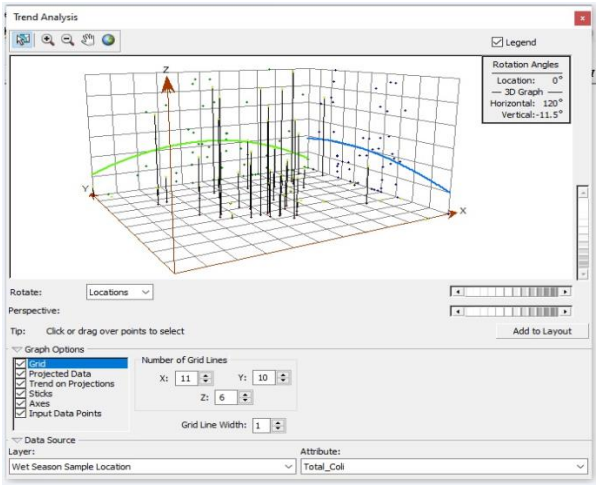
viii. Trend Analysis for DO



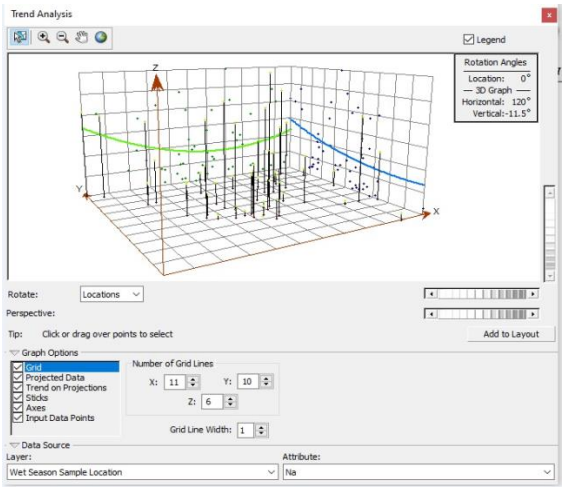
ix. Trend Analysis for BOD



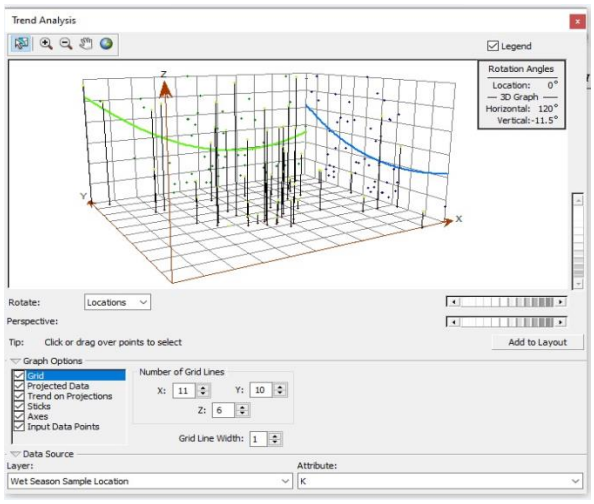
x. Trend Analysis for COD



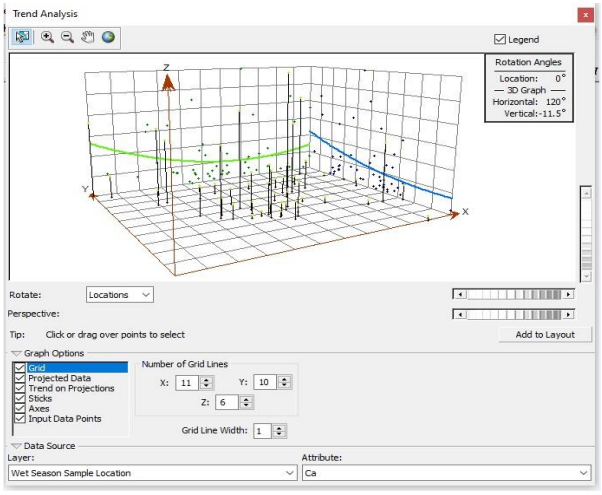
xi. Trend Analysis for Total Coli.



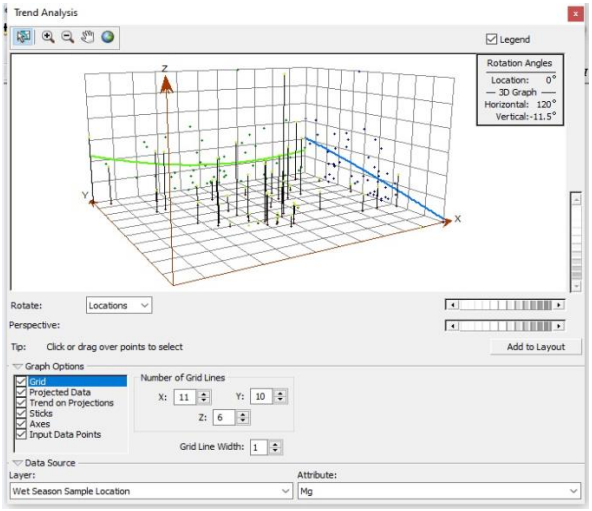
xii. Trend Analysis for Na



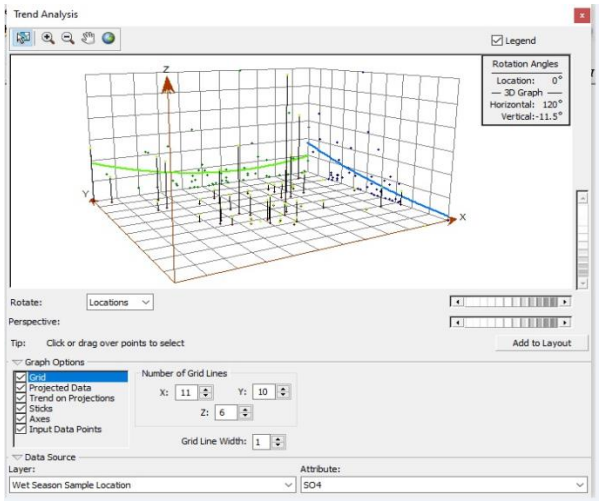
xiii. Trend Analysis for K



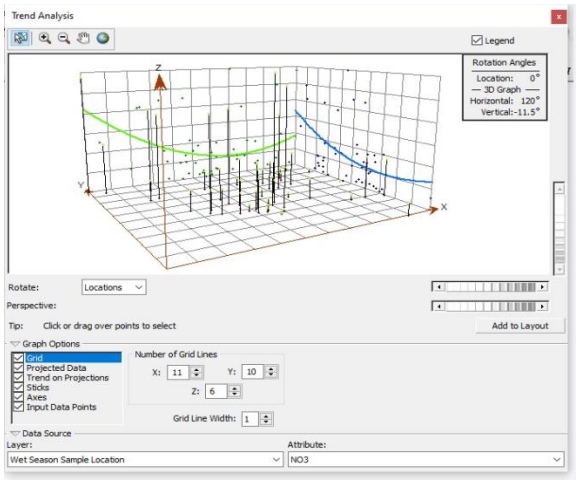
xiv.Trend Analysis for Ca



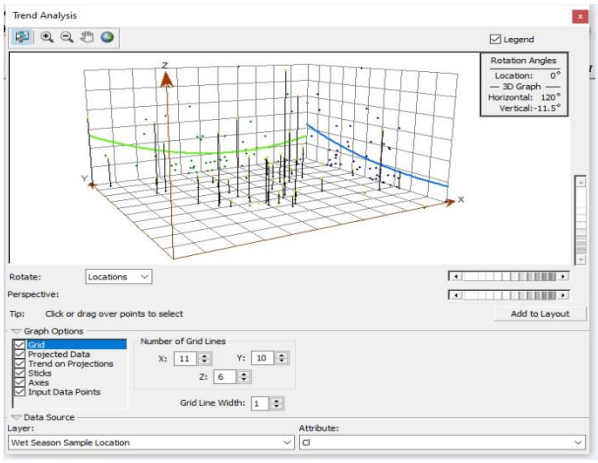
xv. Trend Analysis for Mg



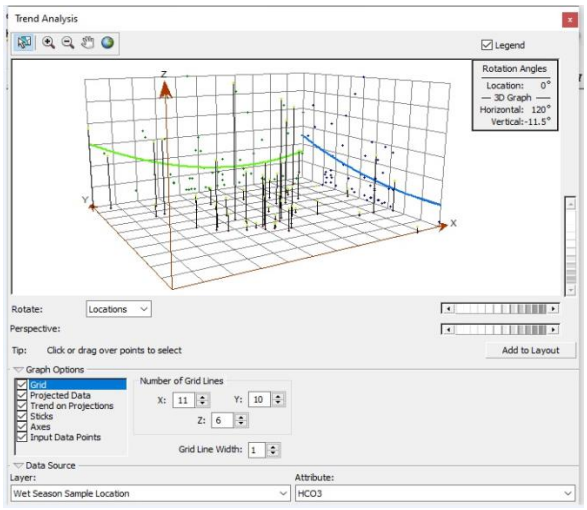
xvi. Trend Analysis for SO_4



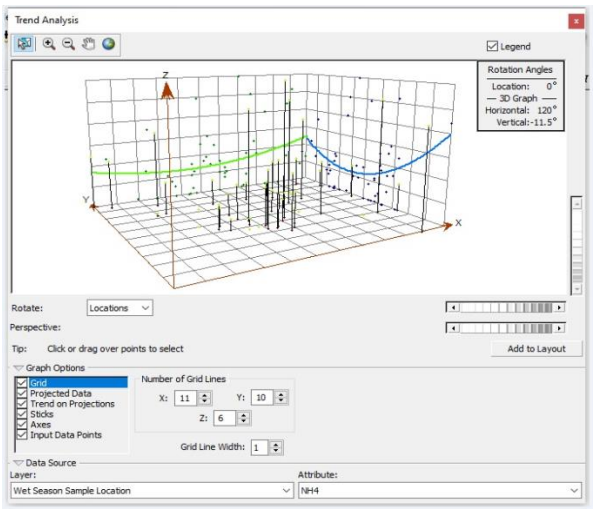
xvii. Trend Analysis for NO_3



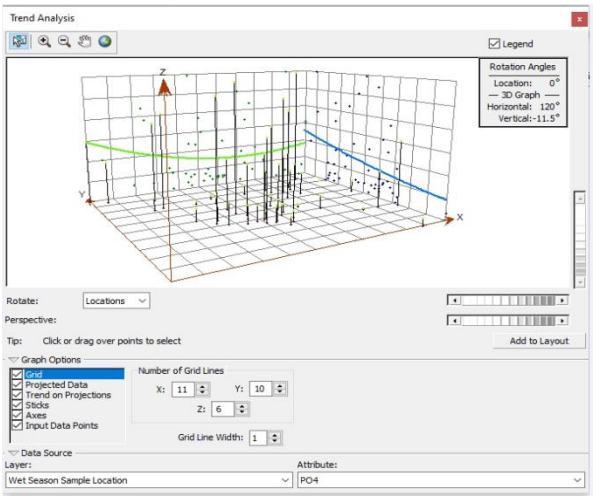
xviii. Trend Analysis for Cl



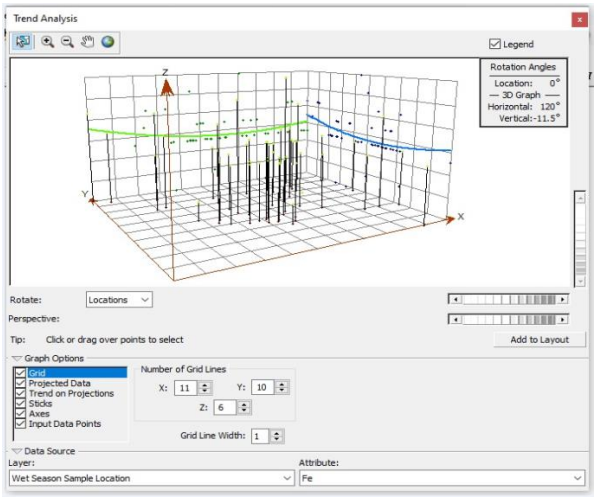
xix. Trend Analysis for HCO_3



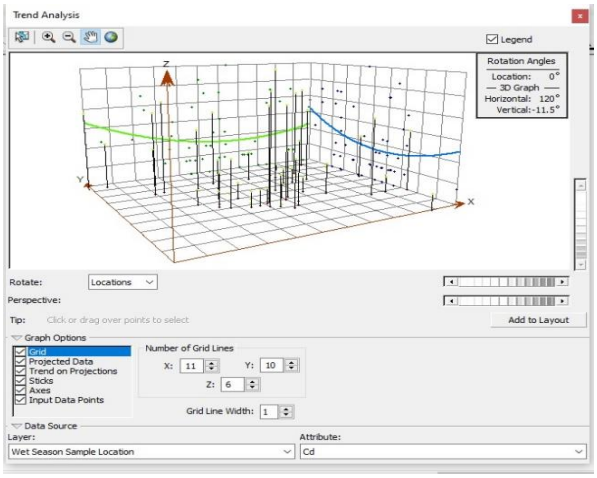
xx. Trend Analysis for NH_4



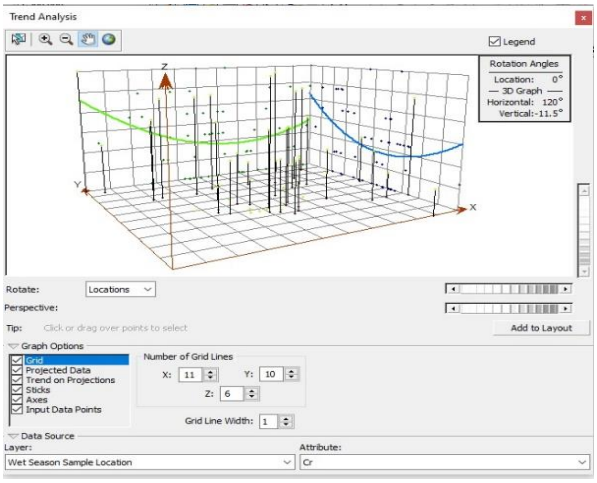
xxi. Trend Analysis for PO_4



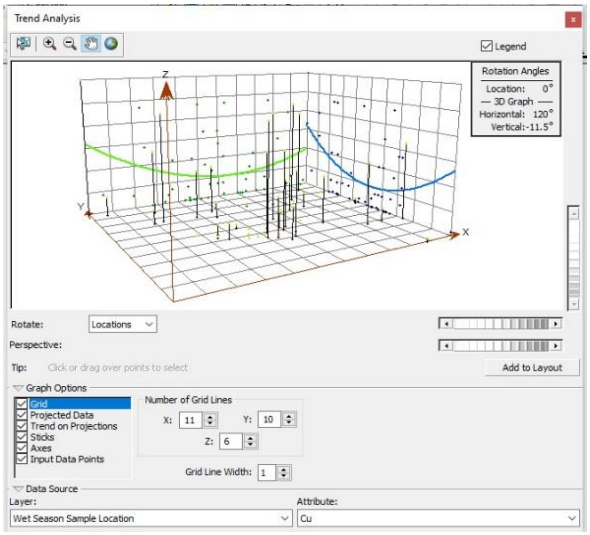
xxii. Trend Analysis for Fe



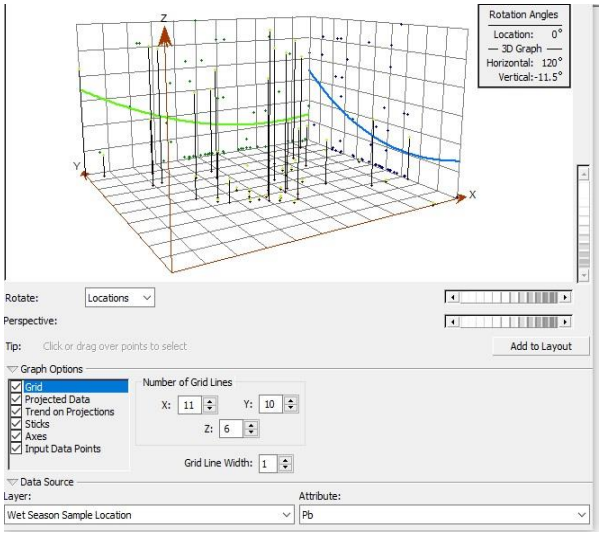
xxiii. Trend Analysis for Cd



xxiv. Trend Analysis for Cr



xxv. Trend Analysis for Cu



xxvi. Trend Analysis for Pb

APPENDIX VIII
CROSS VALIDATION OF TESTED MODELS WITH PREDICTION ERRORS FOR EACH WATER QUALITY PARAMETER

APPENDIX VIII(A): Dry Season

(a) Temperature

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.1266	2.0686	0.0474	0.8616	2.4175
2.	Exponential	0.1219	2.0655	0.0456	0.8615	2.4162
3.	Gaussian	0.1359	2.0694	0.0512	0.8634	2.4143
4.	Hole Effect	0.1324	2.0494	0.0501	0.8567	2.4132
5.	J-bessel	0.1307	2.0519	0.0495	0.8564	2.4184
6.	K-bessel	0.1285	2.0690	0.0477	0.8635	2.4170
7.	**Pentaspherical**	**0.1330**	**2.0446**	**0.0505**	**0.8548**	**2.4172**
8.	Rational Quad.	0.1507	2.0461	0.0574	0.8567	2.4089
9.	Spherical	0.1306	2.0626	0.0484	0.8611	2.4162
10.	Stable	0.1394	2.0448	0.0528	0.8563	2.4082
11.	Tetraspherical	0.1285	2.0690	0.0477	0.8635	2.4170

(b) pH

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.0478	0.6194	0.0730	0.9821	0.6316
2.	Exponential	0.0510	0.6212	0.0778	0.9796	0.6350
3.	**Gaussian**	**0.0457**	**0.6182**	**0.0700**	**0.9830**	**0.6298**
4.	Hole Effect	0.0457	0.6181	0.0699	0.9822	0.6303
5.	J-bessel	0.0457	0.6181	0.0698	0.9822	0.6302
6.	K-bessel	0.0458	0.6182	0.0701	0.9827	0.6300
7.	Pentaspherical	0.0485	0.6200	0.0742	0.9810	0.6327
8.	Rational Quad.	0.0516	0.6211	0.0787	0.9781	0.6358
9.	Spherical	0.0481	0.6195	0.0733	0.9817	0.6319
10.	Stable	0.0457	0.6182	0.0700	0.9830	0.6298
11.	Tetraspherical	0.0483	0.6196	0.0737	0.9814	0.6323

(c) EC

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	5.7062	145.9023	0.0317	1.2693	115.3434
2.	Exponential	1.6743	142.2238	0.0057	1.21038	116.4471
3.	Gaussian	3.9926	144.59.44	0.0181	1.2456	116.4567
4.	Hole Effect	5.3423	144.6028	0.0331	1.2743	114.6774
5.	J-bessel	6.0056	144.8426	0.0363	1.2736	115.0459
6.	K-bessel	1.6429	142.0457	0.0057	1.2047	116.7343
7.	Pentaspherical	1.6937	143.2962	0.0024	1.2400	115.5193
8.	**Rational Quadratic**	**1.0723**	**140.9794**	**0.0014**	**1.2274**	**115.1871**
9.	Spherical	3.6493	144.5320	0.0156	1.2525	115.4830
10.	Stable	2.7978	143.3881	0.0111	1.2230	116.7945
11.	Tetraspherical	2.8060	143.8609	0.0103	1.2455	115.5654

(d) TDS

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	3.2170	81.7459	0.0319	1.2698	64.6052
2.	Exponential	2.0583	80.9738	0.01573	1.2529	64.6839
3.	Gaussian	1.5837	80.5955	0.0104	1.2458	64.7306
4.	Hole Effect	0.9513	80.2682	0.0023	1.2402	64.7051
5.	J-bessel	0.9331	79.6422	0.0056	1.2094	65.2571
6.	K-bessel	2.2572	80.9991	0.0183	1.2458	65.2312
7.	**Pentaspherical**	**0.5970**	**78.9627**	**0.0013**	**1.2276**	**64.5221**
8.	Rational Quad.	3.0054	80.9979	0.0332	1.2747	64.2266
9.	Spherical	0.5689	79.3740	0.0006	1.2029	65.3998
10.	Stable	3.3400	81.1833	0.0359	1.2745	64.4280
11.	Tetraspherical	1.5805	80.3337	0.0112	1.2233	65.4227

(e) DO

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.0457	1.6279	0.0100	0.9224	1.8387
2.	Exponential	0.0457	1.6279	0.0100	0.9224	1.8387
3.	Gaussian	0.0457	1.6279	0.0100	0.9224	1.8387
4.	Hole Effect	0.0457	1.6279	0.0100	0.9224	1.8387
5.	J-bessel	0.0457	1.6279	0.0100	0.9224	1.8387
6.	K-bessel	0.0457	1.6279	0.0100	0.9224	1.8387
7.	Pentaspherical	0.0457	1.6279	0.0100	0.9224	1.8387
8.	Rational Quad.	0.0457	1.6279	0.0100	0.9224	1.8387
9.	Spherical	0.0457	1.6279	0.0100	0.9224	1.8387
10.	**Stable**	**-0.0050**	**0.2533**	**-0.0203**	**1.0610**	**0.2377**
11.	Tetraspherical	0.0457	1.6280	0.0010	0.9224	1.8387

(f) Turbidity

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.0150	8.2503	0.0017	1.0180	8.1012
2.	**Exponential**	**0.0150**	**8.2503**	**0.0017**	**1.0180**	**8.1012**
3.	Gaussian	0.0150	8.2503	0.0017	1.0180	8.1012
4.	Hole Effect	0.0150	8.2503	0.0017	1.0180	8.1012
5.	J-bessel	0.0150	8.2503	0.0017	1.0180	8.1012
6.	K-bessel	0.0150	8.2503	0.0017	1.0180	8.1012
7.	Pentaspherical	0.0150	8.2503	0.0017	1.0180	8.1012
8.	Rational Quad.	0.0443	8.2958	0.0049	1.0344	8.0288
9.	Spherical	0.01450	8.2503	0.0017	1.0180	8.1012
10.	Stable	0.2017	8.8753	0.0189	1.0846	8.2615
11.	Tetraspherical	0.0150	8.2503	0.0017	1.0180	8.1012

(g) TH

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	-4.0424	93.4594	-0.0557	1.3169	69.1077
2.	Exponential	-3.3684	93.8401	-0.0457	1.3214	69.2017
3.	Gaussian	-3.5928	93.7928	-0.0489	1.3203	69.2204
4.	Hole Effect	-3.8400	93.5750	-0.0525	1.3181	69.1788
5.	J-bessel	-3.2525	93.8442	-0.0435	1.3167	69.5587
6.	K-bessel	-5.4202	93.4847	-0.0753	1.3125	69.3120
7.	**Pentaspherical**	**-6.2902**	**92.3086**	**-0.0860**	**1.2989**	**68.9730**
8.	Rational Quad.	-3.9627	95.7430	-0.0526	1.3531	68.6957
9.	Spherical	-4.3412	93.7769	-0.0594	1.3179	69.3296
10.	Stable	-3.8843	96.8625	-0.0498	1.3663	68.7789
11.	Tetraspherical	-5.4202	93.4847	-0.0753	1.3125	69.3120

(h) TSS

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.3673	9.2047	0.0303	1.2858	7.0954
2.	Exponential	0.3539	9.2028	0.0282	1.2845	7.0991
3.	Gaussian	0.3484	9.1999	0.0274	1.2834	7.1026
4.	**Hole Effect**	**0.3443**	**9.1966**	**0.0269**	**1.2824**	**7.1056**
5.	J-bessel	0.3095	9.1200	0.0227	1.2725	7.0954
6.	K-bessel	0.3714	9.3960	0.0325	1.2965	7.2052
7.	Pentaspherical	0.3515	9.3530	0.0273	1.3003	7.1498
8.	Rational Quad.	0.4557	9.4810	0.0418	1.3175	7.1494
9.	Spherical	0.3633	9.3858	0.0314	1.2943	7.2094
10.	Stable	0.4417	9.4682	0.0403	1.3145	7.1563
11.	Tetraspherical	0.3714	9.3960	0.0325	1.2965	7.2052

(i) BOD

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	-0.0050	0.2533	-0.0203	1.0610	0.2377
2.	Exponential	-0.0053	0.2522	-0.0215	2.0422	0.2414
3.	**Gaussian**	**-0.0042**	**0.2364**	**-0.0171**	**1.1028**	**0.0230**
4.	Hole Effect	-0.0043	0.2564	-0.0175	1.0972	0.216
5.	J-bessel	-0.0043	0.2564	-0.0176	1.0970	0.2316
6.	K-bessel	-0.0043	0.2563	-0.0174	1.0992	0.2310
7.	Pentaspherical	-0.0049	0.2533	-0.0202	1.0573	0.2386
8.	Rational Quad.	-0.0046	0.2537	-0.0188	1.0569	0.2391
9.	Spherical	-0.0050	0.2533	-0.0203	1.0593	0.2381
10.	Stable	-0.0042	0.2564	-0.0171	1.1028	0.2303
11.	Tetraspherical	-0.0050	0.2533	-0.0220	1.0582	0.2384

(j) COD

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.0732	2.2327	-0.01175	1.1489	2.6198
2.	Exponential	0.0961	2.2128	-0.0725	1.0027	2.6696
3.	Gaussian	0.0933	2.2077	-0.1084	1.1302	2.6482
4.	Hole Effect	0.1026	2.2189	-0.1255	1.1499	2.5650
5.	**J-bessel**	**0.0881**	**2.1930**	**-0.1012**	**1.0873**	**2.6314**
6.	K-bessel	0.0867	2.2363	-0.0982	1.0841	2.6481
7.	Pentaspherical	0.0763	2.2395	-0.1211	1.1547	2.6161
8.	Rational Quad.	0.1113	2.2377	-0.0949	1.1061	2.6423
9.	Spherical	0.0783	2.2328	-0.1204	1.1575	2.6219
10.	Stable	0.0827	2.2311	-0.0975	1.0747	2.6492
11.	Tetraspherical	0.0832	2.2325	-0.1177	1.1556	2.6224

(k) Total Coliform

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	-0.4237	11.6294	-0.0363	0.9809	11.8434
2.	Exponential	-0.4304	11.6443	-0.0365	0.9783	11.8898
3.	Gaussian	-0.4357	11.6202	-0.0374	0.9817	11.8230
4.	Hole Effect	-0.4158	11.6166	-0.0359	0.9835	11.7993
5.	**J-bessel**	**-0.4086**	**11.6159**	**-0.0353**	**0.9841**	**11.7922**
6.	K-bessel	-0.4375	11.6212	-0.0375	0.9815	11.8266
7.	Pentaspherical	-0.4292	11.6336	-0.0366	0.9800	11.8578
8.	Rational Quad.	-0.4234	11.6522	-0.0359	0.9787	11.8920
9.	Spherical	-0.4224	11.6327	-0.0361	0.9806	11.8511
10.	Stable	-0.4224	11.6327	-0.0361	0.9806	11.8511
11.	Tetraspherical	-0.4357	11.6202	-0.0374	0.9817	11.8230

(l) Na

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.2131	7.4752	-0.0670	0.7515	12.5146
2.	Exponential	0.2798	7.4774	-0.0620	0.7538	12.6666
3.	Gaussian	0.2376	7.4945	-0.0665	0.7529	12.5602
4.	Hole Effect	-0.1966	7.8322	-0.1949	1.0443	11.5691
5.	J-bessel	-0.4163	8.0473	-0.3321	1.4544	11.0356
6.	K-bessel	0.2779	7.4875	-0.0626	0.7528	12.6563
7.	**Pentaspherical**	**0.1682**	**7.4382**	**-0.0688**	**0.7661**	**12.4683**
8.	Rational Quad.	0.2931	7.4574	-0.0599	0.7568	12.7391
9.	Spherical	0.2012	7.4458	-0.0661	0.7560	12.5111
10.	Stable	0.3192	7.4950	-0.0602	0.7522	12.7523
11.	Tetraspherical	0.1847	7.4386	-0.0671	0.7612	12.490

(m) K

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.0847	0.9445	0.0022	0.6708	1.6011
2.	Exponential	0.0894	0.9457	0.0068	0.6533	1.6299
3.	**Gaussian**	**0.0838**	**0.9440**	**0.0017**	**0.6789**	**1.5816**
4.	Hole Effect	0.0847	0.9442	0.0021	0.6761	1.5895
5.	J-bessel	0.0847	0.9442	0.0021	0.6761	1.5895
6.	K-bessel	0.0838	0.9441	0.0016	0.6782	1.5840
7.	Pentaspherical	0.0863	0.9449	0.0036	0.6651	1.6113
8.	Rational Quad.	0.0896	0.9466	0.0073	0.6497	1.6335
9.	Spherical	0.0852	0.9446	0.0026	0.6690	1.6045
10.	Stable	0.0838	0.9440	0.0017	0.6789	1.5816
11.	Tetraspherical	0.0859	0.9447	0.0031	0.6671	1.6079

(n) Ca

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	-0.4074	17.4963	-0.1887	1,3562	17.7218
2.	Exponential	-0.4908	17.4200	-0.1750	1.3334	17.3673
3.	Gaussian	-0.4518	17.5022	-0.1912	1.3717	17.6402
4.	**Hole Effect**	**-0.4627**	**17.3260**	**-0.1787**	**1.3301**	**17.1726**
5.	J-bessel	-0.3965	17.3564	-0.1748	1.3353	17.3525
6.	K-bessel	-0.4894	17.4707	-0.1895	1.3656	17.5740
7.	Pentaspherical	-0.4644	17.4359	-0.1788	1.3471	17.3849
8.	Rational Quad.	-0.5464	17.3472	-0.1711	1.3027	17.3564
9.	Spherical	-0.4949	17.4746	-0.1901	1.3578	17.6283
10.	Stable	-0.4518	17.5022	-0.1912	1.3717	17.6402
11.	Tetraspherical	-0.3885	17.4673	-0.1759	1.3416	17.6007

(o) Mg

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.0148	0.4087	-0.0696	0.9742	0.5240
2.	Exponential	0.0143	0.3997	-0.0491	0.9480	0.5055
3.	Gaussian	0.0154	0.4073	-0.0649	0.9618	0.5207
4.	Hole Effect	0.0150	0.4026	-0.0635	0.9753	0.5109
5.	J-bessel	0.0159	0.4030	-0.0577	0.9719	0.5090
6.	K-bessel	0.0131	0.4063	-0.0651	0.9601	0.5147
7.	Pentaspherical	0.0093	0.3997	-0.0640	0.9588	0.5074
8.	**Rational Quadratic**	**0.0141**	**0.3966**	**-0.0441**	**0.9361**	**0.5060**
9.	Spherical	0.0156	0.4064	-0.0629	0.9582	0.5233
10.	Stable	0.0154	0.4073	-0.0649	0.9618	0.5207
11.	Tetraspherical	0.0093	0.3997	-0.0640	0.9588	0.5074

(p) SO_4

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.0379	1.1519	-0.08496	0.9387	2.0123
2.	Exponential	0.03108	1.1503	-0.0728	0.8899	2.0391
3.	Gaussian	0.03779	1.1546	-0.0830	0.9204	2.0170
4.	**Hole Effect**	**0.01979**	**1.1214**	**-0.0820**	**0.8952**	**1.8696**
5.	J-bessel	0.01519	1.1236	-0.0836	0.8992	1.8962
6.	K-bessel	0.03188	1.1528	-0.07411	0.8932	2.0301
7.	Pentaspherical	0.0203	1.1413	-0.0842	0.9300	1.9414
8.	Rational Quad.	0.0379	1.1483	-0.0574	0.8523	2.0277
9.	Spherical	0.0412	1.1536	-0.0800	0.9225	2.0187
10.	Stable	0.0309	1.1512	-0.0723	0.8920	2.0255
11.	Tetraspherical	0.0294	1.4418	-0.0754	0.9010	1.9651

(q) NO_3

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.0392	0.8222	-0.0461	0.5950	1.9835
2.	Exponential	0.0883	0.8373	-0.0221	0.5834	2.1404
3.	Gaussian	0.0470	0.8235	-0.0398	0.5885	2.0197
4.	Hole Effect	0.0297	0.8467	-0.0521	0.6118	1.8628
5.	J-bessel	0.0618	0.8399	-0.0324	0.5903	2.0120
6.	K-bessel	0.0512	0.8219	-0.0364	0.5805	2.0284
7.	Pentaspherical	0.0595	0.8314	-0.0309	0.5742	1.0186
8.	Rational Quad.	0.0694	0.8265	-0.0216	0.5668	2.0567
9.	Spherical	0.0439	0.8219	-0.0418	0.5864	1.9943
10.	Stable	0.0487	0.8230	-0.0393	0.5872	2.0169
11.	**Tetraspherical**	**0.0459**	**0.8188**	**-0.0375**	**0.5782**	**1.9975**

(r) Cl

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	-0.4002	28.3062	-0.1363	1.2203	29.4594
2.	Exponential	-0.8110	28.1473	-0.1392	1.2256	28.8040
3.	Gaussian	-0.3863	28.3234	-0.1347	1.2202	29.4481
4.	Hole Effect	-0.3643	27.9316	-0.1168	1.1727	28.9356
5.	J-bessel	-0.5854	28.1918	-0.1369	1.2271	28.8428
6.	K-bessel	-0.4884	28.2747	-0.1358	1.2204	29.2884
7.	Pentaspherical	-0.7963	28.1513	-0.1432	1.2257	28.9193
8.	**Rational Quadratic**	**-0.5567**	**27.8948**	**-0.1162**	**1.1789**	**28.9000**
9.	Spherical	-0.5297	28.2063	-0.1362	1.2149	29.2839
10.	Stable	-0.3863	28.3234	-0.1347	1.2203	29.4481
11.	Tetraspherical	-0.7600	28.1889	-0.1440	1.2269	28.9725

(s) HCO_3

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	-0.4044	-17.5168	-0.0970	1.0194	20.1899
2.	Exponential	-0.3723	17.4662	-0.0908	0.9997	20.3823
3.	**Gaussian**	**-0.4019**	**17.4284**	**-0.1035**	**1.0367**	**20.1584**
4.	Hole Effect	-0.3759	17.6158	-0.1010	1.0297	20.2727
5.	J-bessel	-0.3762	17.6150	-0.1010	1.0297	20.2719
6.	K-bessel	-0.3955	17.6208	-0.1027	1.0347	20.1886
7.	Pentaspherical	-0.3836	17.5073	-0.0947	1.0121	20.2940
8.	Rational Quad.	-0.3326	175481	-0.0909	0.9966	20.6029
9.	Spherical	-0.3972	17.5129	-0.0962	1.0171	20.2242
10.	Stable	-0.4019	17.6284	-0.1035	1.0367	20.1584
11.	Tetraspherical	-0.3903	17.5097	-0.0954	1.0954	20.2591

(t) NH_4

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	-0.0003	0.0155	-0.0096	1.1401	0.0131
2.	Exponential	-0.0035	0.0154	-0.0155	1.0445	0.0141
3.	Gaussian	-0.0003	0.0159	0.0096	1.5274	0.0121
4.	Hole Effect	-0.0004	0.0165	0.2263	3.6250	0.0106
5.	J-bessel	-0.0004	0.0166	0.2439	3.8076	0.0105
6.	K-bessel	-0.0003	0.0159	0.0006	1.4501	0.0122
7.	**Pentaspherical**	**-0.0005**	**0.0153**	**-0.0208**	**1.0792**	**0.0135**
8.	Rational Quad.	-0.0004	0.0153	-0.0162	1.0364	0.0140
9.	Spherical	-0.0004	0.0155	-0.0169	1.1138	0.0133
10.	Stable	-0.0003	0.0159	0.0096	1.5274	0.0121
11.	Tetraspherical	-0.0005	0.0155	-0.0214	1.1118	0.0133

(u) PO_4

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.0021	0.1930	0.0218	1.2133	0.1550
2.	Exponential	0.0017	0.1909	0.0173	1.1870	0.1575
3.	Gaussian	0.0004	0.1932	0.0124	1.2168	0.1540
4.	Hole Effect	0.0050	0.1941	0.0369	1.2463	0.1513
5.	J-bessel	0.0037	0.1922	0.0294	1.2280	0.1525
6.	K-bessel	0.0012	0.1935	0.0184	1.2200	0.1541
7.	Pentaspherical	0.0022	0.1919	0.0209	1.2060	0.1553
8.	**Rational Quad.**	**0.0016**	**0.1890**	**0.0155**	**1.1623**	**0.1594**
9.	Spherical	0.0021	0.1930	0.0218	1.2133	0.1550
10.	Stable	0.0004	0.1932	0.0124	1.2168	0.1540
11.	Tetraspherical	0.0019	0.1924	0.0198	1.2081	0.1553

(v) Fe

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	-0.0002	0.0099	-0.0318	1.2339	0.0079
2.	Exponential	0.00001	0.0100	-0.0041	1.2307	0.0081
3.	Gaussian	-0.0001	0.0100	-0.0224	1.2377	0.0079
4.	Hole Effect	-0.0006	0.0099	-0.0694	1.1804	0.0082
5.	J-bessel	0.00008	0.0099	-0.0158	1.2141	0.0080
6.	K-bessel	-0.00006	0.0100	-0.0178	1.2296	0.0080
7.	Pentaspherical	-0.00020	0.0099	-0.03128	1.2171	0.0080
8.	Rational Quad.	-0.00005	0.0100	-0.01314	1.2016	0.0081
9.	Spherical	-0.00018	0.0100	-0.2831	1.2282	0.0080
10.	**Stable**	**-0.00011**	**0.0099**	**-0.2242**	**1.2377**	**0.0079**
11.	Tetraspherical	-0.00019	0.0099	-0.03002	1.2210	0.0080

(w) Cd

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	-0.00014	0.0023	-0.0615	0.9985	0.0023
2.	**Exponential**	**-0.00014**	**0.0023**	**-0.0615**	**0.9985**	**0.0023**
3.	Gaussian	-0.00014	0.0023	-0.0615	0.9985	0.0023
4.	Hole Effect	-0.00014	0.0023	-0.0615	0.9985	0.0023
5.	J-bessel	-0.00035	0.0029	-0.0165	1.0217	0.0024
6.	K-bessel	-0.00014	0.0023	-0.0615	0.9985	0.0023
7.	Pentaspherical	-0.00014	0.0023	-0.0615	0.9985	0.0023
8.	Rational Quad.	-0.00014	0.0023	-0.0615	0.9985	0.0023
9.	Spherical	-0.00014	0.0023	-0.0615	0.9985	0.0023
10.	Stable	0.00014	0.0023	-0.0615	0.9985	0.0023
11.	Tetraspherical	-0.00014	0.0023	-0.0615	0.9985	0.0023

(x) Cr

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	-0.00007	0.0016	-0.0394	0.9908	0.0016
2.	Exponential	-0.00006	0.0016	-0.0337	0.9911	0.0016
3.	Gaussian	-0.00003	0.0016	-0.0188	0.9856	0.0016
4.	Hole Effect	-0.00002	0.0016	-0.0219	0.9905	0.0016
5.	**J-bessel**	**-0.00006**	**0.0016**	**-0.0330**	**0.9945**	**0.0016**
6.	K-bessel	-0.00003	0.0016	-0.0194	0.9903	0.0016
7.	Pentaspherical	-0.00004	0.0016	-0.0256	0.9916	0.0016
8.	Rational Quad.	-0.00005	0.0016	-0.0274	0.9925	0.0016
9.	Spherical	-0.00003	0.0016	-0.0166	0.9812	0.0016
10.	Stable	-0.00003	0.0016	-0.0188	0.9856	0.0016
11.	Tetraspherical	-0.00004	0.0016	-0.0200	0.9908	0.0016

(y) Cu

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	-0.0081	0.2601	-0.0312	1.1221	0.2277
2.	Exponential	-0.0096	0.2625	-0.0371	1.1188	0.2307
3.	Gaussian	-0.0061	0.2559	-0.0232	1.1142	0.2256
4.	Hole Effect	-0.0059	0.2565	-0.0220	1.1147	0.2259
5.	J-bessel	-0.0059	0.2565	-0.0221	1.1146	0.2259
6.	K-bessel	-0.0061	0.2561	-0.0231	1.1144	0.2257
7.	Pentaspherical	-0.0082	0.2608	-0.0318	1.1217	0.2284
8.	**Rational Quad.**	**-0.0082**	**0.2600**	**-0.0314**	**1.1142**	**0.2289**
9.	Spherical	-0.0081	0.2603	-0.0314	1.1219	0.2279
10.	Stable	-0.0061	0.2559	-0.0232	1.1142	0.2256
11.	Tetraspherical	-0.0082	0.2605	-0.0316	1.1218	0.2281

(z) Pb

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	-0.0007	0.0226	-0.0286	0.9859	0.0230
2.	Exponential	-0.0007	0.0226	-0.0309	0.9806	0.0231
3.	Gaussian	-0.0006	0.0226	-0.0272	0.9894	0.0229
4.	Hole Effect	-0.0006	0.0226	-0.0265	0.9883	0.0229
5.	J-bessel	-0.0006	0.0226	-0.0265	0.9883	0.0229
6.	K-bessel	-0.0006	0.0226	-0.0269	0.9890	0.0229
7.	Pentaspherical	-0.0007	0.0226	-0.0289	0.9841	0.0230
8.	**Rational Quad.**	**-0.0007**	**0.0225**	**-0.0297**	**0.9787**	**0.0231**
9.	Spherical	-0.0007	0.0226	-0.0287	0.9853	0.0230
10.	Stable	-0.0006	0.0226	-0.0272	0.9894	0.0290
11.	Tetraspherical	-0.0007	0.0226	-0.0288	0.9847	0.0230

APPENDIX VIII(B): Wet Season

(a) Temperature

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.1686	2.2179	0.0602	0.9304	2.3957
2.	Exponential	0.1545	2.2274	0.0572	0.9333	2.3952
3.	Gaussian	0.1569	2.2020	0.0558	0.9261	2.3890
4.	Hole Effect	0.1901	2.2089	0.0692	0.9278	2.3835
5.	J-bessel	0.1749	2.2108	0.0623	0.9298	2.3815
6.	**K-bessel**	**0.1555**	**2.2001**	**0.0554**	**0.9254**	**2.3891**
7.	Pentaspherical	0.1636	2.2124	0.0581	0,9291	2.3916
8.	Rational Quad.	0.1556	2.2137	0.0555	0.9305	20.9307
9.	Spherical	0.1578	2.2262	0.0562	0.9336	2.3927
10.	Stable	0.1569	2.2020	0.9260	0.9261	2.3890
11.	Tetraspherical	0.1716	2.2232	0.0615	0.9332	2.3920

pH

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	**Circular**	**-0.0019**	**0.6072**	**-0.0247**	**0.9984**	**0.6060**
2.	Exponential	0.0035	0.6094	-0.0184	0.9926	0.6139
3.	Gaussian	-0.0005	0.6077	-0.0226	0.9952	0.6092
4.	Hole Effect	-0.0038	0.6166	-0.0313	1.0142	0.6055
5.	J-bessel	-0.0054	0.6217	-0.0347	1’0265	0.6040
6.	K-bessel	0.0003	0.6079	-0.0219	0.9950	0.6098
7.	Pentaspherical	0.0029	0.6107	-0.0192	1.0014	0.6094
8.	Rational Quad.	0.0073	0.6098	-0.0106	0.9910	0.6147
9.	Spherical	-0.0017	0.6083	-0.0258	0.9990	0.6074
10.	Stable	-0.0005	0.6077	0.0226	0.9952	0.6092
11.	Tetraspherical	0.0009	0.6102	-0.0219	1.0010	0.6087

(c) EC

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	-0.3918	156.4529	-0.1064	1.0935	184.6121
2.	Exponential	-0.2368	156.1542	-0.0971	1.0829	184.8150
3.	Gaussian	-0.4932	156.5790	-0.1063	1.0912	184.6146
4.	Hole Effect	-1.7516	156.4659	-.01124	1.0934	179.2272
5.	J-bessel	-2.3261	154.6706	-0.1090	1.0828	179.9801
6.	K-bessel	-0.6207	156.1911	-0.1008	1,0902	184.6599
7.	Pentaspherical	-2.4272	155.5574	-0.1115	1.0991	180.8953
8.	**Rational Quadratic**	**-1.3902**	**154.1596**	**-0.0873**	**1.0567**	**179.7992**
9.	Spherical	-0.0030	156.2661	-0.1011	1.0859	184.8205
10.	Stable	-0.4932	156.5790	-0.1063	1.0912	184.6146
11.	Tetraspherical	-1.6645	155.6828	-0.1051	1.0817	181.9568

(d) TDS

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	-0.2263	87.7030	-0.1081	1.1012	103.0358
2.	Exponential	-0.3119	87.4003	-0.1005	1.0900	103.0847
3.	Gaussian	-0.3665	87.6706	-0.1080	1.0945	103,0727
4.	Hole Effect	-1.2748	87.3672	-0.1139	1.0954	99.7819
5.	**J-bessel**	**-1.3382**	**86.6640**	**-0.1104**	**1.0874**	**100.4506**
6.	K-bessel	-0.6321	87.5479	-0.1048	1.0969	102.9054
7.	Pentaspherical	-1.3032	87 1979	-0.1122	1.1042	101.0068
8.	Rational Quad.	-0.5268	86.4948	-0.0863	1.1634	100.2612
9.	Spherical	-0.0851	87.5031	-0.1025	1.0900	103.1238
10.	Stable	-0.3665	87.6706	-0.1080	1.0947	103.0727
11.	Tetraspherical	-0.9773	87.2134	-0.1064	1.0861	101.5455

(e) DO

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.0443	2.3543	0.0102	0.9515	2.55121
2.	**Exponential**	**0.0443**	**2.3543**	**0.0102**	**0.9515**	**2.5121**
3.	Gaussian	0.0443	2.3543	0.0102	0.9515	2.5121
4.	Hole Effect	0.0436	2.3543	0.0010	0.9925	2.5096
5.	J-bessel	0.0974	2.3789	-0.0039	0.9129	2.7026
6.	K-bessel	0.0443	2.3543	0.0102	0.9515	2.5121
7.	Pentaspherical	0.0443	2.3543	0,0102	0.9515	2.5121
8.	Rational Quad.	0.0443	2.3543	0.0102	0.9515	2.5121
9.	Spherical	0.0443	2.3543	0.0102	0.9515	2.5121
10.	Stable	0.0443	2.3543	0.0102	0.9515	2.5121
11.	Tetraspherical	0.0443	2.3543	0.0102	0.9515	2.5121

(f) Turbidity

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.0872	8.0085	0.0110	1.0287	7.7823
2.	**Exponential**	**0.0872**	**8.0085**	**0.0110**	**1.0287**	**7.7823**
3.	Gaussian	0.0872	8.0085	0.0110	1.0287	7.7823
4.	Hole Effect	-0.0086	8.6511	-0.0049	1.0768	8.0705
5.	J-bessel	0.0106	8.5963	-0.0027	1.0724	8.0633
6.	K-bessel	0.0872	8.0085	0.0110	1.0287	7.7823
7.	Pentaspherical	0.0872	8.0085	0.0110	1.0287	7.7823
8.	Rational Quad.	0.0872	8.0085	0.0110	1.0287	7.7823
9.	Spherical	0.0872	8.0085	0.0110	1.0287	7.7823
10.	Stable	0.0872	8.0085	0.0110	1.0287	7.7823
11.	Tetraspherical	0.0872	8.0085	0.0110	1.0287	7.7823

(g) TH

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	-12.0054	88.9641	-0.3288	1.9253	91.9364
2.	**Exponential**	**-11.9674**	**87.0415**	**-0.2965**	**1.8001**	**91.5424**
3.	Gaussian	-11.7808	93.0859	-0.3353	1.9509	92.5939
4.	Hole Effect	-11.4568	93.1220	-0.3364	1.9583	95.8457
5.	J-bessel	-11.4498	93.1633	-0.3364	1.9585	95.8857
6.	K-bessel	-11.6938	92.9298	-0.3355	1.9535	93.6425
7.	Pentaspherical	-11.8508	88.4895	-0.3205	1.8950	92.9899
8.	Rational Quad.	-11.3380	87.0699	-0.3061	1.8603	96.5743
9.	Spherical	-11.9483	88.8053	-0.3259	1.9146	92.3323
10.	Stable	-11.7808	93.0859	-0.3353	1.9509	92.5939
11.	Tetraspherical	-11.8970	88.6469	-0.3231	1.9045	92.6821

(h) TSS

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.1403	11.4930	0.0110	1.3545	8.4027
2.	**Exponential**	**0.1338**	**11.5189**	**0.0088**	**1.3359**	**8.5318**
3.	Gaussian	0.0335	11.4803	0.0009	1.3640	8.3325
4.	Hole Effect	0.0166	11.5733	-0.0009	1.3848	8.2745
5.	J-bessel	0.0192	11.5616	-0.0004	1.3839	8.2730
6.	K-bessel	0.0162	11.4857	-0.0010	1.3611	8.3494
7.	Pentaspherical	0.1088	11.4968	0.0071	1.3422	8.4749
8.	Rational Quad.	0.1123	11.6959	0.0058	1.3772	8.3955
9.	Spherical	0.1070	11.5148	0.0070	1.3495	8.4429
10.	Stable	0.0335	11.4803	0.0009	1.3640	8.3325
11.	Tetraspherical	0.1100	11.5015	0.0072	1.3441	8.4666

(i) BOD

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.0317	0.8664	0.0342	0.9794	0.8858
2.	Exponential	0.0317	0.8664	0.0342	0.9794	0.8858
3.	Gaussian	0.0317	0.8664	0.0342	0.9794	0.8858
4.	**Hole Effect**	**0.0309**	**0.8496**	**0.0325**	**0.9509**	**0.8998**
5.	J-bessel	0.0293	0.8556	0.0321	0.9633	0.8960
6.	K-bessel	0.0317	0.8664	0.0342	0.9794	0.8858
7.	Pentaspherical	0.0317	0.8664	0.0342	0.9794	0.8858
8.	Rational Quad.	0.0317	0.8664	0.0342	0.9794	0.8858
9.	Spherical	0.0317	0.8664	0.0342	0.9794	0.8858
10.	Stable	0.0317	0.8664	0.0342	0.9794	0.8858
11.	Tetraspherical	0.0317	0.8664	0.0342	0.9794	0.8858

(j) COD

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.3817	2.6613	-0.1032	1.0274	5.3649
2.	Exponential	0.3836	2.5920	-0.0939	1.0372	5.1698
3.	Gaussian	0.3963	2.6689	-0.1078	1.0660	5.3922
4.	Hole Effect	0.4370	2.7656	-0.0851	0.9380	5.4204
5.	J-bessel	0.3979	2.7118	-0.1080	1.0508	5.2160
6.	**K-bessel**	**0.3784**	**2.5905**	**-0.0922**	**1.0408**	**5.1680**
7.	Pentaspherical	0.3757	2.6325	-0.1033	1.0473	5.2381
8.	Rational Quad.	0.3758	2.6142	-0.1113	1.0937	5.1373
9.	Spherical	0.3899	2.6491	-0.1010	1.0487	5.3025
10.	Stable	0.3750	2.5957	-0.0974	1.0443	5.1574
11.	Tetraspherical	0.3749	2.6410	-0.1004	1.0423	5.2499

(k) Total Coliform

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	-0.2864	10.7944	-0.0280	0.9739	11.1001
2.	Exponential	-0.2792	10.8253	-0.0271	0.9732	11.1400
3.	**Gaussian**	**-0.3033**	**10.7804**	**-0.0295**	**0.9721**	**11.1009**
4.	Hole Effect	-0.2623	10.7811	-0.0260	0.9757	11.0644
5.	J-bessel	-0.2510	10.7817	-0.0251	0.9766	11.0556
6.	K-bessel	-0.3067	10.7816	-0.0298	0.9718	11.1057
7.	Pentaspherical	-0.2854	10.8035	-0.0278	0.9733	11.1151
8.	Rational Quad.	-0.2517	10.8409	-0.0246	0.9741	11.1437
9.	Spherical	-0.2835	10.8005	-0.0277	0.9737	11.1078
10.	Stable	-0.3033	10.7804	-0.0295	0.9721	11.1009
11.	Tetraspherical	-0.2841	10.8026	-0.0277	0.9735	11.1119

(l) Na

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.3608	8.2017	-0.0560	0.7256	14.3010
2.	Exponential	0.4351	8.2018	-0.0510	0.7281	14.4708
3.	Gaussian	0.3884	8.2211	-0.0553	0.7268	14.3512
4.	Hole Effect	-0.1037	8.5880	-0.1870	1.0307	13.2041
5.	J-bessel	-0.3291	8.9561	-0.3413	1.4906	12.5571
6.	K-bessel	0.4334	8.2016	-0.0511	0.7281	14.4668
7.	**Pentaspherical**	**0.3113**	**8.1414**	**-0.0577**	**0.7449**	**14.2406**
8.	Rational Quad.	0.4505	8.1776	-0.0490	0.7318	14.5498
9.	Spherical	0.3477	8.1545	-0.0548	0.7324	14.2913
10.	Stable	0.4766	8.2177	-0.0493	0.7271	14.5680
11.	Tetraspherical	0.3294	8.1421	-0.0558	0.7390	14.2658

(m) K

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.1385	1.2901	0.0102	0.6601	2.2883
2.	Exponential	0.1444	1.2908	0.0150	0.6428	2.3175
3.	**Gaussian**	**0.1351**	**1.2892**	**0.0076**	**0.6714**	**2.2635**
4.	Hole Effect	0.0771	1.3409	-0.0810	0.7776	2.6102
5.	J-bessel	0.0583	1.3905	-0.1138	0.8117	2.6165
6.	K-bessel	0.1356	1.2893	0.0079	0.6700	2.2671
7.	Pentaspherical	0.1411	1.2904	0.0123	0.6526	2.3015
8.	Rational Quad.	0.1444	1.2908	0.0150	0.6428	2.3175
9.	Spherical	0.1394	1.2902	0.0109	0.6576	2.2928
10.	Stable	0.1351	1.2892	0.0076	0.6714	2.2635
11.	Tetraspherical	0.1402	1.2903	0.0116	0.6551	2.2971

(n) Ca

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	-0.5536	21.1111	-0.1783	1.3006	21.6374
2.	Exponential	-0.6581	20.9950	-0.1644	1.2832	21.2953
3.	Gaussian	-0.5912	21.1356	-0.1805	1.3132	21.5316
4.	Hole Effect	-0.5917	20.8289	-0.1654	1.2891	20.8537
5.	**J-bessel**	**-0.6072**	**20.8012**	**-0.1654**	**1.2863**	**20.7485**
6.	K-bessel	-0.6082	21.1457	-0.1824	1.3215	21.5136
7.	Pentaspherical	-0.6628	21.0070	-0.1724	1.3027	21.2687
8.	Rational Quad.	-0.7585	20.8585	-0.1615	1.2686	20.9866
9.	Spherical	-0.6320	21.0971	-0.1801	1.3074	21.5104
10.	Stable	-0.5912	21.1356	-0.1805	1.3132	21.5
11.	Tetraspherical	-0.6839	21.0382	-0.1767	1.2993	21.3937

(o) Mg

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.0293	0.4708	-0.0354	0.8301	0.7110
2.	Exponential	0.0212	0.4667	-0.0476	0.8274	0.7125
3.	Gaussian	0.0294	0.4708	-0.0347	0.8244	0.7120
4.	**Hole Effect**	**0.0206**	**0.4615**	**-0.0363**	**0.8317**	**0.6833**
5.	J-bessel	0.0201	0.4623	-0.0391	0.8305	0.6792
6.	K-bessel	0.0278	0.4695	-0.0353	0.8219	0.7101
7.	Pentaspherical	0.0313	0.4666	-0.0224	0.8193	0.7068
8.	Rational Quad.	0.0245	0.4676	-0.0456	0.8247	0.7153
9.	Spherical	0.0281	0.4674	-0.0316	0.8245	0.7070
10.	Stable	0.0294	0.4708	-0.0347	0.8244	0.7120
11.	Tetraspherical	0.0269	0.4684	-0.0338	0.8357	0.7044

(p) SO_4

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.0312	1.5719	-0.1134	1.0240	2.6664
2.	Exponential	0.0284	1.5691	-0.1022	1.0007	2.6623
3.	Gaussian	0.0194	1.5653	-0.1126	1.0136	2.5920
4.	Hole Effect	0.0246	1.5467	-0.1020	0.9888	2.4825
5.	J-bessel	0.0200	1.5496	-0.1064	0.9989	2.4576
6.	K-bessel	0.0311	1.5734	-0.1015	0.9973	2.6830
7.	Pentaspherical	-0.0006	1.5455	-0.1122	1.0115	2.5262
8.	**Rational Quad.**	**0.0218**	**1.5391**	**-0.0821**	**0.9528**	**2.5195**
9.	Spherical	0.0146	1.5624	-0.1169	1.0280	2.5856
10.	Stable	0.0041	1.5541	-0.1062	1.0176	2.5665
11.	Tetraspherical	0.0072	1.5583	-0.1194	1.0440	2.5596

(q) NO_3

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.1595	1.1936	-0.0613	0.7507	3.3437
2.	Exponential	0.1772	1.1978	-0.0535	0.7605	3.3588
3.	Gaussian	0.1590	1.1656	-0.0576	0.7569	3.2889
4.	Hole Effect	0.1828	1.2337	-0.1329	0.9492	3.4380
5.	J-bessel	0.1587	1.2267	-0.1530	0.9797	3.4387
6.	**K-bessel**	**0.1633**	**1.1650**	**-0.0525**	**0.7507**	**3.2942**
7.	Pentaspherical	0.1736	1.2113	-0.0737	0.8045	3.3259
8.	Rational Quad.	0.1820	1.1924	-0.0498	0.7602	3.3243
9.	Spherical	0.1637	1.1919	-0.0578	0.7473	3.3420
10.	Stable	0.1633	1.1664	-0.0529	0.7496	3.2992
11.	Tetraspherical	0.1729	1.2010	-0.0506	0.7388	3.3268

(r) Cl

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	-0.2069	31.8947	-0.1107	1.1468	34.9951
2.	Exponential	-0.2763	31.7183	-0.0977	1.1360	34.2267
3.	Gaussian	-0.1698	31.9148	-0.1088	1.1492	34.9651
4.	**Hole Effect**	**-0.2060**	**31.6487**	**-0.0969**	**1.1155**	**34.1584**
5.	J-bessel	-0.4444	31.8108	-0.1136	1.1553	34.1970
6.	K-bessel	-0.3835	31.8944	-0.1133	1.1508	34.6221
7.	Pentaspherical	-0.6873	31.7860	-0.1204	1.1592	34.2824
8.	Rational Quad.	-0.3270	31.5675	-0.0933	1.1189	34.1794
9.	Spherical	-0.4169	31.8348	-0.1128	1.1432	34.6435
10.	Stable	-0.1698	31.9148	-0.1088	1.1492	34.9651
11.	Tetraspherical	-0.5439	31.8332	-0.1179	1.1587	34.4513

(s) HCO_3

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.5893	20.0119	-0.0725	0.9055	30.0769
2.	Exponential	-0.0417	19.9946	-0.0900	0.8850	29.9977
3.	Gaussian	0.4329	20.0319	-0.0844	0.9439	29.6730
4.	Hole Effect	-1.0092	19.8047	-0.1164	0.9615	28.4840
5.	**J-bessel**	**-1.0802**	**19.7986**	**-0.1186**	**0.9660**	**28.3452**
6.	K-bessel	-0.0456	19.9824	-0.0899	0.8871	29.9703
7.	Pentaspherical	-0.3100	19.9182	-0.0926	0.8841	29.6671
8.	Rational Quad.	-0.0100	19.8239	-0.0793	0.8811	30.0295
9.	Spherical	0.3661	19.9552	-0.0821	0.9331	29.5040
10.	Stable	0.4462	19.9510	-0.0712	0.9000	30.2506
11.	Tetraspherical	-0.2907	19.9223	-0.0932	0.8868	29.6739

(t) NH_4

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	-0.0003	0.0171	-0.0118	1.1133	0.0152
2.	Exponential	-0.0001	0.0171	-0.0043	1.0922	0.0156
3.	Gaussian	-0.0003	0.0169	-0.0095	1.1041	0.0151
4.	Hole Effect	-0.0006	0.0167	-0.0275	1.0691	0.0153
5.	**J-bessel**	**-0.0007**	**0.0165**	**-0.0390**	**1.0800**	**0.0149**
6.	K-bessel	-0.0002	0.0168	-0.0069	1.0847	0.0152
7.	Pentaspherical	-0.0003	0.0169	-0.0164	1.0795	0.0154
8.	Rational Quad.	-0.0002	0.0168	-0.0081	1.0736	0.0154
9.	Spherical	-0.0002	0.0169	-0.0109	1.0814	0.0154
10.	Stable	-0.0002	0.0169	-0.0075	1.0898	0.0152
11.	Tetraspherical	-0.0003	0.0169	-0.0128	1.0781	0.0154

(u) PO_4

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	-0.005	0.2644	-0.1846	1.33118	0.2931
2.	Exponential	-0.0038	0.2635	-0.1547	1.2093	0.2948
3.	Gaussian	-0.0051	0.2635	-0.1855	1.3209	0.2916
4.	Hole Effect	-0.0004	0.2655	-0.1810	1.3251	0.2946
5.	J-bessel	-0.0007	0.2651	-0.1790	1.3187	0.2941
6.	K-bessel	-0.0048	0.2628	-0.1793	1.3119	0.2909
7.	Pentaspherical	-0.0033	0.2640	-0.1648	1.2585	0.2933
8.	**Rational Quadratic**	**-0.0042**	**0.2618**	**-0.1421**	**1.1544**	**0.2967**
9.	Spherical	-0.0032	0.2646	-0.1748	1.2953	0.2948
10.	Stable	-0.0051	0.2635	-0.1855	1.3209	0.2916
11.	Tetraspherical	-0.0037	0.2633	-0.1624	1.2504	0.2925

(v) Fe

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	0.0015	0.0145	0.0904	1.4028	0.0105
2.	**Exponential**	**0.0003**	**0.0136**	**0.0122**	**1.2054**	**0.0111**
3.	Gaussian	0.0015	0.0144	0.0880	1.3773	0.0105
4.	Hole Effect	0.0008	0.0149	0.0450	1.4418	0.0105
5.	J-bessel	0.0008	0.0139	0.0337	1.3508	0.0105
6.	K-bessel	0.0011	0.0141	0.0588	1.3416	0.0106
7.	Pentaspherical	0.0008	0.0138	0.0350	1.3105	0.0107
8.	Rational Quad.	0.0004	0.0137	0.0167	1.2799	0.0107
9.	Spherical	0.0012	0.0142	0.0637	1.3563	0.0106
10.	Stable	0.0011	0.0141	0.0596	1.3385	0.0106
11.	Tetraspherical	0.0010	0.0141	0.0515	1.3365	0.0106

(w) Cd

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	**Circular**	**-0.0001**	**0.0023**	**-0.0621**	**0.9934**	**0.0023**
2.	Exponential	-0.0001	0.0026	-0.0621	0.9934	0.0023
3.	Gaussian	-0.0001	0.0026	-0.0621	0.9934	0.0023
4.	Hole Effect	-0.0001	0.0026	-0.0621	0.9934	0.0023
5.	J-bessel	-0.0000	0.0023	-0.0172	1.0213	0.0023
6.	K-bessel	-0.0001	0.0023	-0.0621	0.9933	0.0023
7.	Pentaspherical	-0.0001	0.0023	-0.0621	0.9934	0.0023
8.	Rational Quad.	-0.0001	0.0023	-0.0621	0.9934	0.0023
9.	Spherical	-0.0001	0.0023	-0.0621	0.9934	0.0023
10.	Stable	-0.0001	0.0023	-0.0621	0.9934	0.0023
11.	Tetraspherical	-0.0001	0.0023	-0.0621	0.9934	0.0023

(x) Cr

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	-0.0001	0.0016	-0.0369	0.9881	0.0016
2.	**Exponential**	**-0.0001**	**0.0016**	**-0.0312**	**0.9871**	**0.0016**
3.	Gaussian	-0.0000	0.0016	-0.0166	0.9817	0.0016
4.	Hole Effect	-0.0000	0.0016	-0.0269	0.9914	0.0016
5.	J-bessel	-0.0001	0.0016	-0.0301	0.9919	0.0016
6.	K-bessel	-0.0000	0.0016	-0.0181	0.9862	0.0016
7.	Pentaspherical	-0.0000	0.0016	-0.0228	0.9877	0.0016
8.	Rational Quad.	-0.0001	0.0016	-0.0321	0.9870	0.0016
9.	Spherical	-0.0000	0.0016	-0.0171	0.9807	0.0016
10.	Stable	-0.0000	0.0016	-0.0166	0.9817	0.0016
11.	Tetraspherical	-0.0000	0.0016	-0.0188	0.9867	0.0016

(y) Cu

S/N	Model Type	ME	RMSE	MSE	RMSSE	ASE
1.	Circular	-0.0082	0.2596	-0.0317	1.1196	0.2277
2.	Exponential	-0.0097	0.2621	-0.0375	1.1169	0.2307
3.	**Gaussian**	**-0.0063**	**0.2551**	**-0.0238**	**1.1105**	**0.2256**
4.	Hole Effect	-0.0060	0.2557	-0.0225	1.1111	0.2259
5.	J-bessel	-0.0060	0.2558	-0.0226	1.1110	0.2259
6.	K-bessel	-0.0063	0.2554	-0.0236	1.1107	0.2257
7.	Pentaspherical	-0.0083	0.2603	-0.0322	1.1194	0.2283
8.	Rational Quad.	-0.0081	0.2596	-0.0312	1.1123	0.2289
9.	Spherical	-0.0082	0.2598	-0.0318	1.1195	0.2279
10.	Stable	-0.0063	0.2551	-0.0238	1.1105	0.2256
11.	Tetraspherical	-0.0083	0.2600	-0.0319	1.1194	0.2281

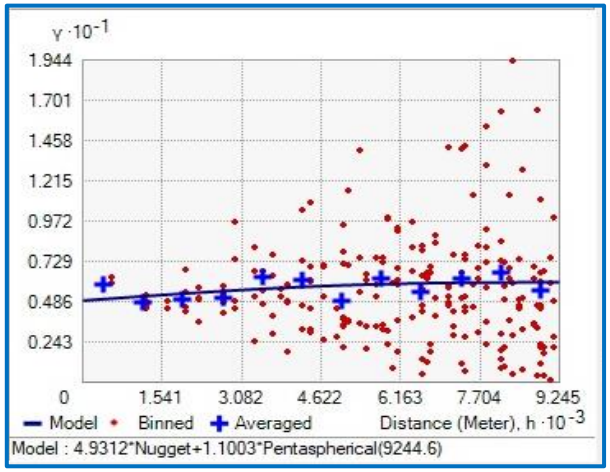
(z) Pb

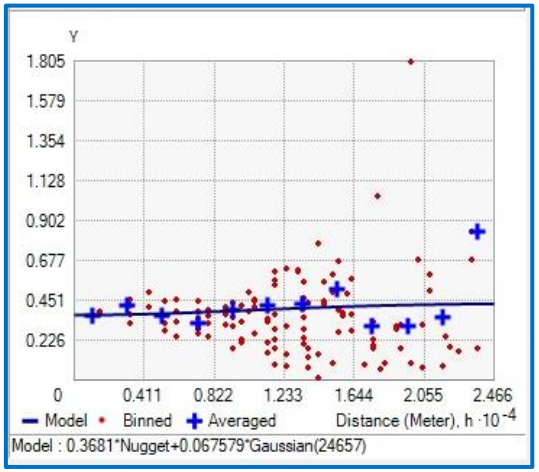
S/N	Model Type	ME	(RMSE)	(MSE)	(RMSSE)	(ASE)
1.	Circular	-0.0007	0.0225	-0.0297	0.9814	0.0230
2.	Exponential	-0.0007	0.0225	-0.0320	0.9762	0.0231
3.	Gaussian	-0.0007	0.0225	-0.0283	0.9846	0.0229
4.	Hole Effect	-0.0006	0.0225	-0.0276	0.9836	0.0229
5.	J-bessel	-0.0006	0.0225	-0.0276	0.9836	0.0229
6.	K-bessel	-0.0007	0.0225	-0.0279	0.9843	0.0229
7.	Pentaspherical	-0.0007	0.0225	-0.0299	0.9796	0.0229
8.	**Rational Quadratic**	**-0.0007**	**0.0224**	**-0.0308**	**0.9743**	**0.0231**
9.	Spherical	-0.0007	0.0225	-0.0297	0.9808	0.0229
10.	Stable	-0.0007	0.0225	-0.0283	0.9846	0.0229
11.	Tetraspherical	-0.0007	0.0225	-0.0298	0.9802	0.0229

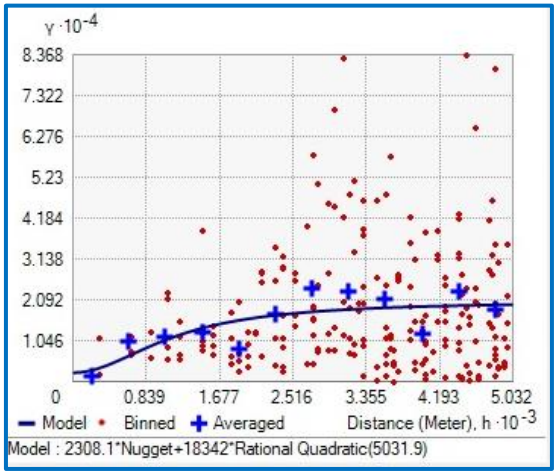
APPENDIX IX

BEST FITTED VARIOGRAM MODELS FOR WATER QUALITY PARAMETERS

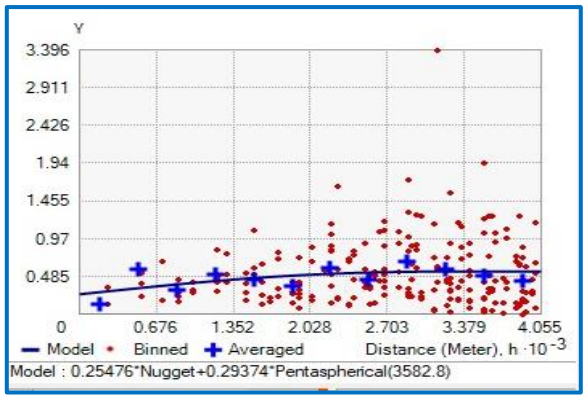
APPENDIX IX(A): Dry Season

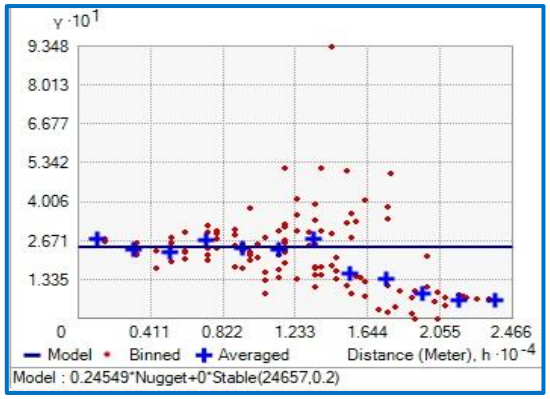


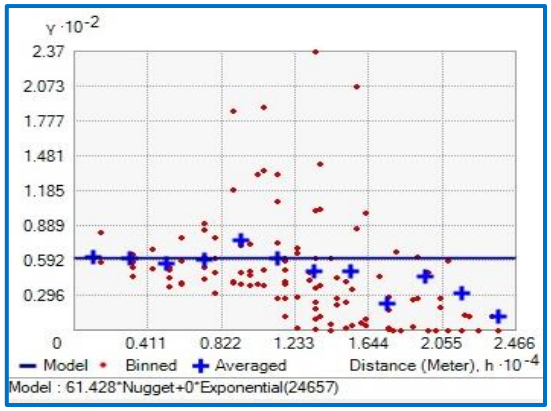




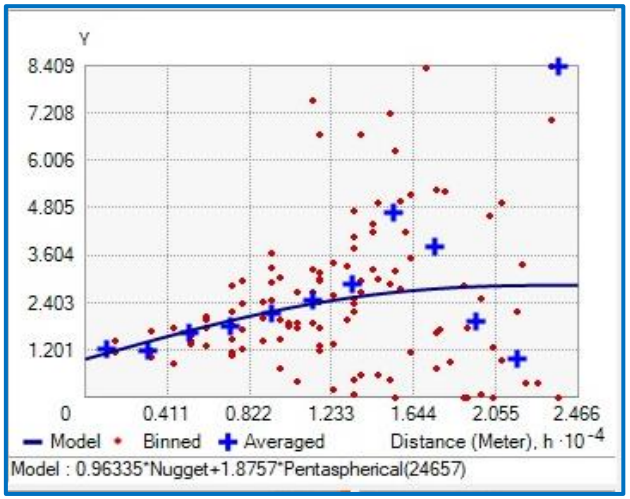
Temperature: Pentaspherical Semivariogram Model pH: Gaussian Semivariogram Model EC: Rational Quadratic Semivariogram Model



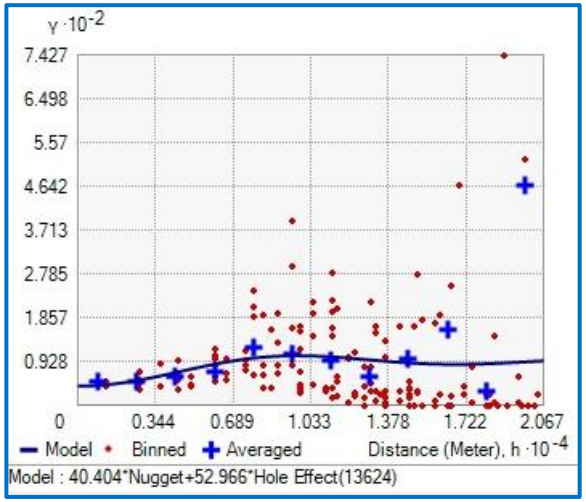




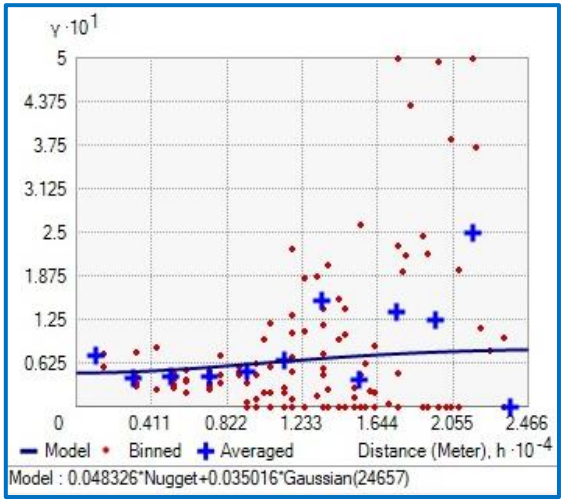
TDS: Pentaspherical Semivariogram Model DO: Stable Semivariogram Model Turbidity: Exponential Semivariogram Model



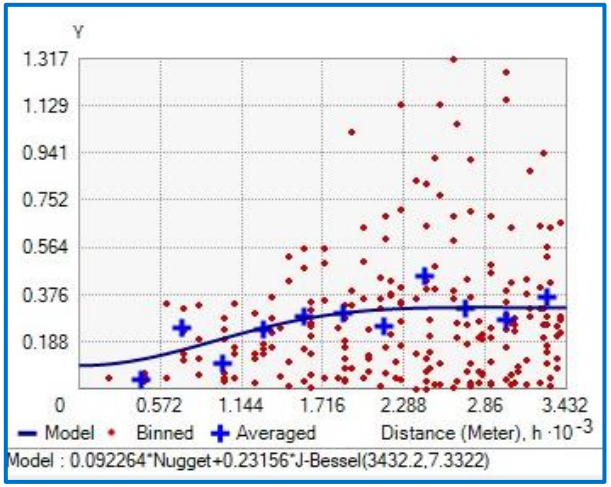
TH: Pentaspherical Semivariogram Model



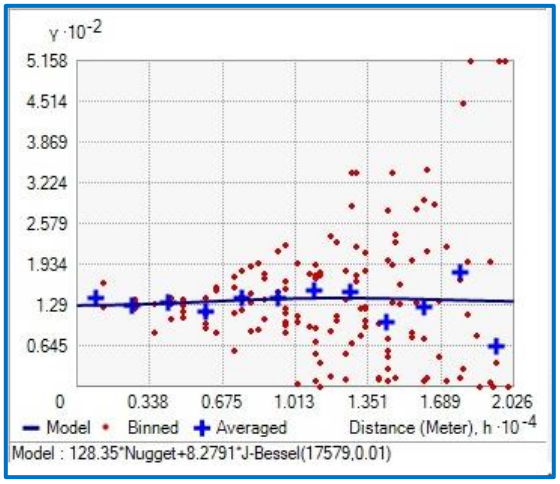
TSS: Hole Effect Semivariogram Model



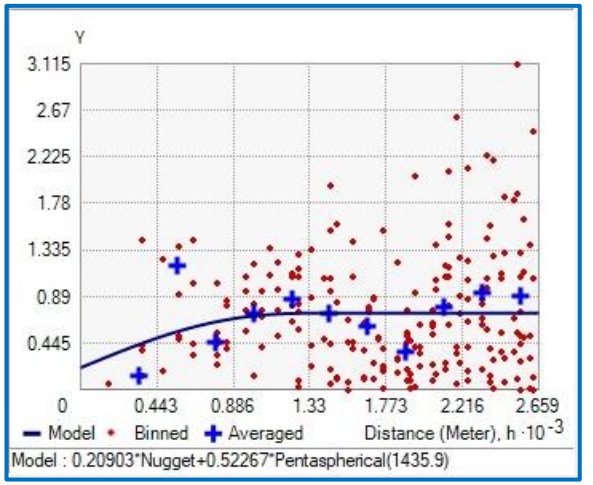
BOD: Gaussian Semivariogram Model



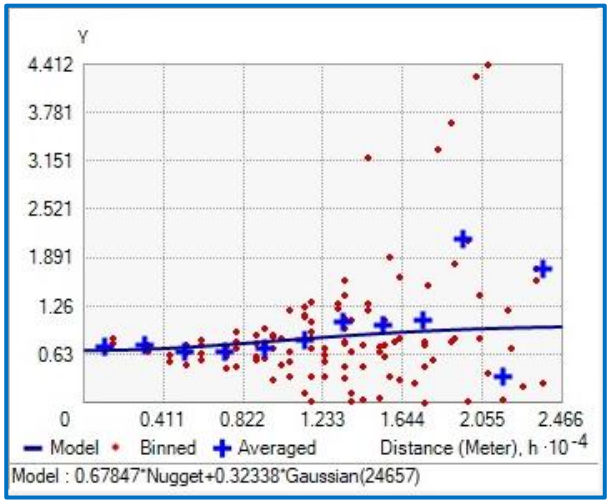
COD: J-bessel Semivariogram Model



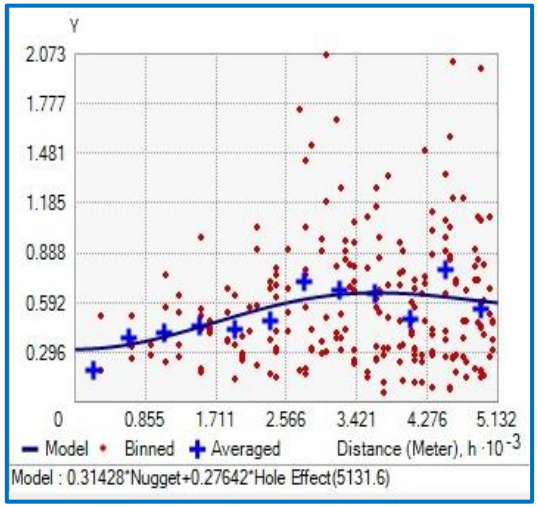
Total Coliform: J-bessel Semivariogram Model



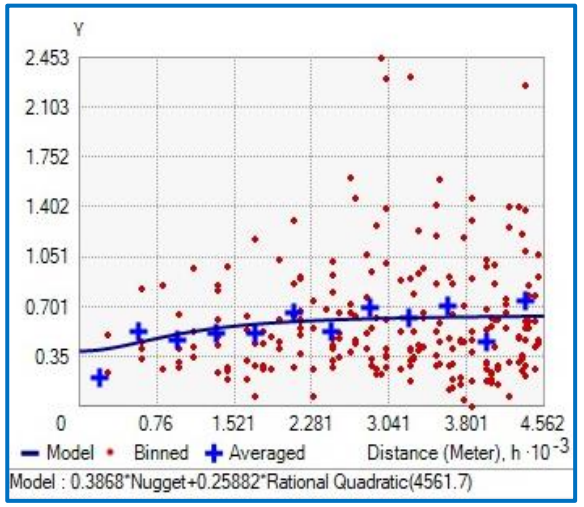
Na: Pentaspherical Semivariogram Model



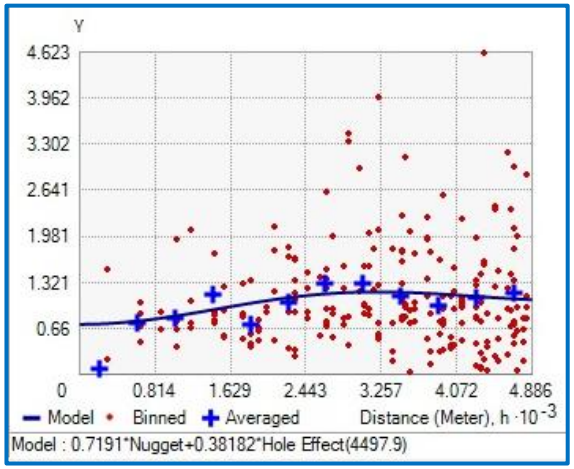
K: Gaussian Semivariogram Model



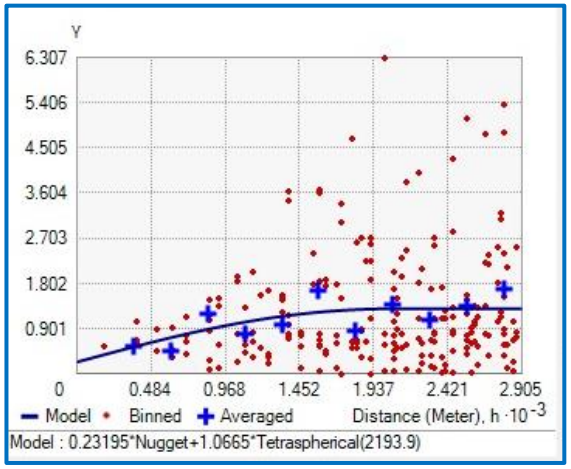
Ca: Hole Effect Semivariogram Model



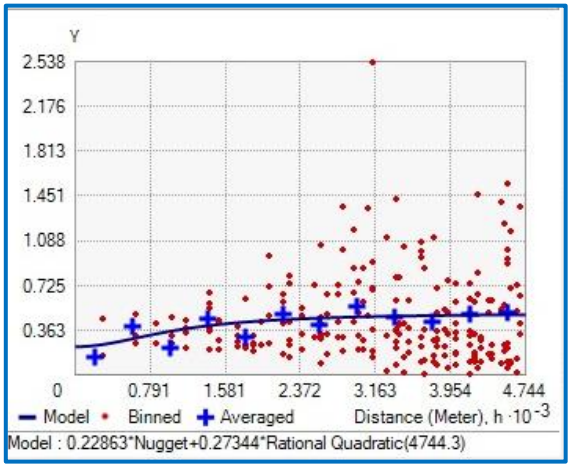
Mg: Rational Quadratic Semivariogram Model



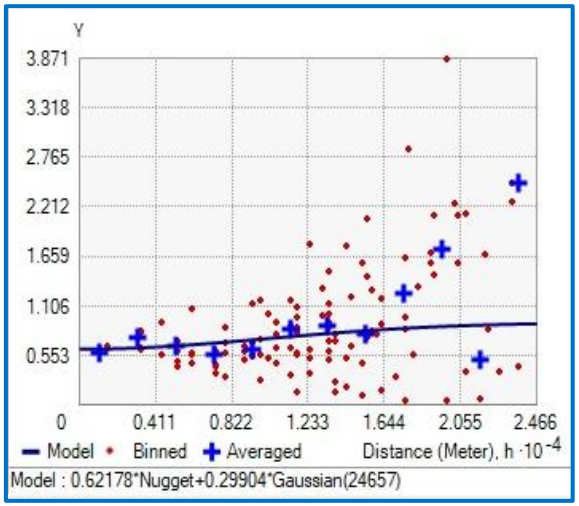
SO_4: Hole Effect Semivariogram Model



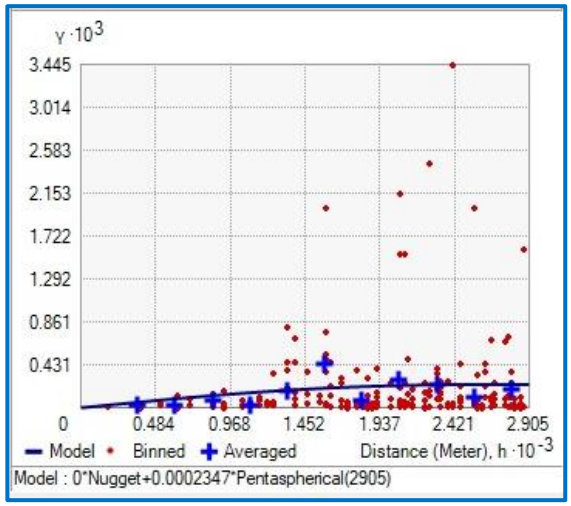
NO_3: Tetraspherical Semivariogram Model



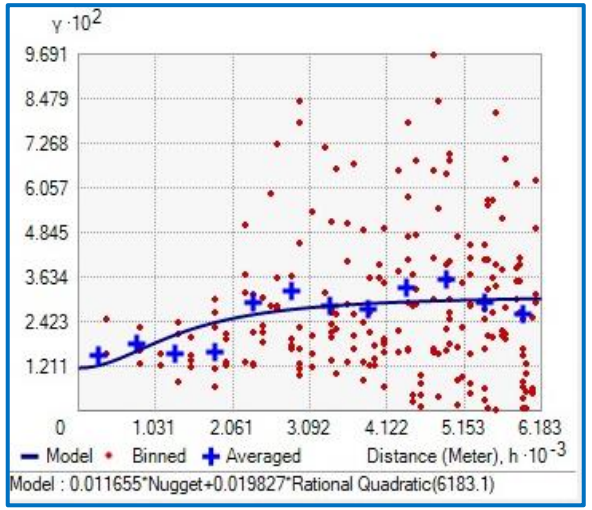
Cl: Rational Quadratic Semivariogram Model



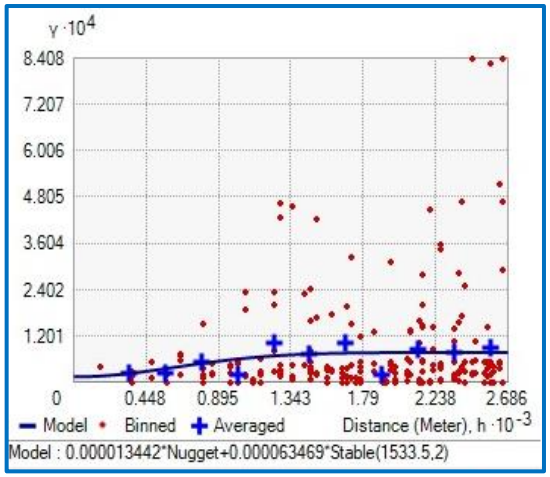
HCO_3: Gaussian Semivariogram Model



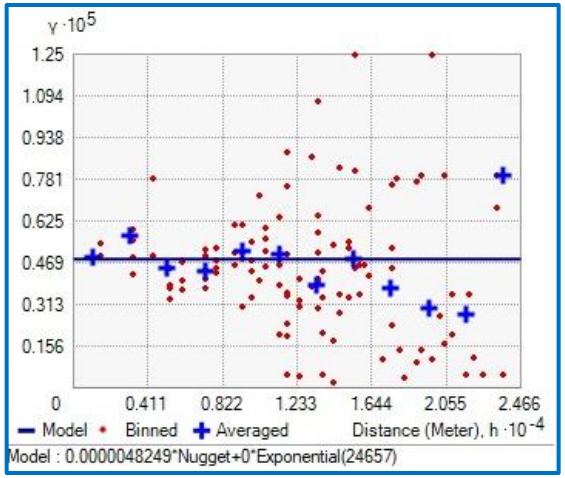
NH_4: Pentaspherical Semivariogram Model



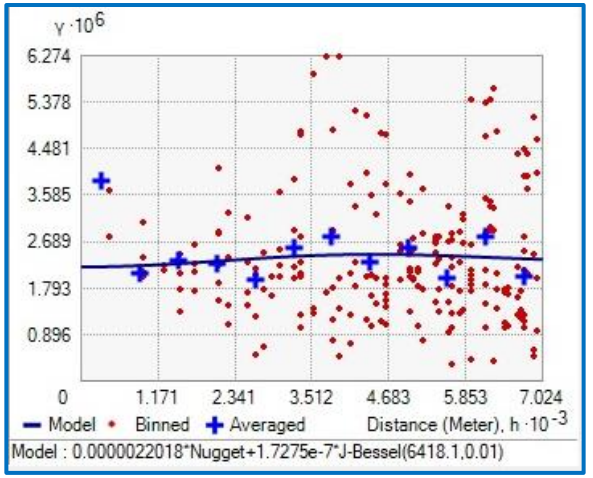
PO_4: Rational Quadratic Semivariogram Model



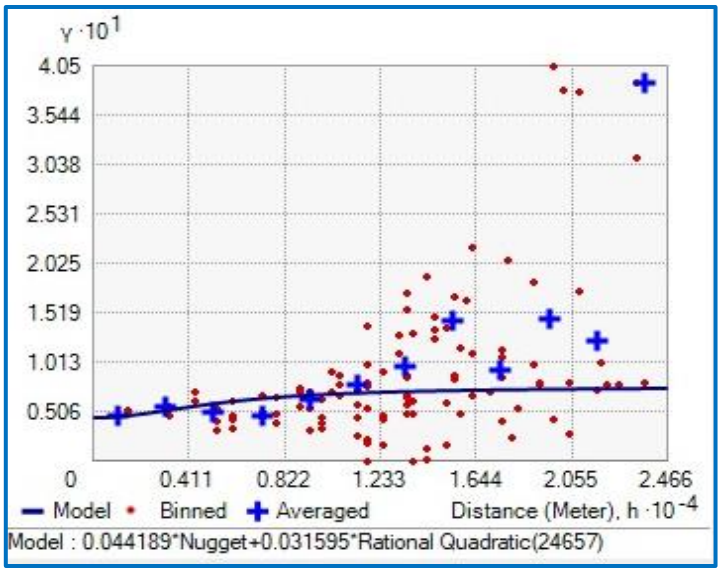
Fe: Stable Semivariogram Model



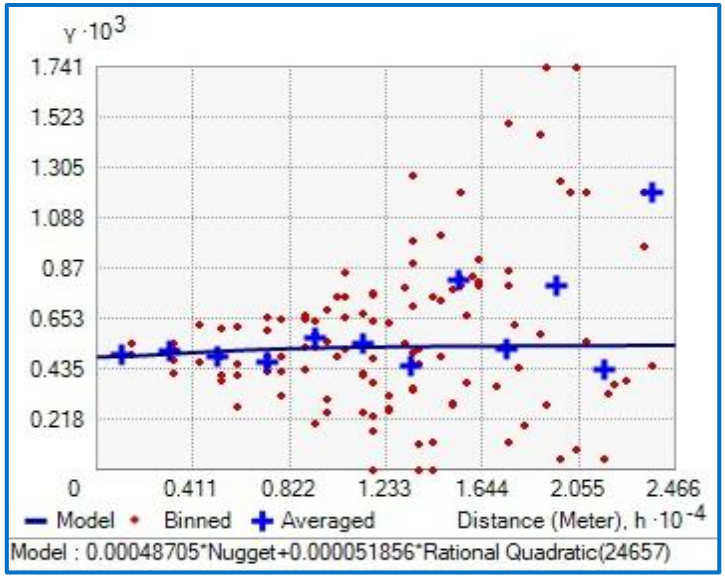
Cd: Exponential Semivariogram Model



Cr: J-bessel Semivariogram Model

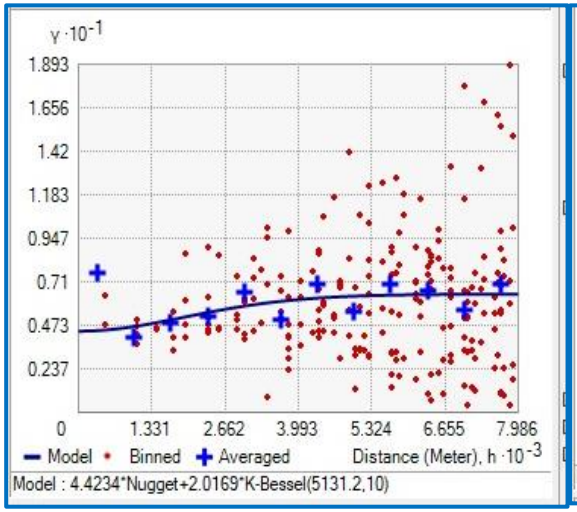


Cu: Rational Quadratic Semivariogram Model

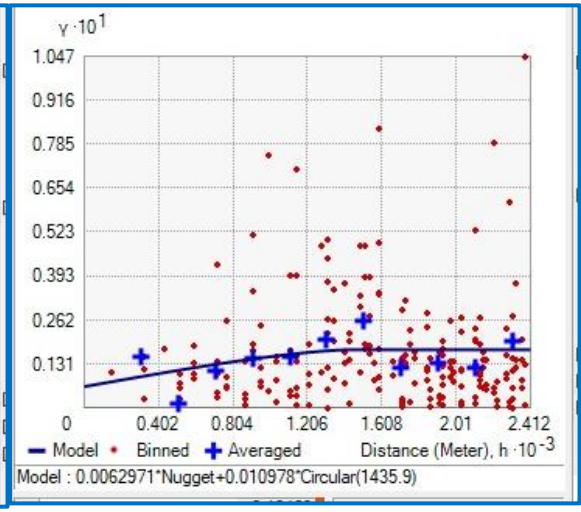


Pb: Rational Quadratic Semivariogram Model

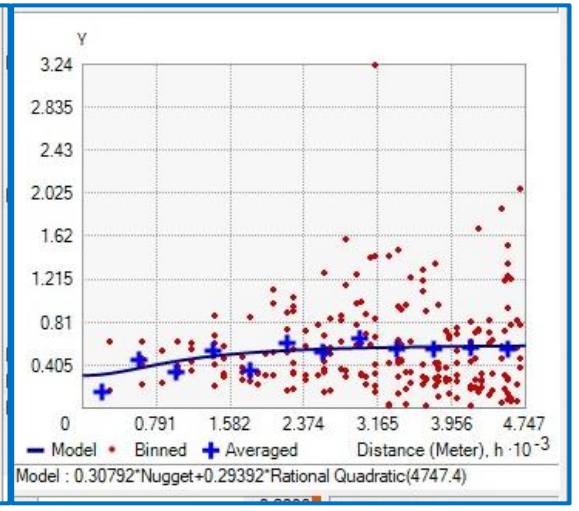
APPENDIX IX(B): Wet Season



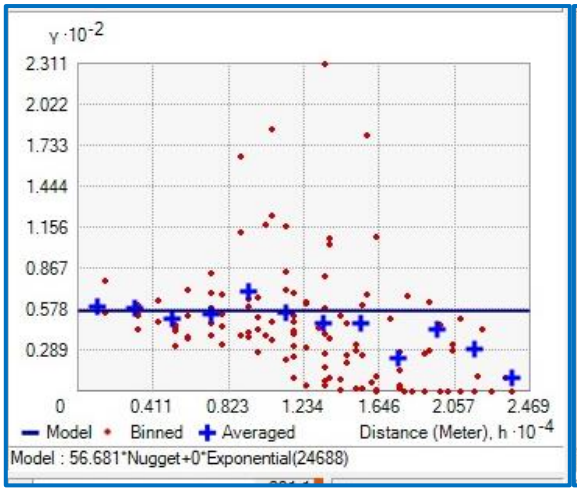
Temperature: K- Bessel Semivariogram Model



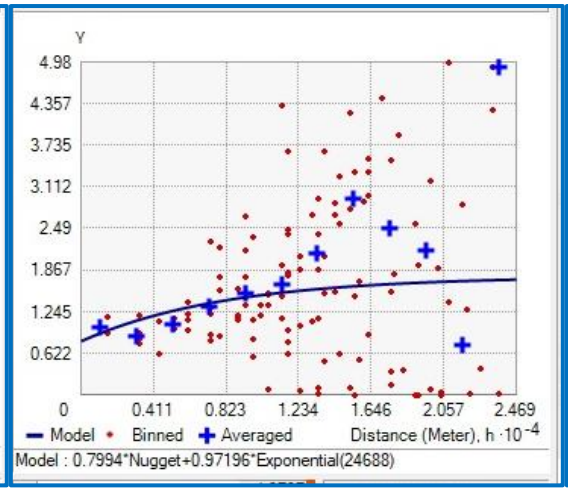
pH: Circular Semivariogram Model



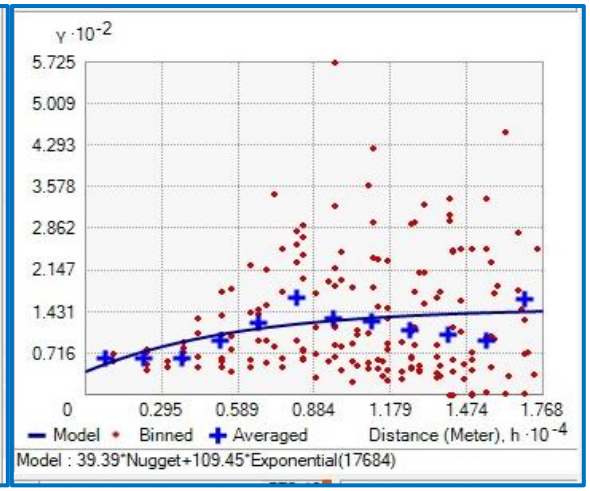
EC: Rational Quadratic Semivariogram Model



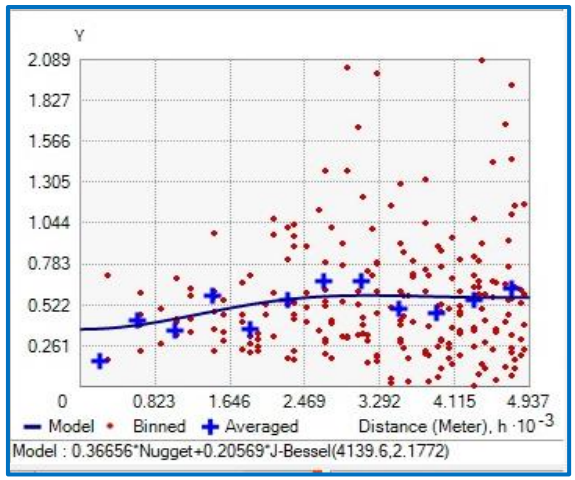
Turbidity: Exponential Semivariogram Model



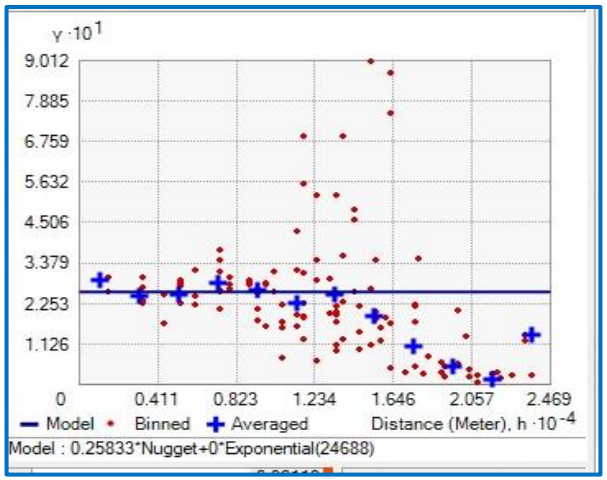
TH: Exponential Semivariogram Model



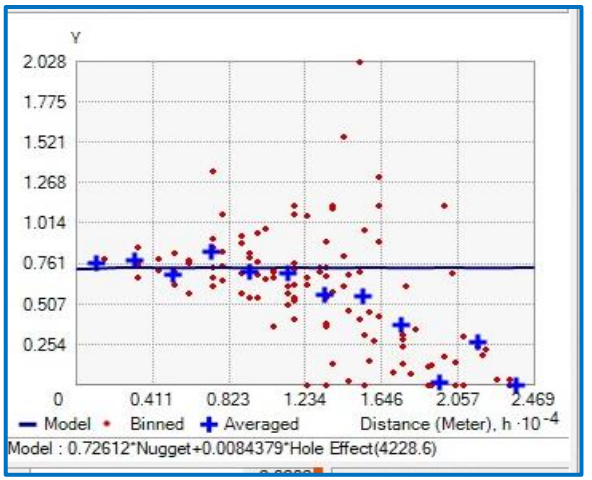
TSS: Exponential Semivariogram Model



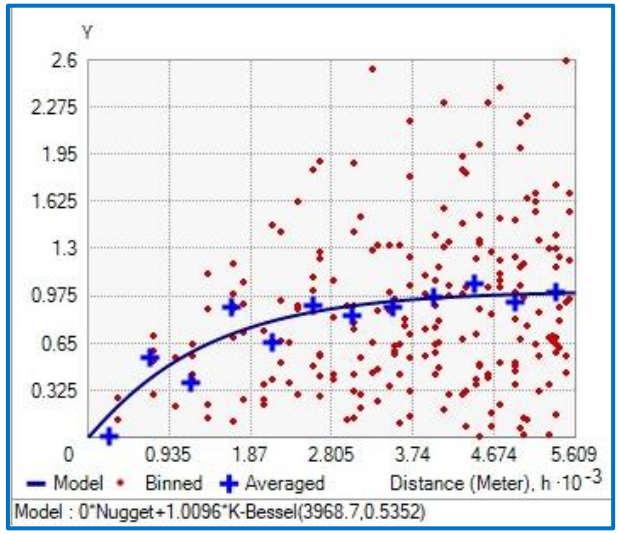
TDS: J-bessel Semivariogram Model



DO: Exponential Semivariogram Model

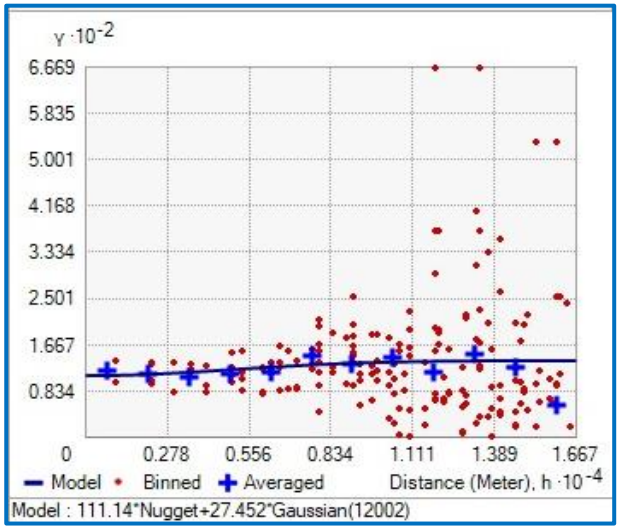


BOD: Hole Effect Semivariogram Mode

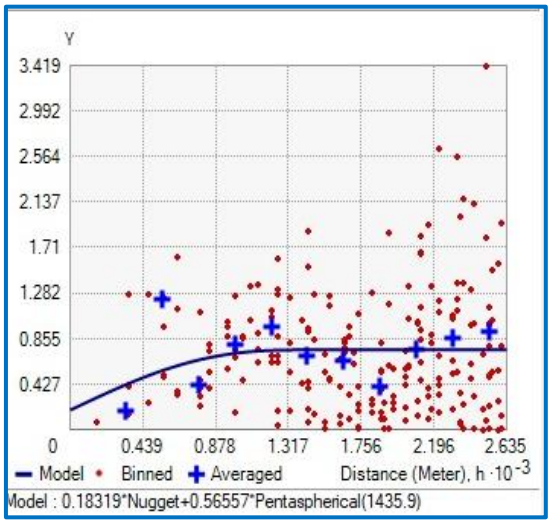


COD: K-bessel Semivariogram Model

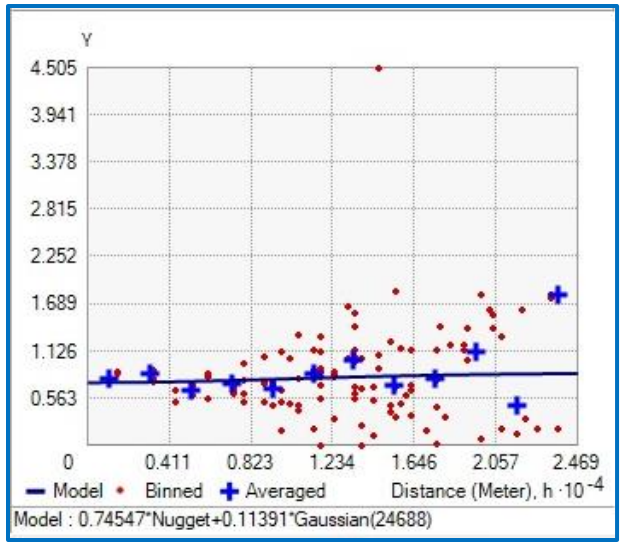
Model



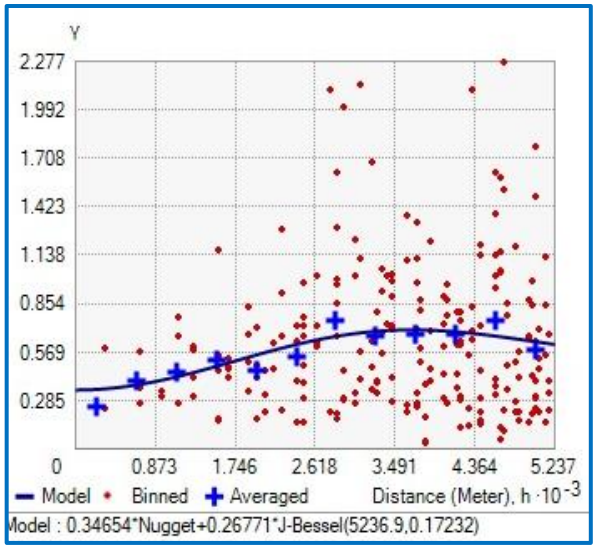
Total Coli: Gaussian Semivariogram Model



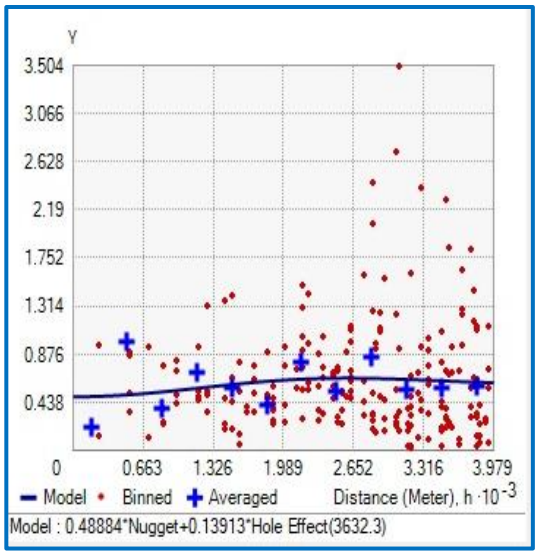
Na: Pentaspherical Semivariogram



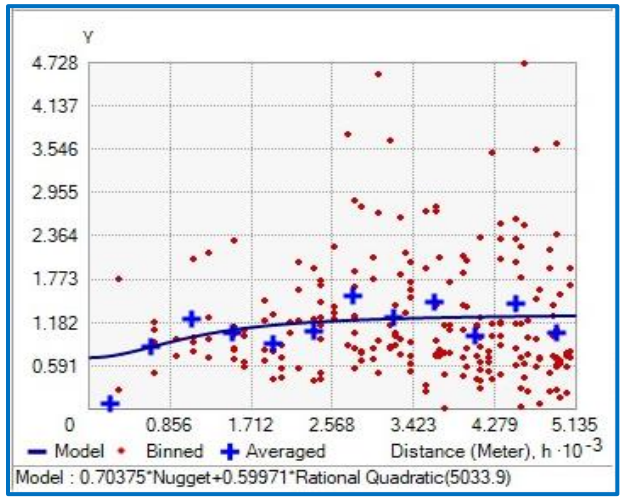
K: Gaussian Semivariogram Model



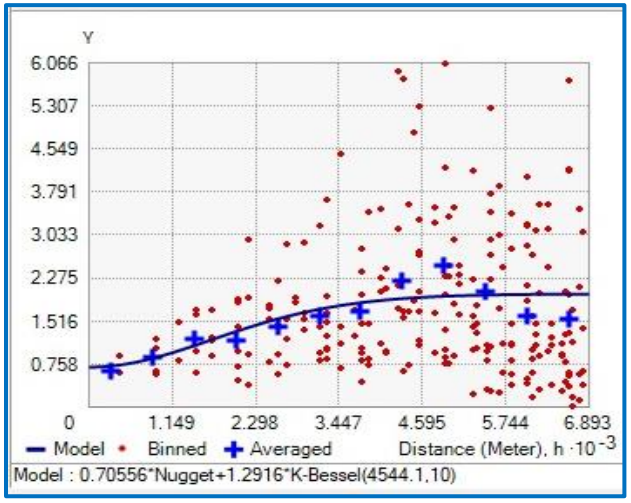
Ca: J-bessel Semivariogram Model



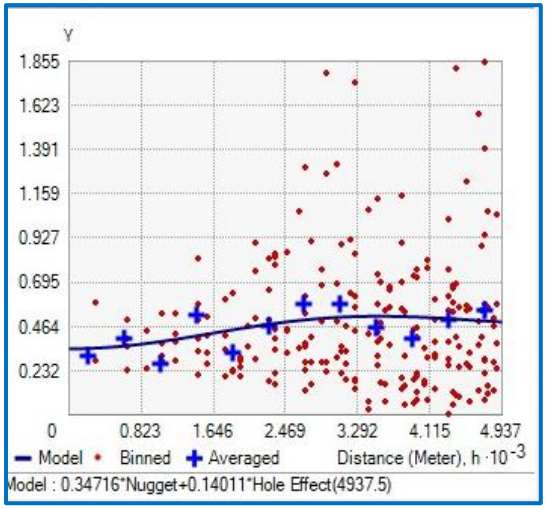
Mg: Hole Effect Semivariogram



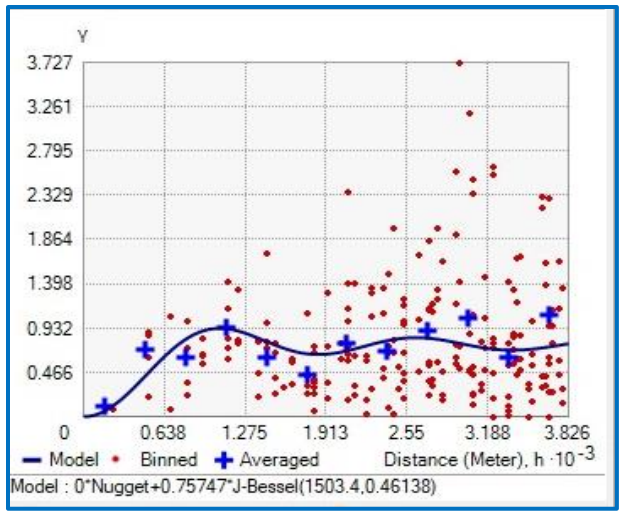
SO_4: Rational Quadratic Semivariogram Model



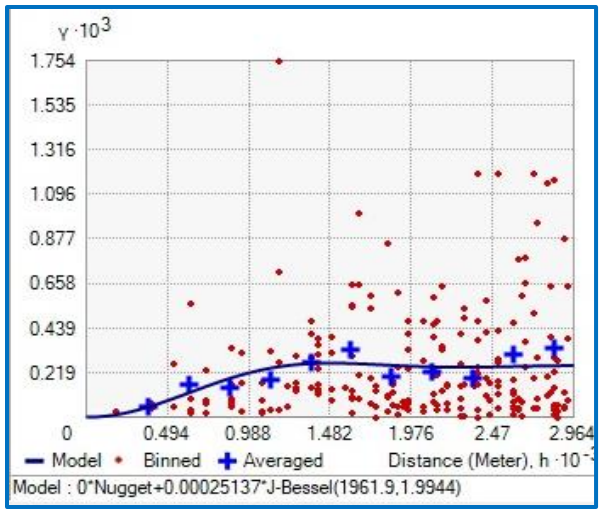
NO_3: K-bessel Semivariogram Model



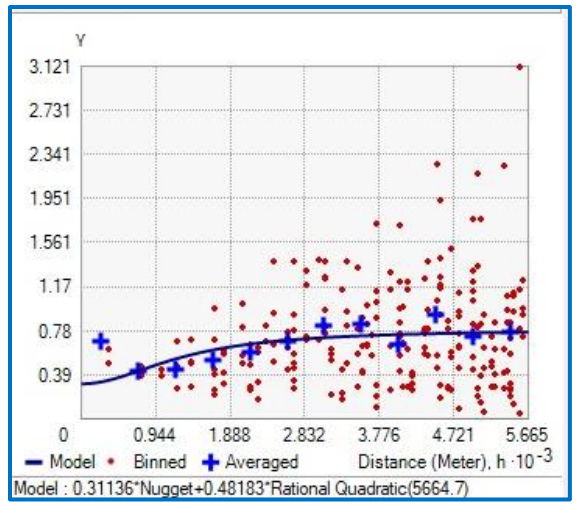
Cl: Hole Effect Semivariogram Model



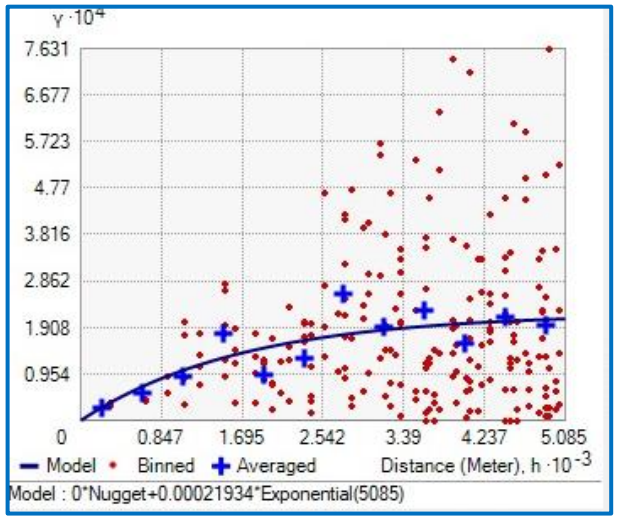
HCO_3: Rational Quadratic Semivariogram Model

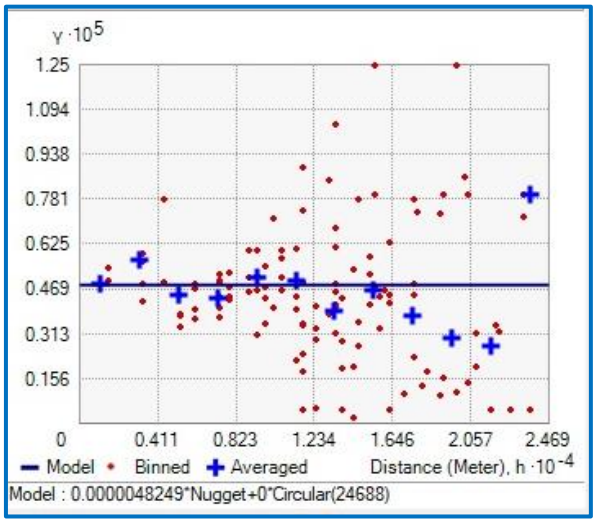


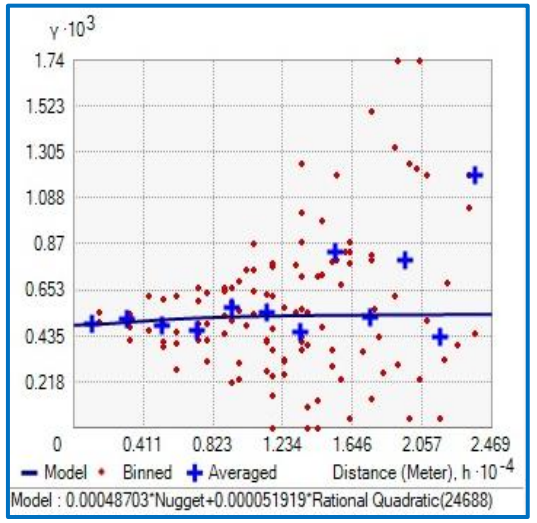
NH_4: J-bessel Semivariogram Model



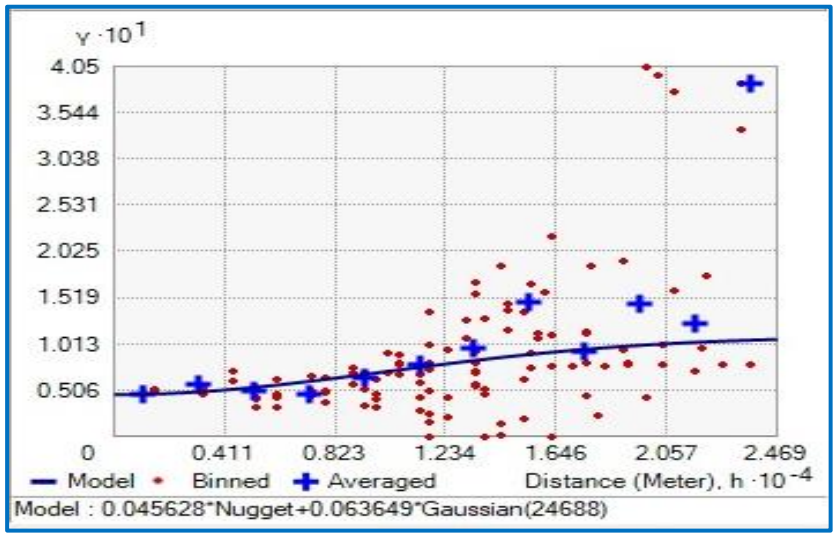
PO_4: Rational Quadratic Semivariogram Model

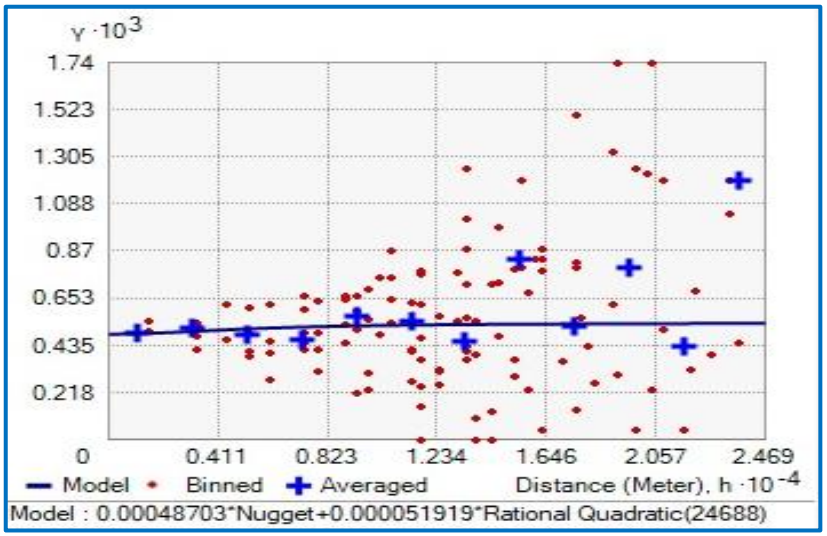






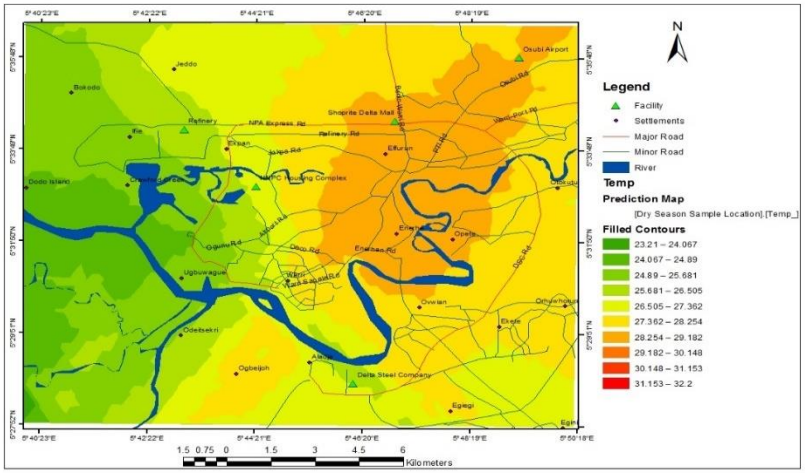
Fe: Exponential Semivariogram Model Cd: Circular semivariogram Model Cr: Exponential Semivariogram Model



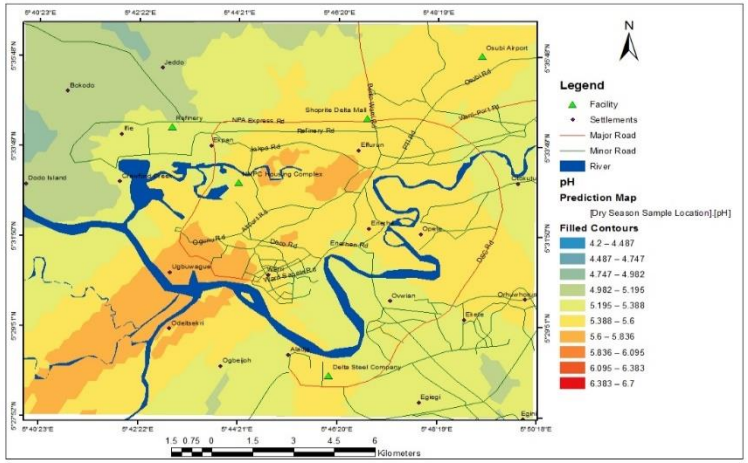


Cu: Gaussian Semivariogram Model Pb: Rational Quadratic Semivariogram Model

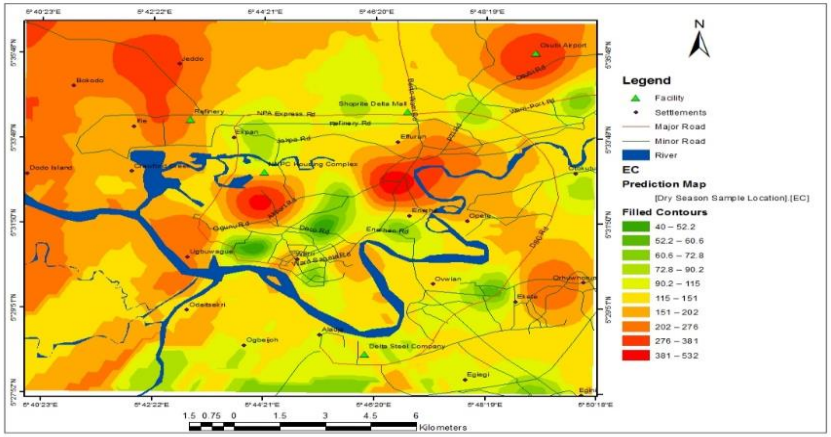
APPENDIX X
SPATIAL DISTRIBUTION PREDICTION MAPS OF GROUNDWATER QUALITY
APPENDIX X(A): DRY SEASON PREDICTION MAPS



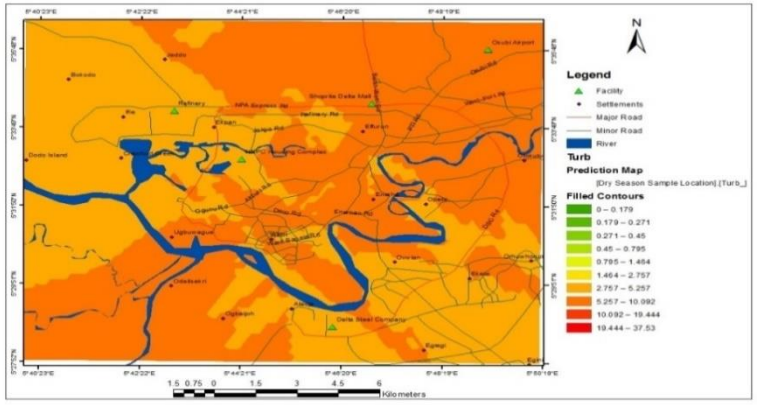
(a) Temperature



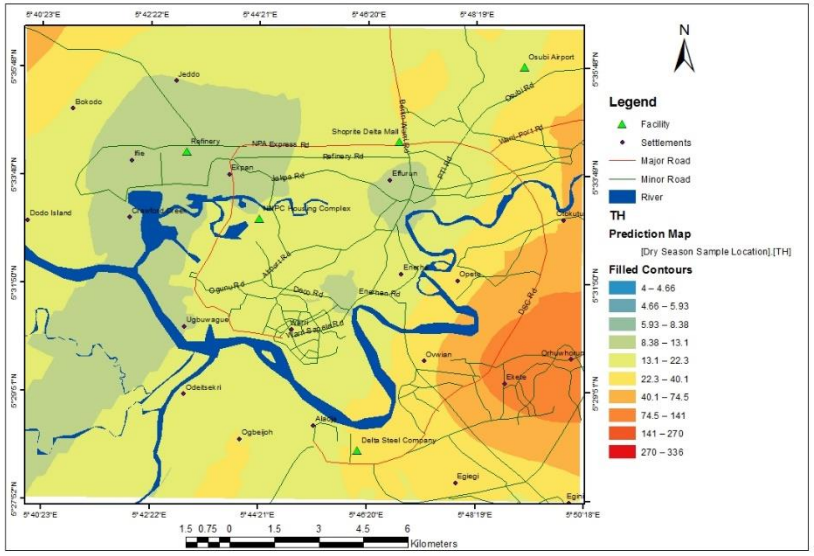
(b): pH



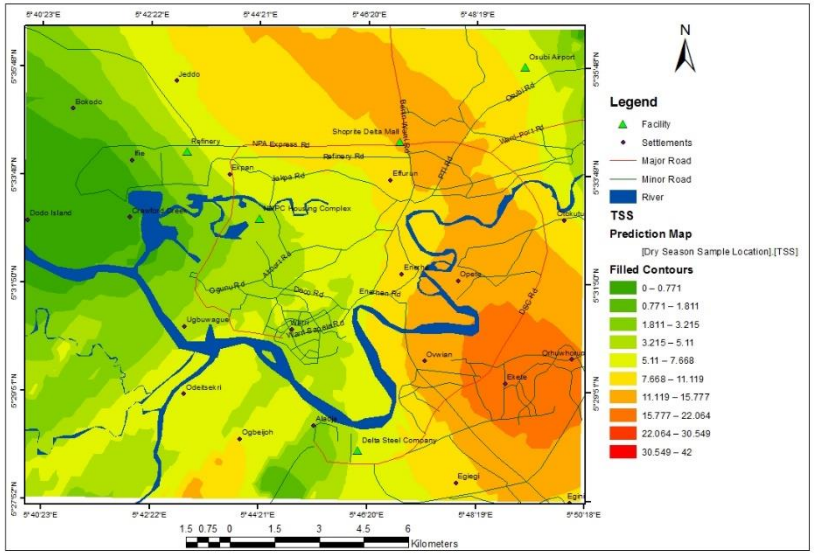
(c): Electrical Conductivity (EC)



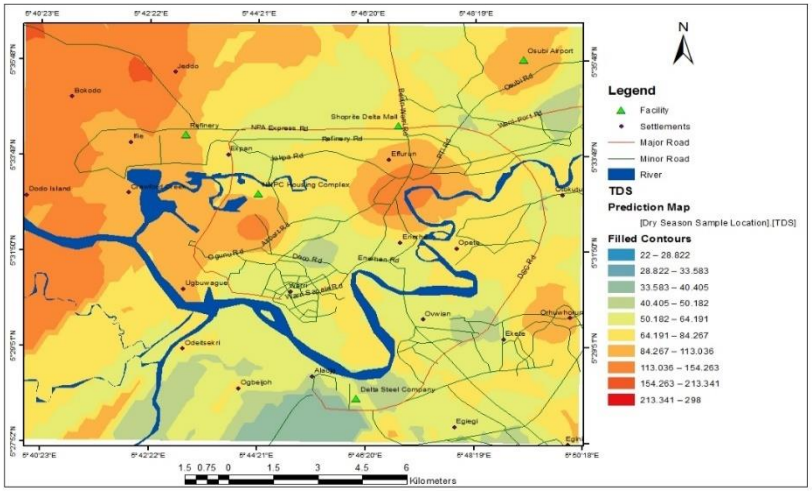
d) Turbidity



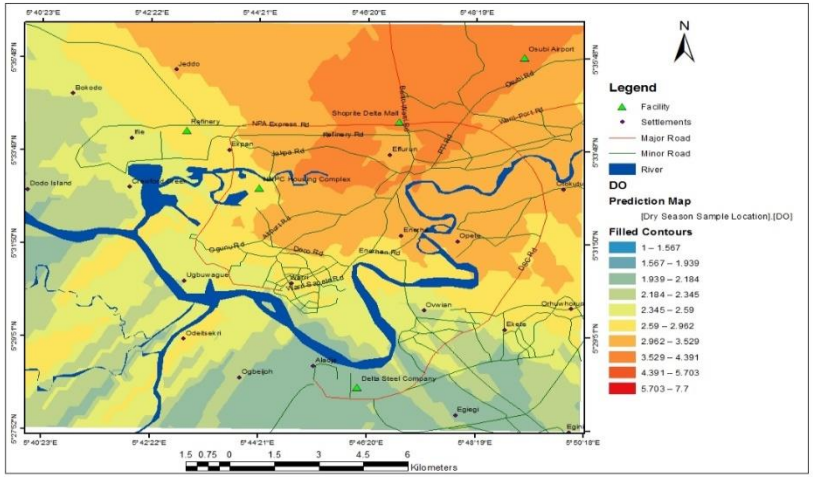
(e): Total Hardness (TH)



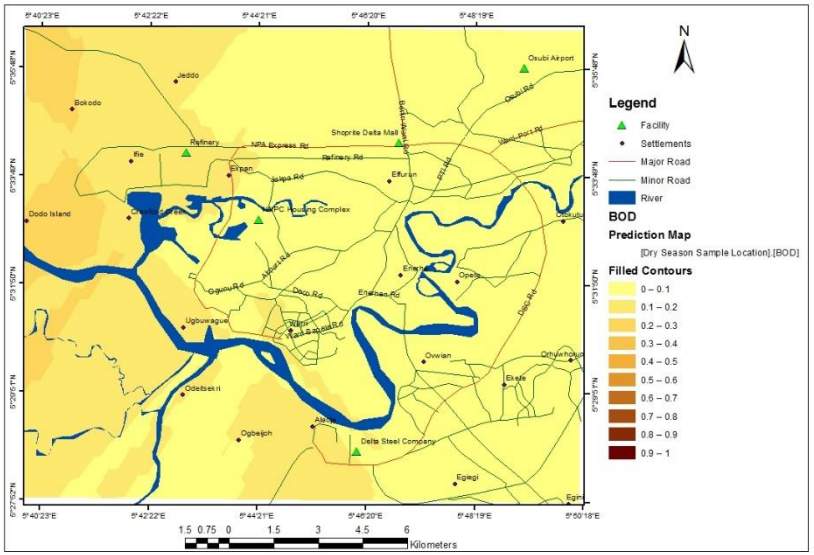
(f): Total Suspended Solid (TSS)



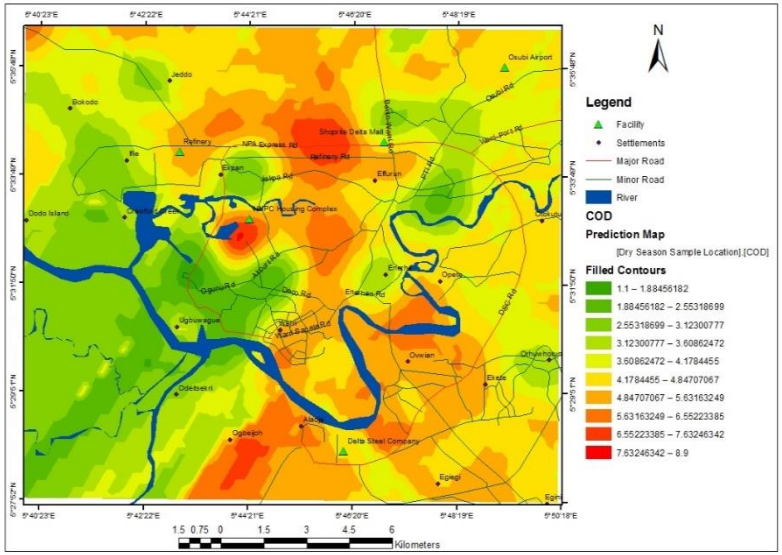
(g): Total Dissolve Solid (TDS)



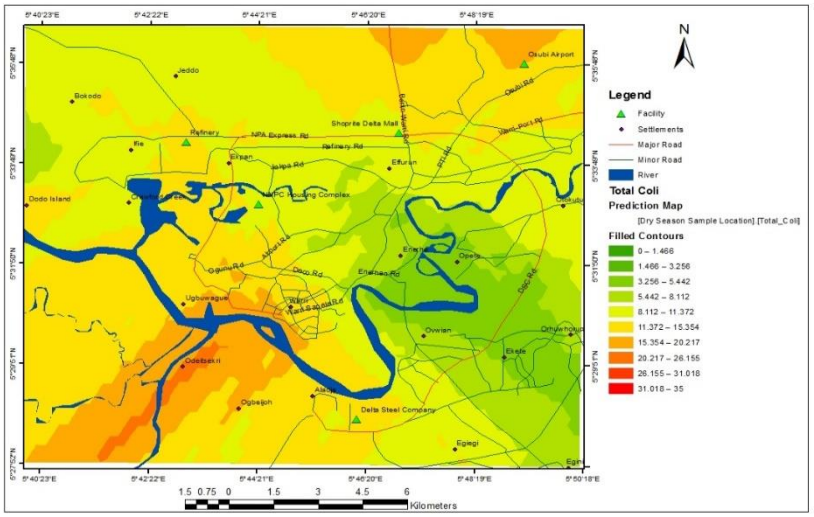
(h): DO



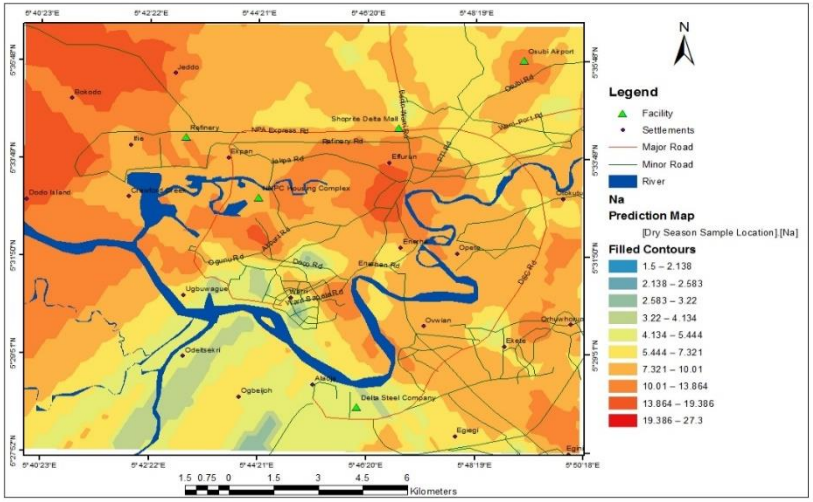
(i): BOD



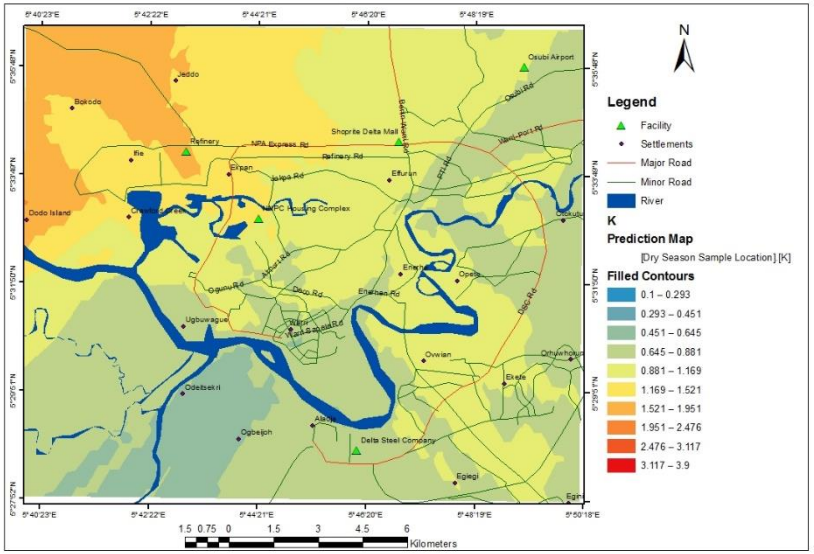
(j):COD



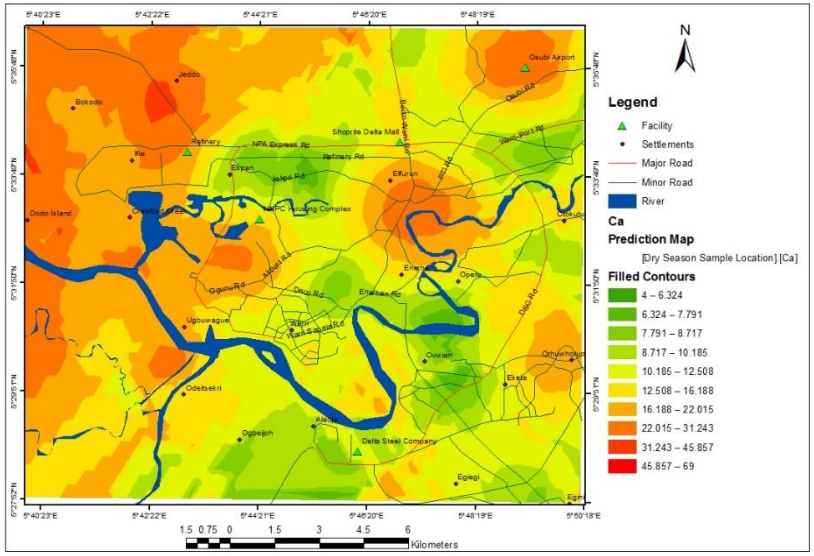
(k): Total Coliform



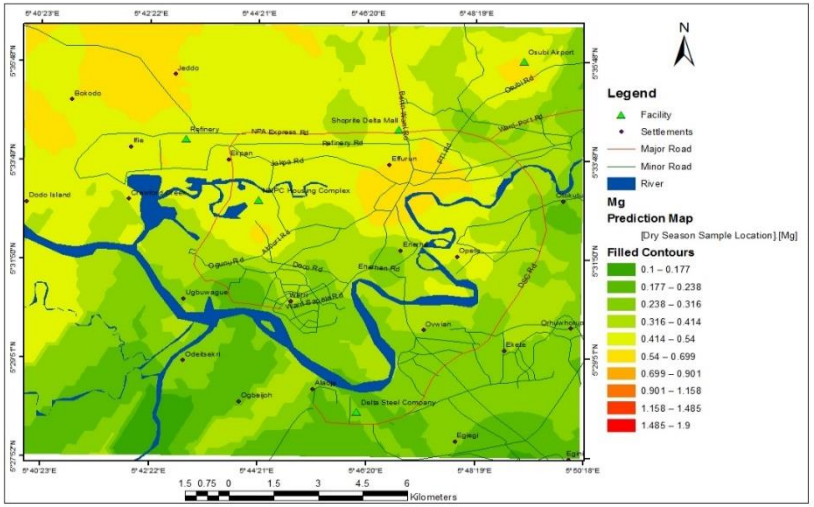
(l): Na



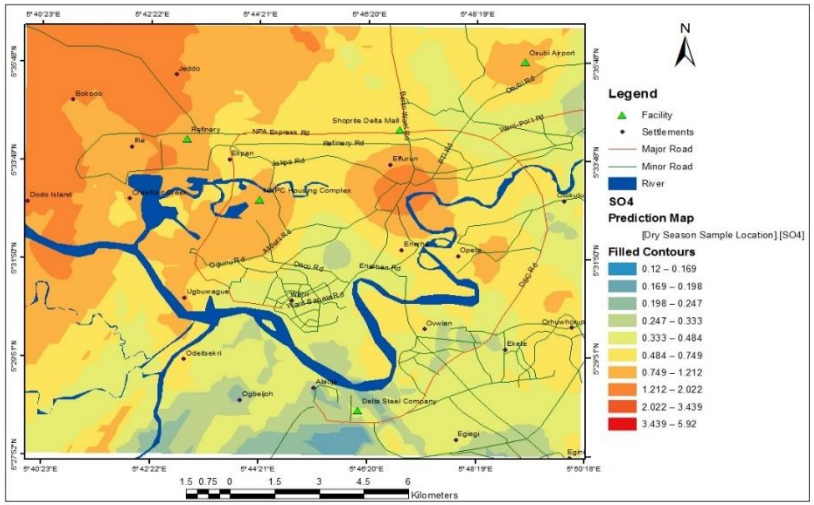
(m): K



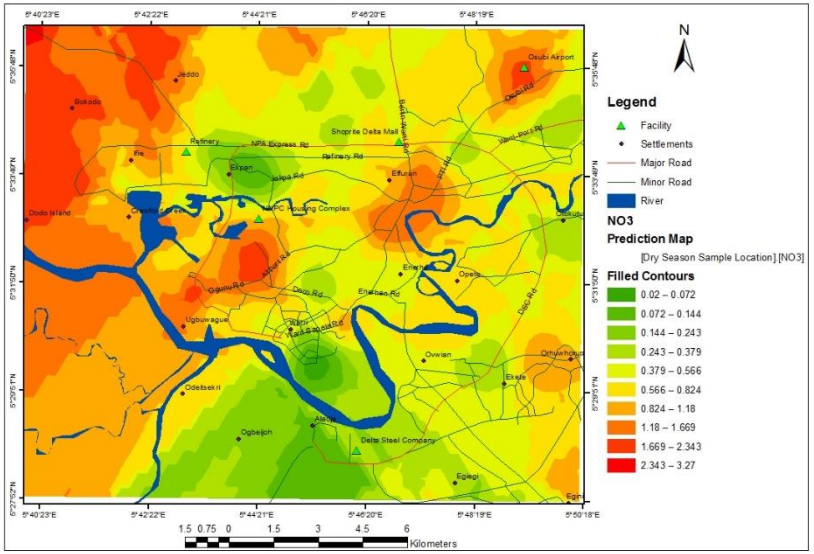
(n): Ca



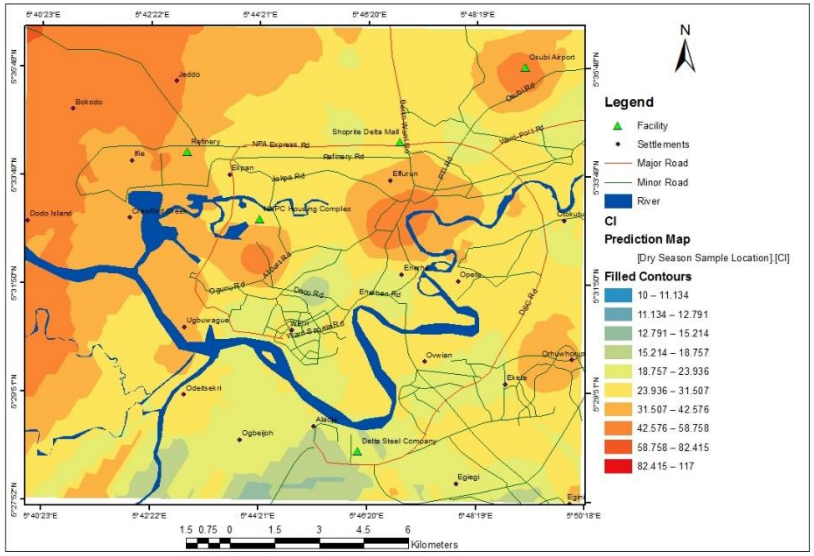
(o): Mg



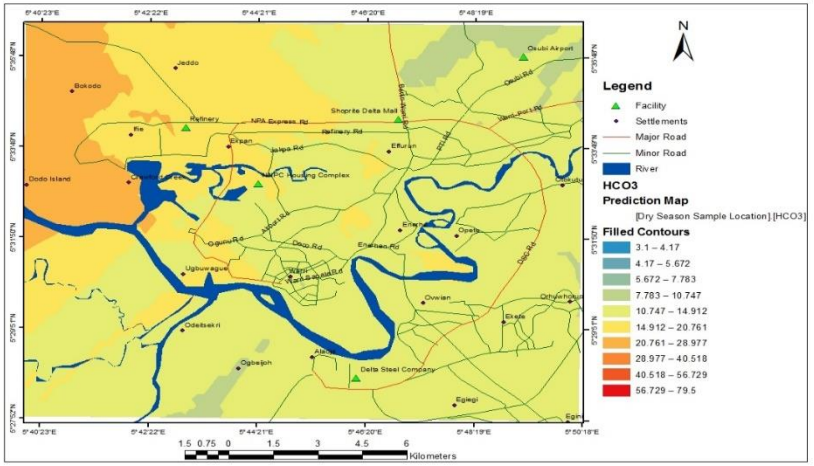
(p): SO_4



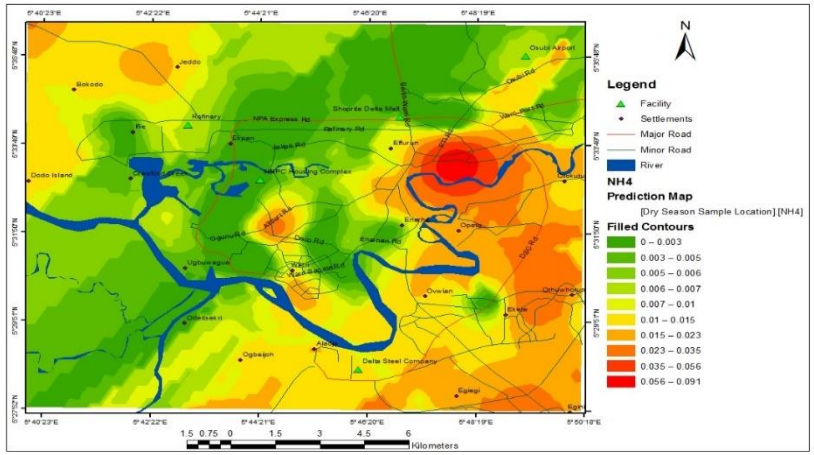
(q): NO_3



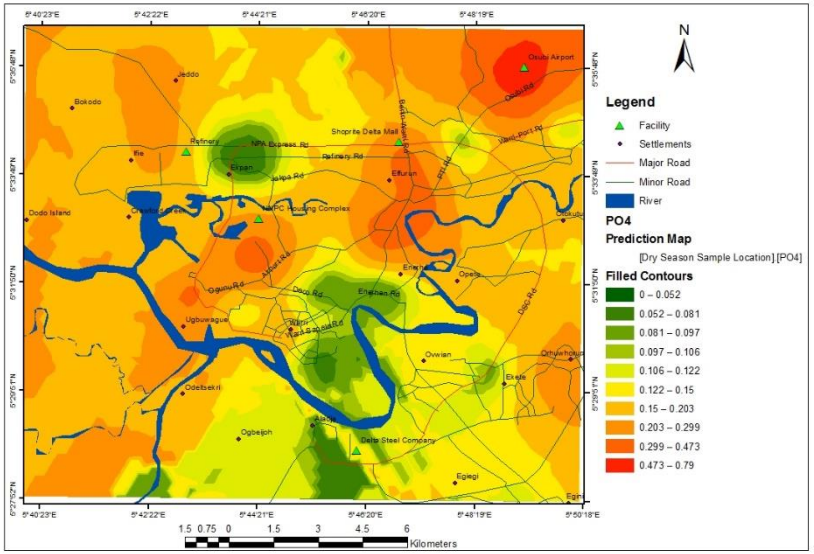
(r): Cl



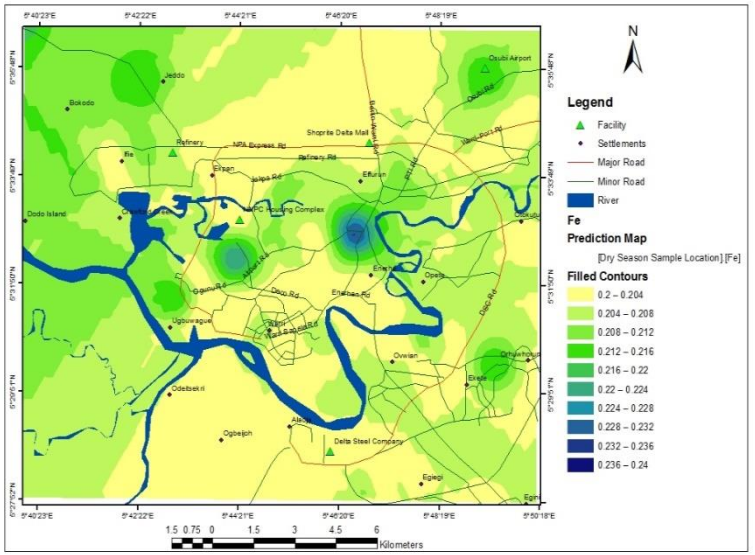
(s): HCO_3



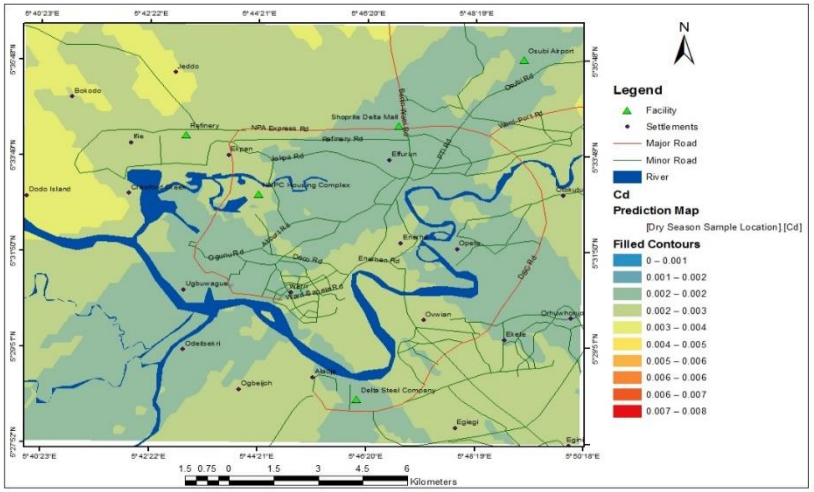
(t): NH_4



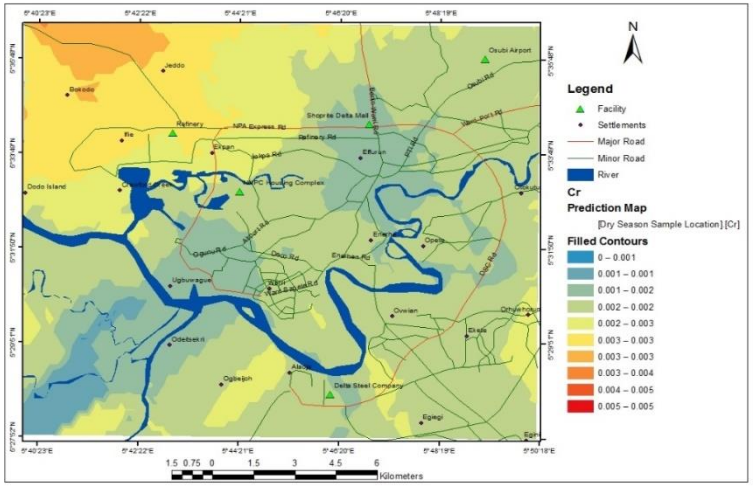
(u) PO_4



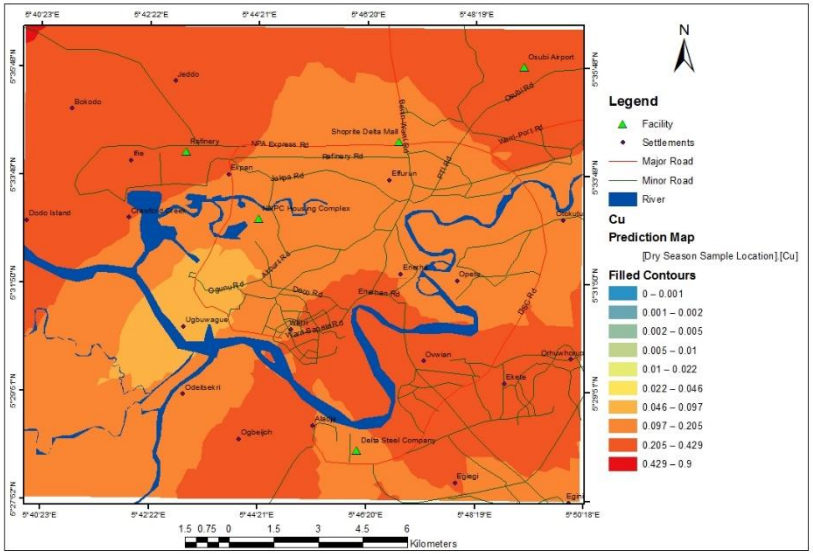
(v): Fe



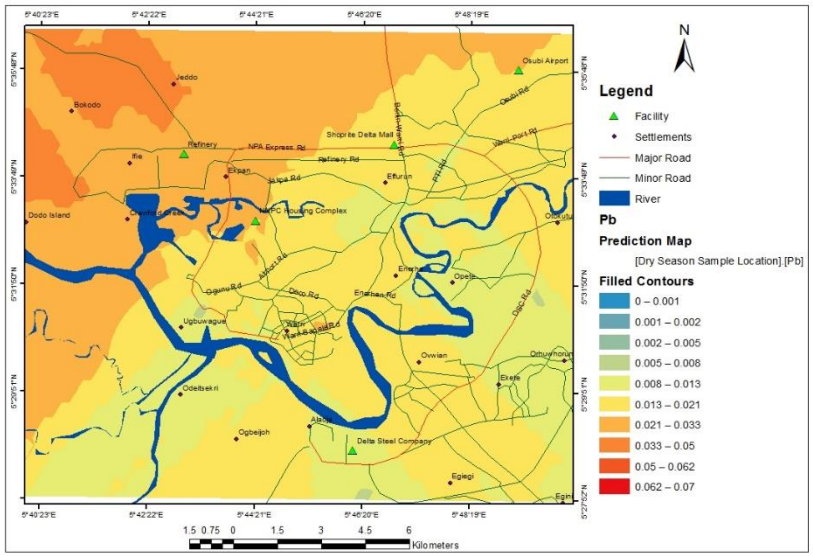
(w): Cd



(x): Cr

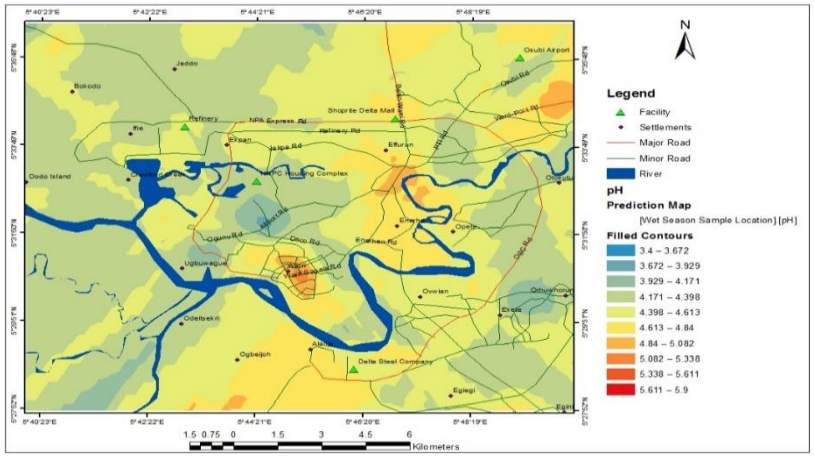

Legend
Facility
Settlements
Major Road
Minor Road
River
Cu
Prediction Map
[Dry Season Sample Location].[Cu]
Filled Contours
0 – 0.001
0.001 – 0.002
0.002 – 0.005
0.005 – 0.01
0.01 – 0.022
0.022 – 0.046
0.046 – 0.097
0.097 – 0.205
0.205 – 0.429
0.429 – 0.9
N
Kilometers

(y): Cu

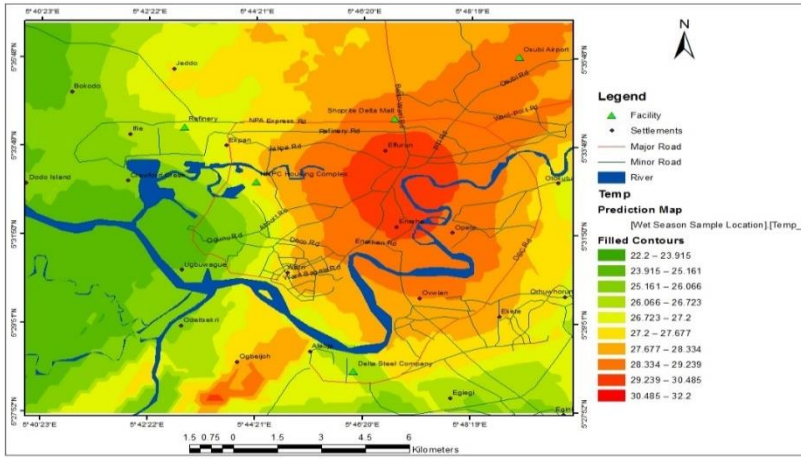

Legend
Facility
Settlements
Major Road
Minor Road
River
Pb
Prediction Map
[Dry Season Sample Location].[Pb]
Filled Contours
0 – 0.001
0.001 – 0.002
0.002 – 0.005
0.005 – 0.008
0.008 – 0.013
0.013 – 0.021
0.021 – 0.033
0.033 – 0.05
0.05 – 0.062
0.062 – 0.07
N
Kilometers

(z): Pb

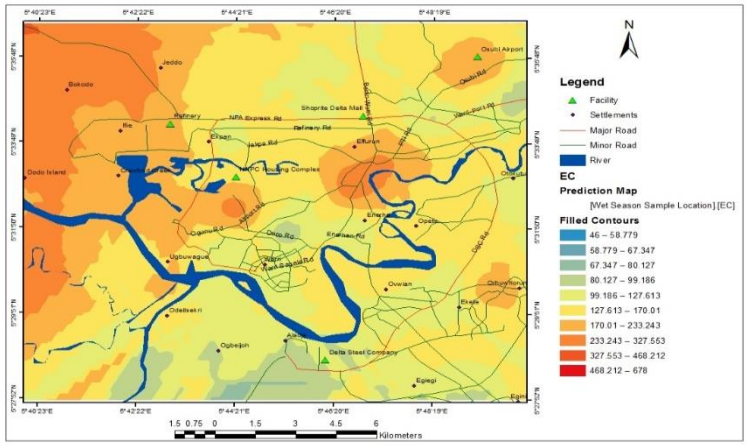
APPENDIX X(B): WET SEASON PREDICTION MAPS



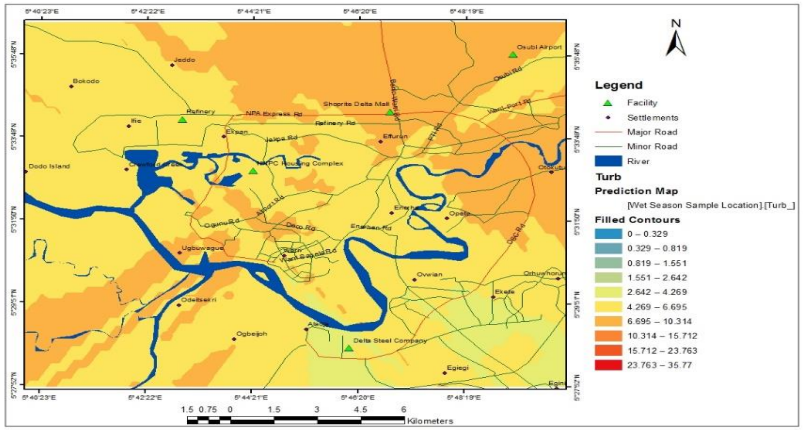
(a): Temperature



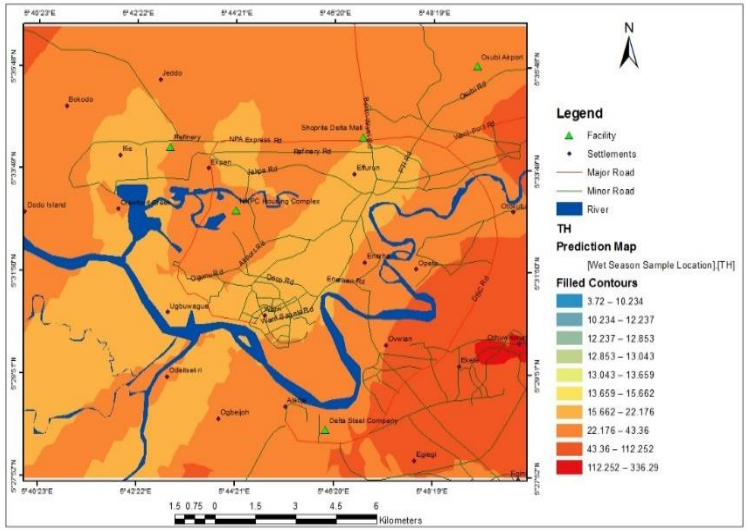
(b): pH



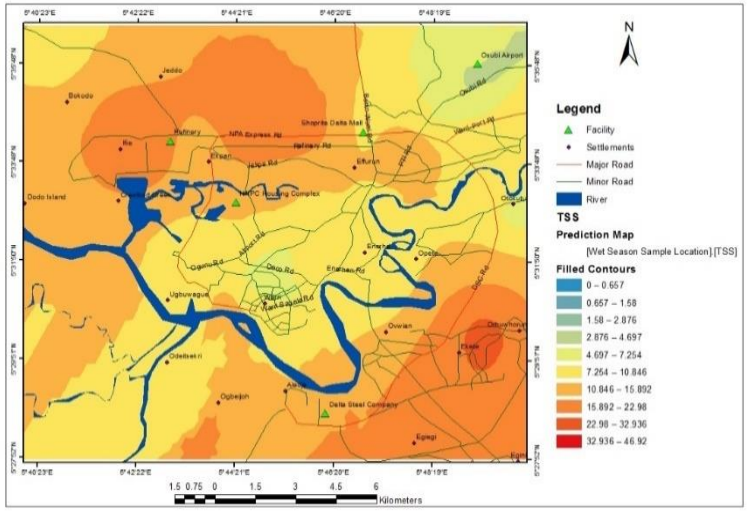
(c): EC



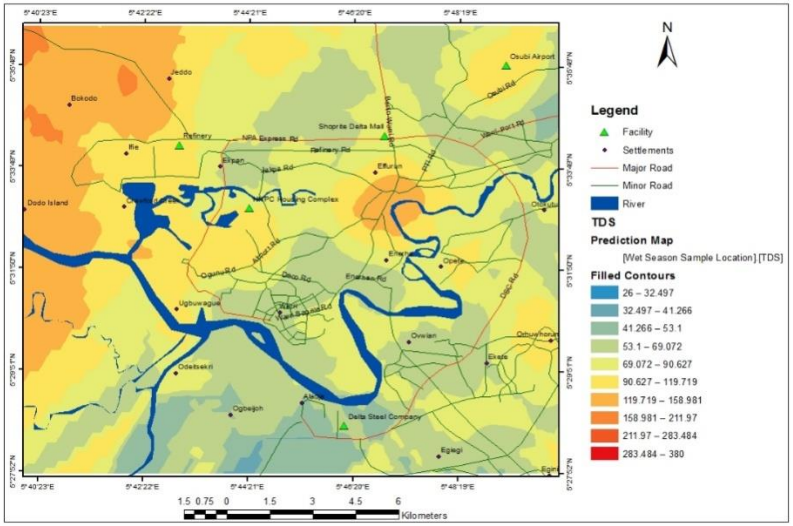
(d): Turbidity



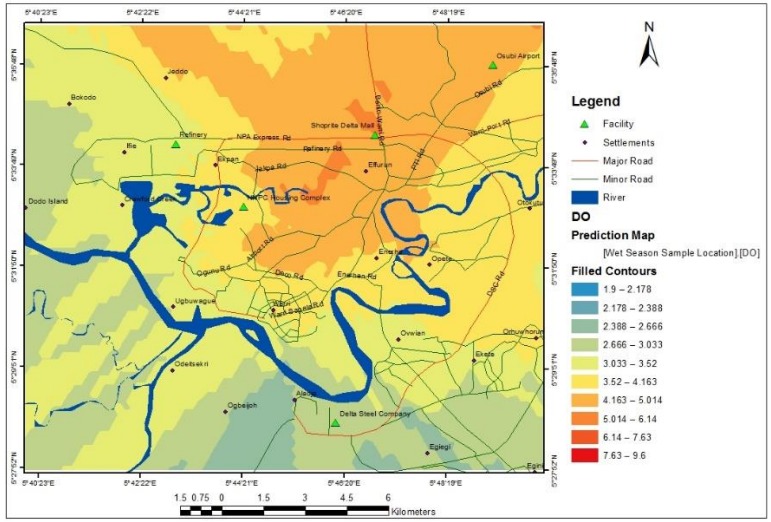
(e): TH



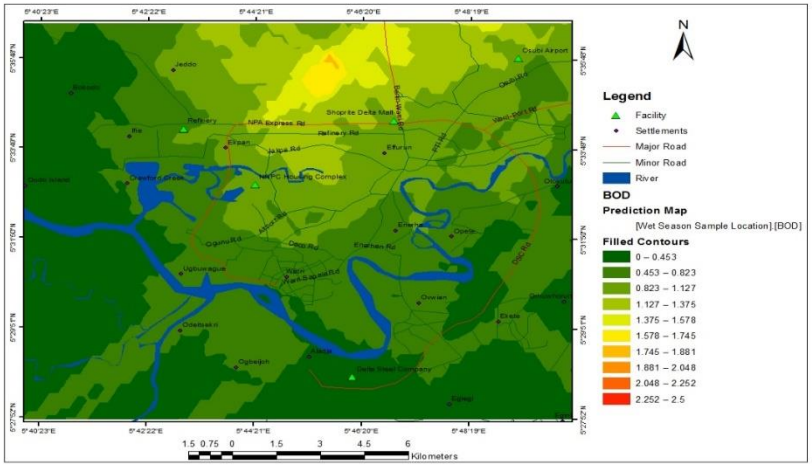
(f): TSS



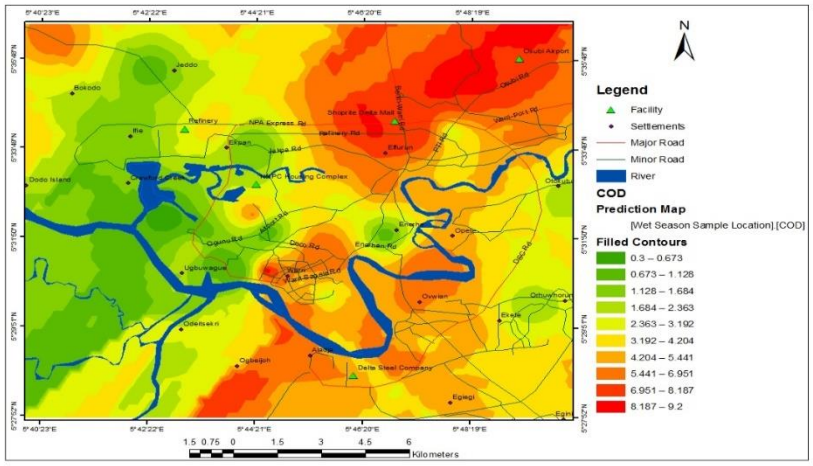
(g):TDS



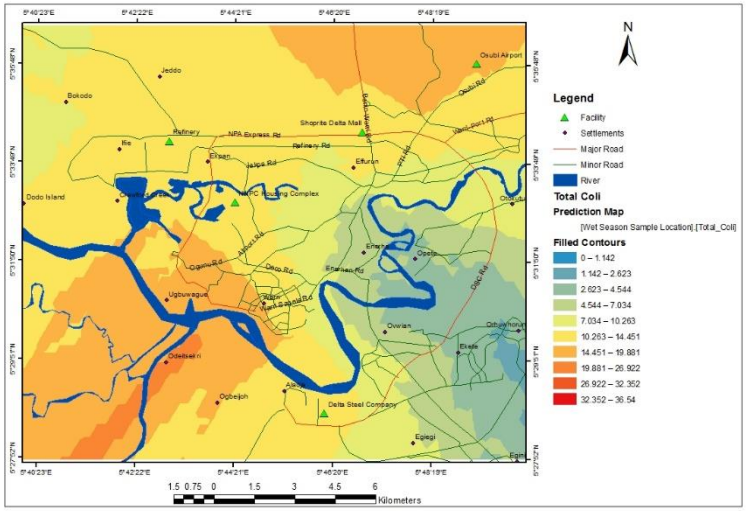
(h):DO



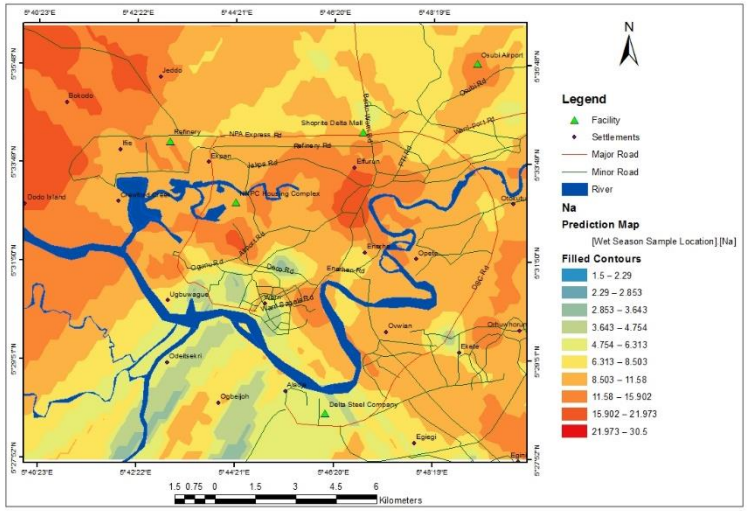
(i): BOD



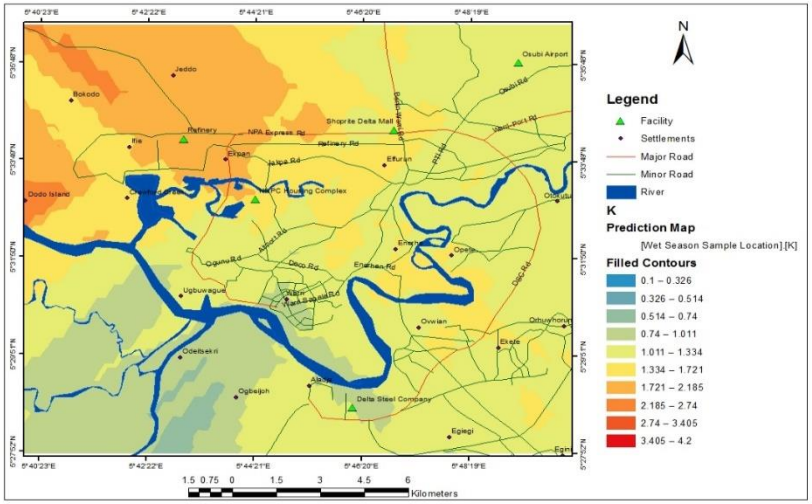
(j): COD



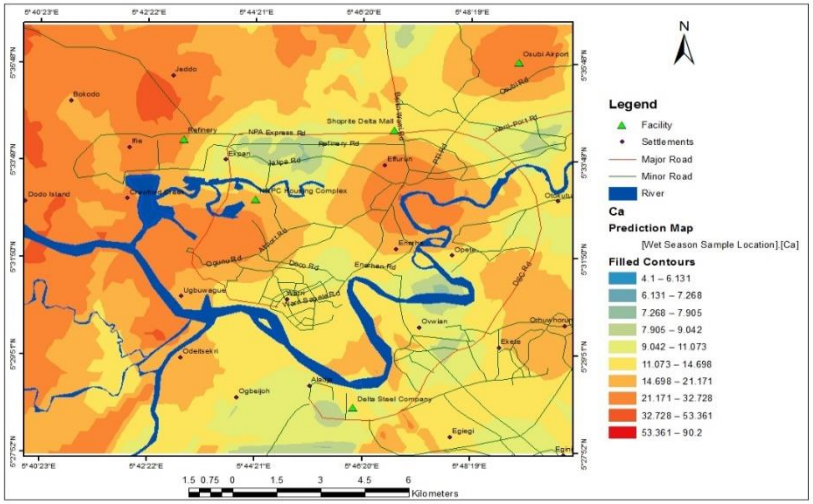
(k): Total Coli



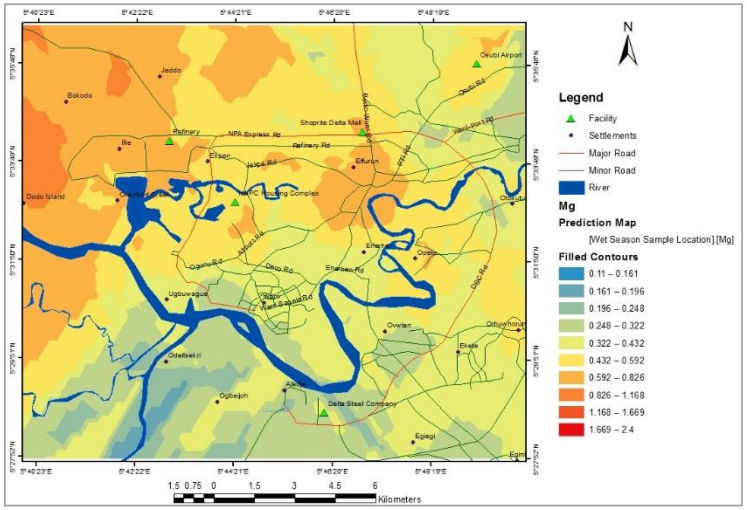
(l): Na



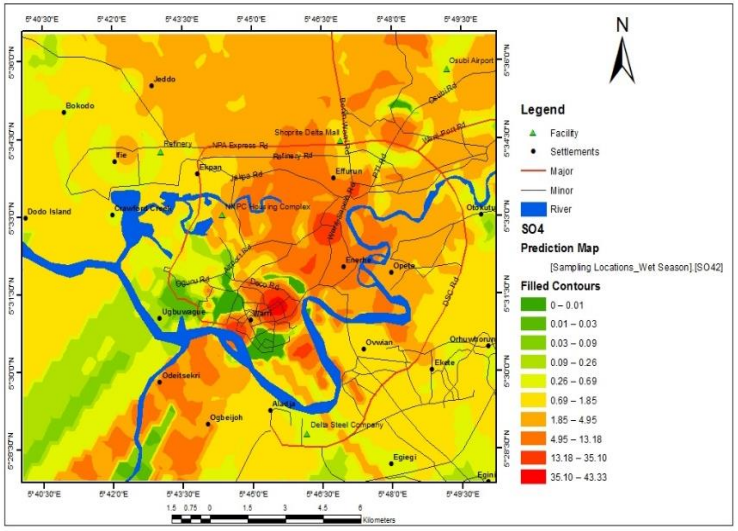
(m): K



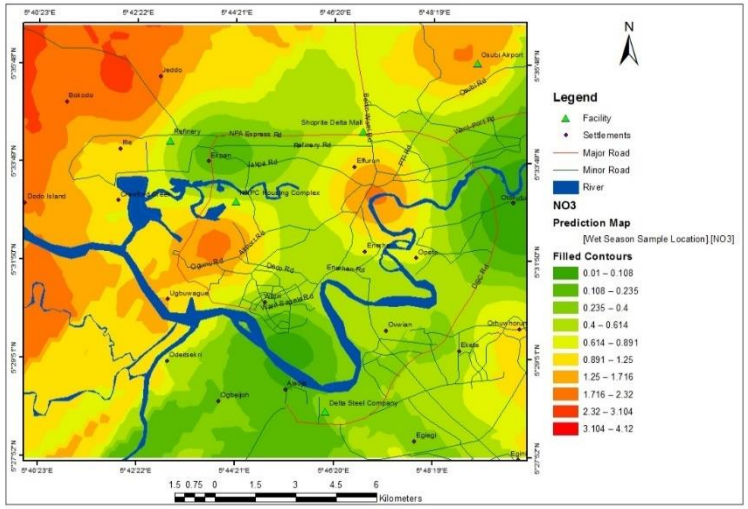
(n): Ca



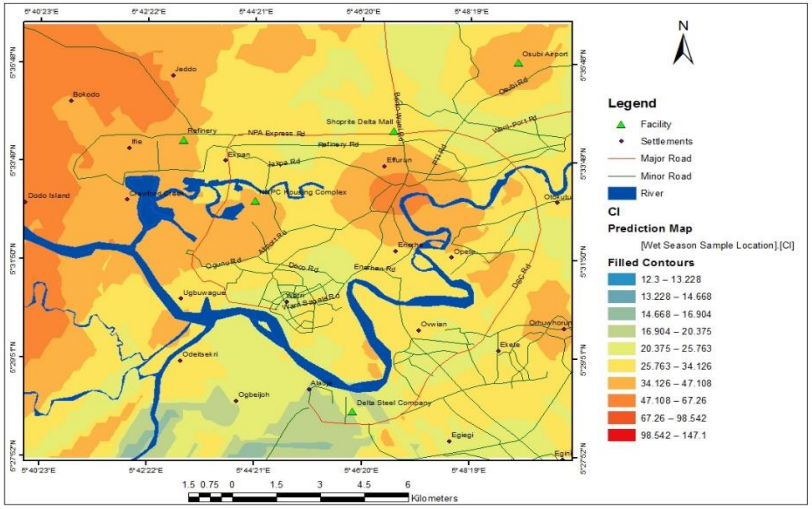
(o): Mg



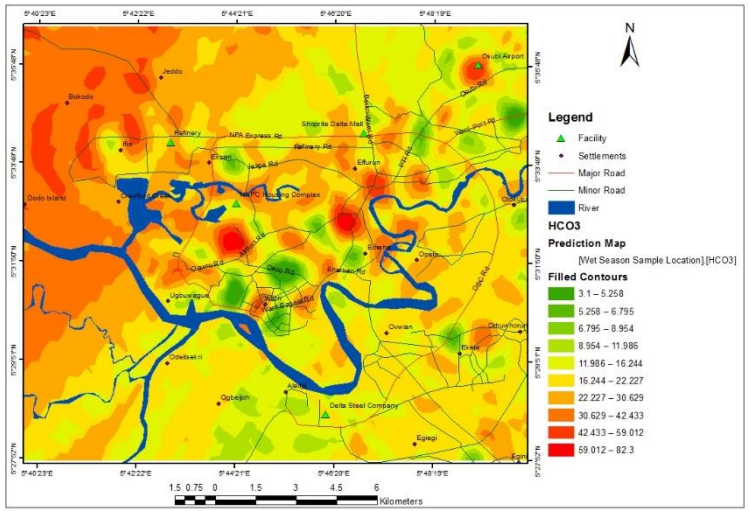
(p): SO_4



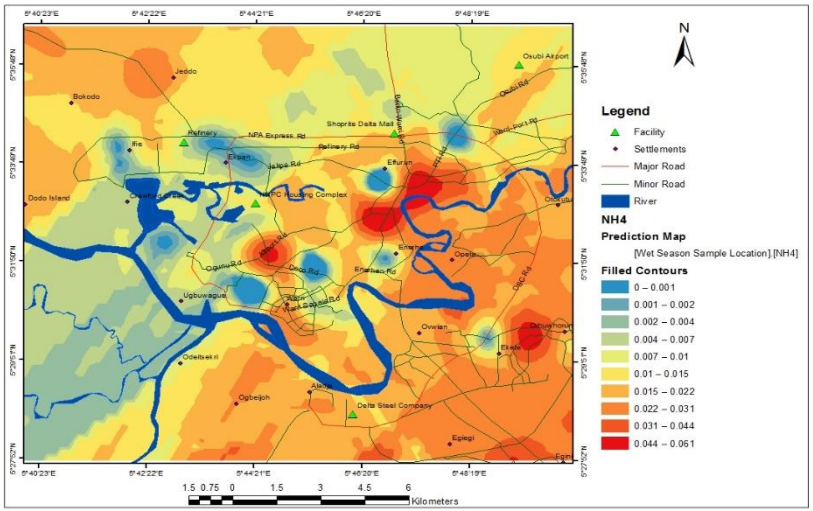
(q): NO_3



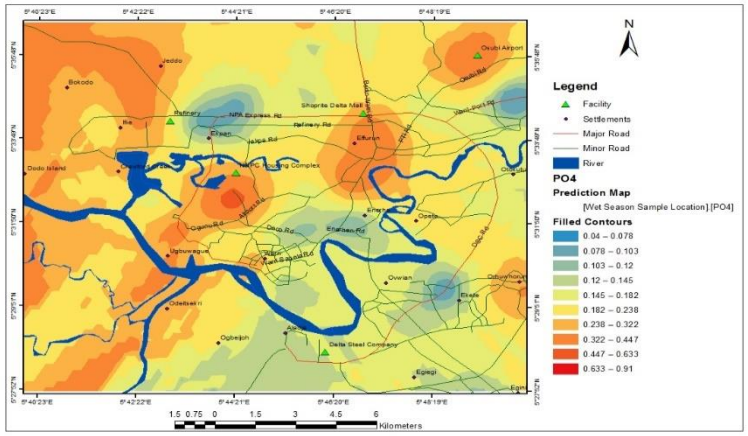
(r): Cl



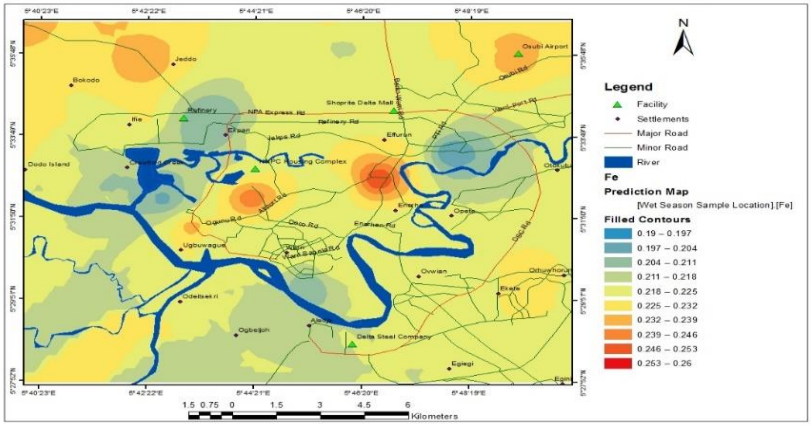
(s): HCO_3



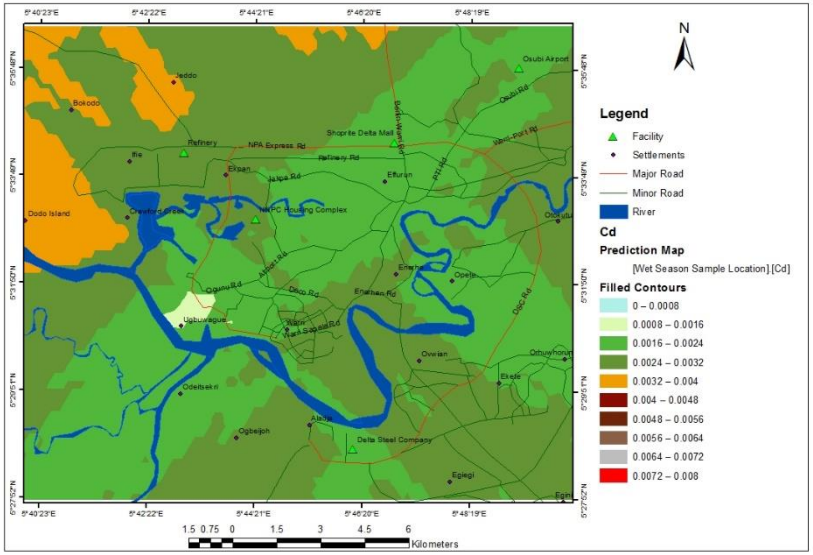
(t): NH_4



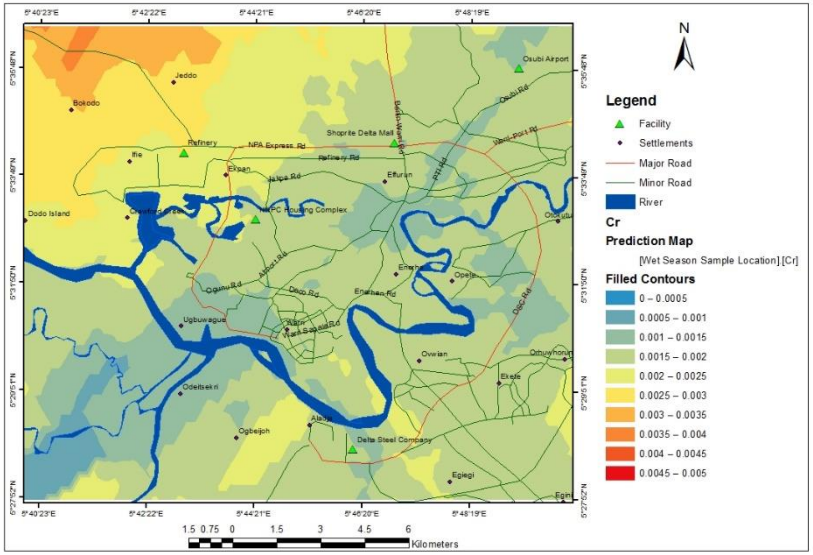
(u): PO_4



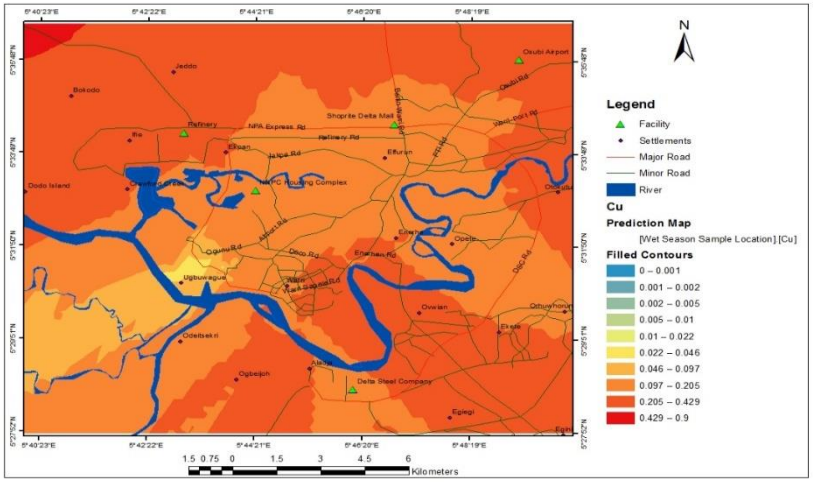
(v): Fe



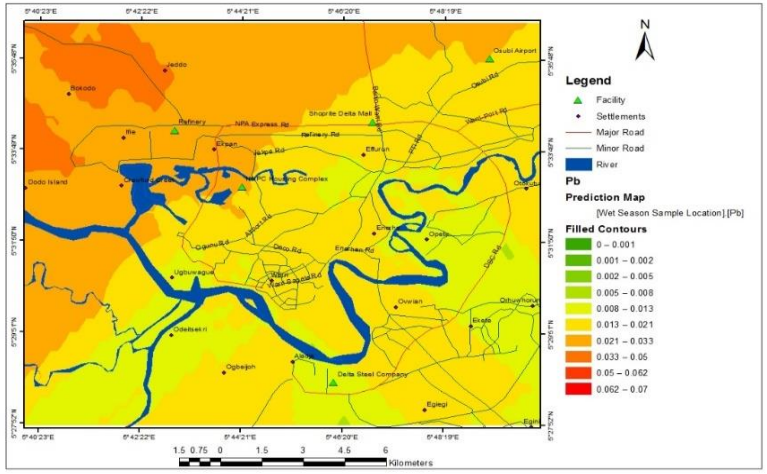
(w): Cd



(x): Cr


Legend
Facility
Settlements
Major Road
Minor Road
River
Cu
Prediction Map
[Wet Season Sample Location].[Cu]
Filled Contours
0 – 0.001
0.001 – 0.002
0.002 – 0.005
0.005 – 0.01
0.01 – 0.022
0.022 – 0.046
0.046 – 0.097
0.097 – 0.205
0.205 – 0.429
0.429 – 0.9
Kilometers

(y): Cu


Legend
Facility
Settlements
Major Road
Minor Road
River
Pb
Prediction Map
[Wet Season Sample Location].[Pb]
Filled Contours
0 – 0.001
0.001 – 0.002
0.002 – 0.005
0.005 – 0.008
0.008 – 0.013
0.013 – 0.021
0.021 – 0.033
0.033 – 0.05
0.05 – 0.062
0.062 – 0.07
Kilometers

(z): Pb