GROUNDWATER RESOURCES OF OWERRI AND ENVIRONS, OWERRI SHEET 320 NE SOUTH EASTERN NIGERIA

BY

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P15SCGL8011

DEPARTMENT OF GEOLOGY

AHMADU BELLO UNIVERSITY,

ZARIA, NIGERIA

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DEDICATION

This Research work is dedicated to Jesus, Mary and Joseph of the holy family, to my lovely parents, Sir and Lady E.O.C Dim, my wife and siblings.

QUOTATION

Everything comes to you at the right moment. Be patient.

DECLARATION

I declare that the work in this Dissertation entitled "Groundwater Resources of Owerri and Environs, Owerri Sheet 320 NE South Eastern Nigeria" has been carried out by me in the Department of Geology, Faculty of Science, Ahmadu Bello University Zaria. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this Dissertation was previously presented for another degree or diploma at this or any other Institution.

Nwanya Anthony Chikwado	.....	21-11-2016
Student	Signature	Date

CERTIFICATION

This Dissertation entitled "Groundwater Resources of Owerri and Environs, Owerri Sheet 320 NE South Eastern Nigeria by NWANYA ANTHONY CHIKWADO meets the regulations governing the award of the degree of Master of Science in Geology (Hydrogeology) of the Ahmadu Bello University, Zaria, Nigeria and is approved for its contribution to knowledge and literally presentation.

Prof. S.A Alagbe Chairman Supervisory Committee	..... Signature	22/11/2016 Date
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Prof. Bala Kabir Dean, School of Postgraduate Studies	..... Signature	..... Date

vi

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Any omission is unintentional and quite regretful.

ABSTRACT

Evaluation of groundwater resources of Owerri and environs in Imo State, southeastern Nigeria has been done. This involved assessment of groundwater occurrence and flow, aquifer hydraulics (borehole yields, hydraulic conductivity, transmissivity and groundwater flow velocity), hydrochemistry and totalwater reserves (water budget). This was achieved through detailed hydrogeological mapping at the end of wet season (October, 2012) and peak of dry season (April, 2013).The area is underlain by the Benin Formation which is a major lithostratigraphicunit in Niger Delta Basin. One major aquifer unit (unconfined aquifer) is present in the study area. The grain size of the Benin Formation are classified as medium to coarse sand and fine gravel, well to moderately sorted and negatively skewed. The borehole yields (432 to 840 m^3/day) and hydraulic properties ($K = 4 \times 10^{-1}$), ($T = 864{,}000$ m/s) of the aquifer shows efficiency. Groundwater available for supply that will meet the current and/or projected (years 2015 to 2065) demand in Owerri (study area) is adequate, with surplus of 35,627,867,441.8 m^3/a.Average physical parameters of waters in the area such as temperature (26^oC), hydraulic conductivity (0.2235µS/cm) and pH(8.5) indicated excellent water for drinking and other purposes. The cations measuredare: Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Cu^{2+}, Pb^{2+}, Zn^{2+}, Cd^{2+},Hg^{2+}. The anions measured are: SO_4^{2-},NO_3^-,Cl^-, HCO_3^-. Water quality problems were identified at some sampling points of the study area where the average concentration of mercury (0.001 mg/l), lead (0.0055 mg/l) and cadmium (0.0628 mg/l) are high. The water in the area is largely characterized as Na - Ca - Mg - $HCO_3$with alkaline bicarbonate water type being the most dominant; and amounting to 85 % of the water. The ions trend is in the order: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$, for cations and $HCO_3^- > Cl^-$, for anions.Bacteriological analyses of waters, indicated presence of faecal coliform especially the E-coli.

TABLE OF CONTENTS

Contents **Page**

Title Page i

Dedication iii

Quotation iv

Declaration v

Certification vi

Acknowledgement vii

Abstract ..... …viii

Table of Contents .....ix - xix

List of Figure xv

List of Tables xvi

List of Plates ……... xvii

List of Appendices xviii

Acronyms xix

CHAPTER ONE

1INTRODUCTION 1

1.1 Aim and Objective 2

1.2 Scope of Study 3

1.3 Significance of the Study 3

1.4 Limitation 3

1.5 Previous Work Done 4

1.6 Location, Extent and Accessibility of the Study Area 7

1.7 Physiography 7

1.7.1 Relief and Drainage 7

1.7.2 Climate 9

1.7.3 Evaporation 10

1.7.4 Vegetation and Land-use Pattern 10

CHAPTER TWO

LITERATURE REVIEW 11

2 Introductions 11

2.1 Regional Geology in the Study Area 11

2.1.1 Stratigraphic Succession of Rocks in the Area. 13

2.2Hydrogeology and Groundwater Assessmentsof the Study Area 15

CHAPTER THREE

MATERIALS AND METHOD

3 Introductions 20

3.1 Methods of Investigation 20

3.1.1 Desk Study 20

3.1.1.2Evaluation of Field Data 26

3.1.1.3 Hydrogeological Maps 26

3.1.1.4Watertable Contour Maps 26

3.1.1.5 Hydrogeological Cross-section 27

3.1.2 FIELD WORK 27

3.1.2.1 Reconnaissance Survey 27

3.1.2.2 Water Level Measurements 27

3.1.2.3 Water Sampling 28
3.1.2.4 Sample Collection and Storage 28
3.1.2.5 Sediment Sample Collection 30
3.1.2.6 Geological Mapping 30
3.1.3 The Laboratory Work 30
3.1.3.1 Analysis of Physical Properties of Water Samples 31
3.1.3.2 Colour Determination by LovibondComparism Method 31
3.1.3.3 Turbidity Determination by using Turbidimeter 32
3.1.3.4 Alkalinity Determination by H_2SO_4 Titrimetric Method 33
3.1.3.5 Hardness Determination by EDTA Titrimetric method 34
3.1.3.6 Total Dissolved Solids (TDS) Determination by Instrumental method 35
3.1.4 Analysis of Chemical Characteristics of Water Sample 36
3.1.4.1 Determination of Sodium (Na^+) and $(K+)$ by Flame Photometer or Flame Photometry Method 36
3.1.4.2 Determination of Calcium (Ca^{2+}) and Magnesium $(Mg^{2+})$by Atomi Absorption Spectrophotometry (AAS) Method 37
3.1.4.3 Determination of Mercury (Hg^{2+}) by Cold Vapour Atomic Absorption Spectrophotometry (CVAAS) Method 38
3.1.4.4 Determination of Copper (Cu^{2+}), lead (Pb^{2+}), zinc (Zn^{2+}) and Cadmium (Cd^{2+}) by Extraction/Acetylene Flame Method 39
3.1.4.5 Determination of Iron II (Fe^{2+}) by a Spectrophotometry Method 40
3.1.4.6 Determination of Chloride (Cl^-) by Argent metric Method 40
3.1.4.7 Determination of Carbonate and Bi-Carbonate by Titrimetric Method 41
3.1.4.8 Determination of SulphateSO_4^{2-} and Nitrate (NO_3^-) by Photometric Method 42
3.2.3.2.9 Determination of (NO_3^-) Nitrate by Cadmium Reduction Method using Bench Photometers 43
3.1.5 Water Samples Bacteriological Analysis 43

3.1.5.1 Membrane Filtration Technique 44

3.1.6 Sediments Grain Size Analysis 44

CHAPTER FOUR

RESULTS AND INTERPRTATION 45

4 Geology of the Study Area 45

4.1 Determination of Watertable Elevation 49

4.1.1Watertable Contour and Groundwater Flow 49

4.1.2 End of Wet Season 53

4.1.3 Peak of Dry Season 53

4.1.4 Recharge in the Study Area 53

4.1.5 Discharge in the Study Area 54

4.2 Aquifer of the Study Area 54

4.3 Hydraulic Properties of Aquifer in the Study Area 55

4.3.1 Hydraulic Conductivity (K) 56

4.3.2 Transmissivity (T) 56

4.3.3 Groundwater Flow Velocity 56

4.4 Grain Size Evaluation of the Area 56

4.5 Evaluation of Total Water Reserves (Water Budget) 57

4.5.1 Total Static Water Resources of the Study Area (tWRs) 57

4.5.2 Total Dynamic Water Resources of Owerri 58

4.5.3 Utilizable Dynamic Water Resources of the Study Area (uWRd) 60

4.6 Water Demand and Consumption 60

4.6.1 Population of Water Consumers in Owerri (Study area) 60

4.6.2 Water Demand in Owerri 61

4.7 Hydrochemistry and Water Quality 62
4.7.1 Physical Qualities of Water in the Area 62
4.7.1.1 Colour 62
4.7.1.2 Temperature 63
4.7.1.3 Conductivity 63
4.7.1.4 Hydrogen Exponent (pH) 65
4.7.1.5Odour 65
4.7.1.6 Total Dissolved Solid (TDS) 65
4.7.2 Chemical Qualities of Water of the Study Area 65
4.7.2.1Total Hardness (calcium and magnesium ions in mg/l) 65
4.7.2.2 Calcium (Ca^{2+}) ion 66
4.7.2.3 Magnesium (Mg^{2+}) 66
4.7.2.4 Sodium (Na^{+}) 66
4.7.2.5 Potassium (K^{+}) 66
4.7.2.6 Iron (Fe^{2+}) 67
4.7.2.7 Zinc (Zn^{2+}) 67
4.7.2.8 Mercury (Hg^{2+}) 67
4.7.2.9 Copper (Cu^{2+}) 68
4.7.2.10 Cadmium (Cd^{2+}) 68
4.7.2.11 Lead (Pb^{2+}) 68
4.7.2.12 Chloride (Cl^{-}) 68
4.7.2.13Sulphate (SO_4^{2-}) and Nitrate (NO_3^{-}) 69
4.7.2.14 Bicarbonate (HCO_3^{-}) 69
4.7.3 Microbial analysis 69
4.7.4 Salinity Hazard and Sodium Absorption Ratio (SAR)70
4.7.5 Classification of Water in the Study Area (Owerri) 71

CHAPTER FIVE

5 Discussions 73

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATIONS 84

6Summary and Conclusion 84

6.1 Recommendations 86

6.2 Contribution to Knowledge 87

REFERENCES 88

APPENDICES 94

LIST OF FIGURES

Figure	Description	Page
1	Location Map of the Study Area	8
2	Geological and Mineral Resources Map of Imo State	12
3	Grain Size Graph of Sediment Sample Located at Orji mechanic	22
4	Grain Size Graph of Sediment Sample Located at Concorde villa	23
5	Grain Size Graph of Sediment Sample Located at Uratta	23
6	Water Sampling Locations in the Study Area	29
7	Geological Map of the Study Area	48
8	Groundwater Contour Map at the End of Wet Season in the Study Area	51
9	Groundwater Contour Map at the Peak of Dry Season in the Study Area	52
10	Correlation between Depth of Rainfall and Runoff Coefficient in Drainage Basins	59
11	Wilcox Classification of Irrigation Waters using Water Samples Collected	70
12	Piper Trilinear Diagram Showing the Water Types in the Study Area	72
13	Schoeller Semi Logarithmic Diagram Showing the Relative Abundance of Cations and Anions in the Study Area	72

LIST OF TABLES

Tables	Description	Page
1	Stratigraphic Succession of Rocks in the Study area	14
2	Well Characteristics from Accessible Boreholes in the Study Area	50
3	Aquifer Properties of the Study Area	55
4	Data from Sediments Grain Size of the Study Area	56
5	Classification of Total water Reserve	57
6	2006 Population Census of Owerri by Local Governments	61
7	Summary of Water Budget for Owerri (Study Area)	62
8	Range of Values of Physico-chemical and Microbial Analysis from the Study Area and WHO Guidelines for Drinking Water	63
9	Result of the Physico-chemical and Bacteriological Analysis of Water Samples of the Study Area	64
10	Hydrochemical Data in meq/l for the Study Area (Owerri)	71
11	Folk and Ward's (1957) Verbal Terms and Scales for Grain Size Parameters	73
12	Groundwater Flow Potentials Trends in Owerri	75
13	Freeze and Cherry's (1979) Range of Values of Hydraulic Conductivity of Geological Material	75
14	Kampsax-Kruger's (1985) Rating of Transmissivity Values	76
15	Gheorge's (1978) Standard for Aquifer Transmissivity	76
16	Kransny's (1993) Classification of Aquifer Transmissivity	77
17	Suitability of Water for Irrigation, in Respect of Salinity Hazard	82

LIST OF PLATES

Plates	Description	page
1	Outcrops of Benin Formation at Nekede Gravel Mines Showing Reddish-brown Medium Sand with Intercalation of Clay, brownish-white Gravel Beds and whitish Coarse Sand in the Study Area	45
2	Outcrops of Benin Formation at Egbeada-Amakohia Gravel Mines Showing Reddish-brown Medium Sand with Intercalation of Clay and Brownish-white Gravel Beds in the Study Area	46
3	Outcrops of Benin Formation at Nekede Gravel Mines Showing Typical Aquifer (Whitish Coarse Sand) of Coastal plain Sand in the Study Area	46
4	Mined Gravel of Benin Formation beside Otamiri River in the Study Area	47
5	Sand Mine of Benin Formation beside Otamiri River in the Study Area	47

LIST OF APPENDICES

Appendix	Description	page
1A	Values of Rainfall inOwerri	94-95
1B	Values of Evaporation inOwerri	96-97
1C	Values of Temperature inOwerri	98-99
2A	Particle Size Distribution Analysis Result for Sediment Sample at Orji mechanic	100
2B	Particle Size Distribution Curve for Sediment Sample at Orji Mechanic	101
2C	Particle Size Distribution Analysis Result for Sediment Sample at Concorde Villa	102
2D	Particle Size Distribution Curve for Sediment Sample at Concorde Villa	103
2E	Particle Size Distribution Analysis Result for Sediment Sample at Uratta	104
2F	Particle Size Distribution Curve for Sediment Sample at Uratta	105
3A	Hydraulic Conductivity (K) Calculation	106
3B	Transmissivity (T) Calculation	107
4	Area of Owerri (study area) using topographical map studied	108
5	Certified Copy of Physicochemical Analysis	109-111
6, 7, 8	Logging Details of Water Boreholes in the Study Area	112-114
9, 10	Pumping Test Data in the Study Area	115-123

ACRONYMS

a.m.s.l.	Above Mean Sea Level
NE	Northeast
BDL	Below Detective Limit
GPS	Global Positioning System
Km^2	Square Kilometer
Lat.	Latitude
Long.	Longitude
m/s.	Meter per second
m	Meters
b.m.s.l.	Below Mean Sea Level
mg / l	Milligram per liter
*u*S / cm	Microsiemens per centimeter
µg/l	Microgram per liter
ml	Milliliter
m^2/d	Meter Square per Day
m^3/d	Cubic Meter per Day
m^3/hr	Cubic Meter per Hour
g/hr	Gallon per hour
N	North
P^H	Hydrogen Exponent
SWL	Static Water Level
T	Coefficient of Transmissivity
K	Hydraulic Conductivity
NA	Not Analyzed
TDS	Total Dissolved Solids
tWRs	Total Static Water Resources
tWRd	Total Dynamic Water Resources
uWRs	Utilizable Water Resources
uWR	Utilizable Water Resources
uWRd	Utilizable Dynamic Water Resources
nWRd	Non –utilizable Dynamic Water Resources
nWRs	Non-utilizable Static Water Resources
nWR	Non-utilizable Water Resources
ND	Not Detected
NIMET	Nigeria Meteorological
WHO	World Health Organization
APHA	America Public Health Association

CHAPTER ONE

1 INTRODUCTION

Groundwater has been exploited for domestic use, livestock and irrigation since the earliest times.About two billion people (approximately one-third of the world's population) depend on groundwater supplies, withdrawing about 20 percent of global water (600 to 700km^3) annually, much of which is from shallow aquifers (Foster,Garduno, Kemper, Tuinhof and Dumars;*2005*). Groundwater provides a reasonably constant source of water supply that is not likely to dry up under natural conditions.

Offodile (2002) maintained that groundwater is an important resource and it is known to occur more widely than surface water, but its availability is limited by so many factors such as porosity, permeability, storativity etc. Groundwater in storage is made available to man through discharge processes which could be natural or artificial. Discharge without replenishment (recharge) could result to a number of problems, including depletion of groundwater which can lead to well failure or low yield.Groundwater is known to be reasonably safe for domestic use when it occurs at acceptable depths, free of surface contamination and exploited by means of boreholes or any other technically sanitary means (Offodile, 2002).

Domestic and industrial discharges into groundwater and surface water bodies vary in nature, quality and quantity, thus contributing significantly to chemical, biological and physical pollution of these water bodies.

Owerri is one of the rapidly growing urbanization centers of Nigeria and industrialization has placed an increasing demand for water, many privately-owned boreholes have been sunk into the shallow aquifers hence; regular evaluation of groundwater is of fundamental importance,

sinceabout 95 percent of the inhabitants of Owerri rely on groundwater sources for their daily water needs.

Groundwater resources in this work has been taken to include variation of groundwater levels, the recharge and discharge characteristics of groundwater which would be useful in identifying areas of potential groundwater pollution and/or contamination, calculation of some aquifer parameters (include hydraulic conductivity, specific yield and transmissivity), groundwater flow directions, physico-chemical, bacteriological analyses of groundwater and water budget. In continual evaluation of groundwater resource especially in the study area (Owerri), the researcher decided to carry out Groundwater Resources of Owerriand Environs, Owerri Sheet 320 NE South Eastern Nigeria

1.1Aim and Objectives

This work aims to study the hydrogeology; qualitatively and quantitatively evaluate Groundwater Resources of Owerri and Environs Owerri Sheet 320 NE, south-eastern Nigeria.

The objectives of this study included:

a) Determination of the favourable aquifer for groundwater development,

b) determining the availability of groundwater for the present and future use in the study area (water budget),

c) establishing the groundwater flow direction and hence, the recharge and discharge characteristics from the hydrogeological map,

d) forecasting the future water resource surplus/deficit and ways of curbing it,

e) determination of the quality of groundwater and its suitability for drinking and other uses.

1.2 Scope of the Study

These included reconnaissance survey, collection of journals, literatures and hydrometeorological data from the appropriate agencies such as (NIMET, Imo State Water cooperation and Census Commission), hydrogeological investigation using the appropriate apparatus at the right time of the season, collection of water and sediment samples, hydrochemistry of the water samples, sediment grain size analyses, production of hydrogeological maps (wet and dry seasons), production of hydrogeological cross sections (both seasons), interpretation and evaluation of hydrogeological data.

1.3 Significance of the study

This study will:

(i). Help hydrogeologists and water related disciplines in the State to know the nature and

occurrence of groundwater in the area;

(ii). serve as a reference to researchers for further research(s).

1.4 Limitations

The major problems encountered in this project included:

a. difficulty in gaining access to privately-owned boreholes,
b. difficulty in acquiring borehole lithological logs and pumping test data, since drilling records were hardly kept,

c. financial constraints in successful completion of the required field work, laboratory analysis, and requisite materials for data processing and interpretation

1.5 Previous Work Done

The continued expansion in the utilization of groundwater has resulted in an ever increasing need for professionals to keep evaluatinggroundwater resources.

Ibe, Nwankwo and Onyekuru(2007) worked on groundwater pollution vulnerability and groundwater protection strategy for the Owerri area and identified that landfill in its present condition creates nuisance of odour, destroys the aesthetic nature of the environment and imperils water resources. By far the most significant result of his investigation is the high concentration of phosphate and nitrate in the water bodies.

Amadi, Olasehinde and Yisa(2010) assessed the characterization of groundwater chemistry in the coastal plain-sand aquifer of Owerri using factor analysis and observed that the result of the multivariate statistical analysis, as applied to the chemical data set of groundwater in the Coastal Plain sand of Owerri area provides an insight into the underlying controlling hydrochemical processes in the area.

Nwachukwu, Feng and Ophori (2010) assessed the groundwater flow model and particle track analysis for selected water quality monitoring wells in Owerri and observed that natural direction of surface drainage fairly corresponded to the direction of groundwater flow except diversions due to man-made structures. Nwachukwu*et al. (2010)* also reported a typical geologic section (Geo-electric) using Vertical Electric Sounding (VES) in Owerri and environs, describing the composition of the layers predominantly of fine sand, gravels, silts and clay lenses.

Amadi and Olasehinde(2008) attributed salt water incursion into Coastal Plain sand aquifer in the study area as the aquifer recharge from the tide-influenced Imo river area. High nitrate, nitrite and sulphate in water are majorly induced by fertilizer application (Amadi*et al, 2008*). Amadi*et al,(2008)* further reported that understanding the quality of groundwater with its temporal and seasonal variation is important because it is the factor that determines the suitability for drinking, domestic, agricultural and industrial purposes.

Owuama and Uzoije (2005) studied extensively the microbial pollution of groundwater in Owerri area and established that the bacteria contents exceeded the permissible limits allowed for drinking water.

Akaolisa and Selemo (2009) reported the geophysical investigation at Owerri area using vertical electrical sounding (VES) approach. They considered the high resistivity values encountered at depths of 30 m to 100m and even beyond which is indicative of fresh-water saturated sand and gravel (Benin Formation). They further reported that the area lacks impermeable units overlying the aquifer, and strongly proposed that the construction of sewage system at this area should be avoided for this will pose very serious health hazards to the aquifer catchments.

Offodile (2002) explained that groundwater is held in porous formations, often described as reservoirs or aquifers. Porosity of such reservoirs depends on the texture of the rock formation.

Ibe, Sowa and Osondu(1990)observed and reported that low pH in Otamiri river could be due to existence of compounds like chloride of iron or aluminium, which hydrolyze in excess water to produce solutions (Lewis acids).

Akubugwo and Duru(2011) evaluated Otamiri river and observed that metals such as Sodium, Calcium, Potassium, Magnesium, Iron, Zinc, Copper, Manganese values were lower than

recommended WHO standard, while Cadmium, Chromium, Lead, Arsenic and Mercury were not detected in the river.

Ibe and Uzoukwu (2001) studied groundwater flow assessment using empirical methods and found out that groundwater flow to the SW in Owerri area based only on topographic analysis.

Nwankwo and Anyaogu (2000) described groundwater's interaction with wetland and streams based on piezometric data in part of study area.

Ibe and Njoku (1999) used the electrical resistivity method to observe groundwater flow from the abandoned solid waste dumps near Obinze. The results indicated flows in three directions: NE-SE, N-S and E-W.

Ibe*et al., (2007)* reported using environmental impact models, stating that pollutants could easily migrate to watertable and immediately contaminate groundwater.

Nnaji and Duru (2007) reported physicochemical analysis representing land use patterns along the watershed of Otamiririver. The water samples were analyzed in the laboratory with data logging spectrophotometer and in situ measurements in the field were taken with multi-probe meter. In his report, Otamiri is polluted and posed health threat to Owerri residents.

Owuama*et al., (2005)* studied microbial pollution of groundwater in Owerri and established that the bacterial content exceeded the maximum permissible limit allowed for drinking water.

Oparaocha, Iroegbu and Obi (2010) reported water quality deterioration due to the physical conditions of immediate environment of water sources in federal University of Science and Technology Owerri, noting that the domestic activities and proximity of drainage within the

boreholes resulted to the P^H of water samples to be slightly acidic when compared to WHO standards.

Ibe*et al., (1999)* reported that most of the wastes from Owerri are dumped at Avu landfill along Portharcourt high way, which creates a high concentration of phosphate and nitrate in Otamiririver in south Owerri.

Iwegbu (2007) studied the metal fractionation in soil profile at automobile mechanic waste dump around Portharcourt road and observed that metals such as Pb, Cd, Fe contaminated the soil.

Ahiarakwem, Nwankwo,Chinemelu and Pascal (2014) studied groundwater potential in Owerri and observed that Owerri is segmented into areas characterized by moderate and high groundwater flow potential.

1.6 Location, Extent and Accessibility of the Study Area

The study area; Owerri and environs, comprises Owerri Municipal, Owerri-west and Owerri-north Local Government Areas with parts of Mbaitoli and Ikeduru, It lies between latitudes $5^0 20'$ to $5^0 32'$N and longitudes $6^0 51'$ to $7^0 08'$ E, covering an area of about 740km^2 (Fig 1).

1.7 Physiography

1.7.1 Relief and Drainage: The area is predominantlylow-lying with a good road network (Fig 1) and the terrain is characterized by two types of land forms namely, the undulating in the northeast and nearly flat topography in the southwest (Ibe*et al., 2007*). The area is well drained by rivers Otamiri, Nworie, Mbaa, and seasonal Okitankwo(Fig. 1). Surface water recharge is mainly from surface run off and ground water base flow; peak discharge occurs in September and October (Enuvie, Ophori, Enebeli and Nwadibia.,1991).

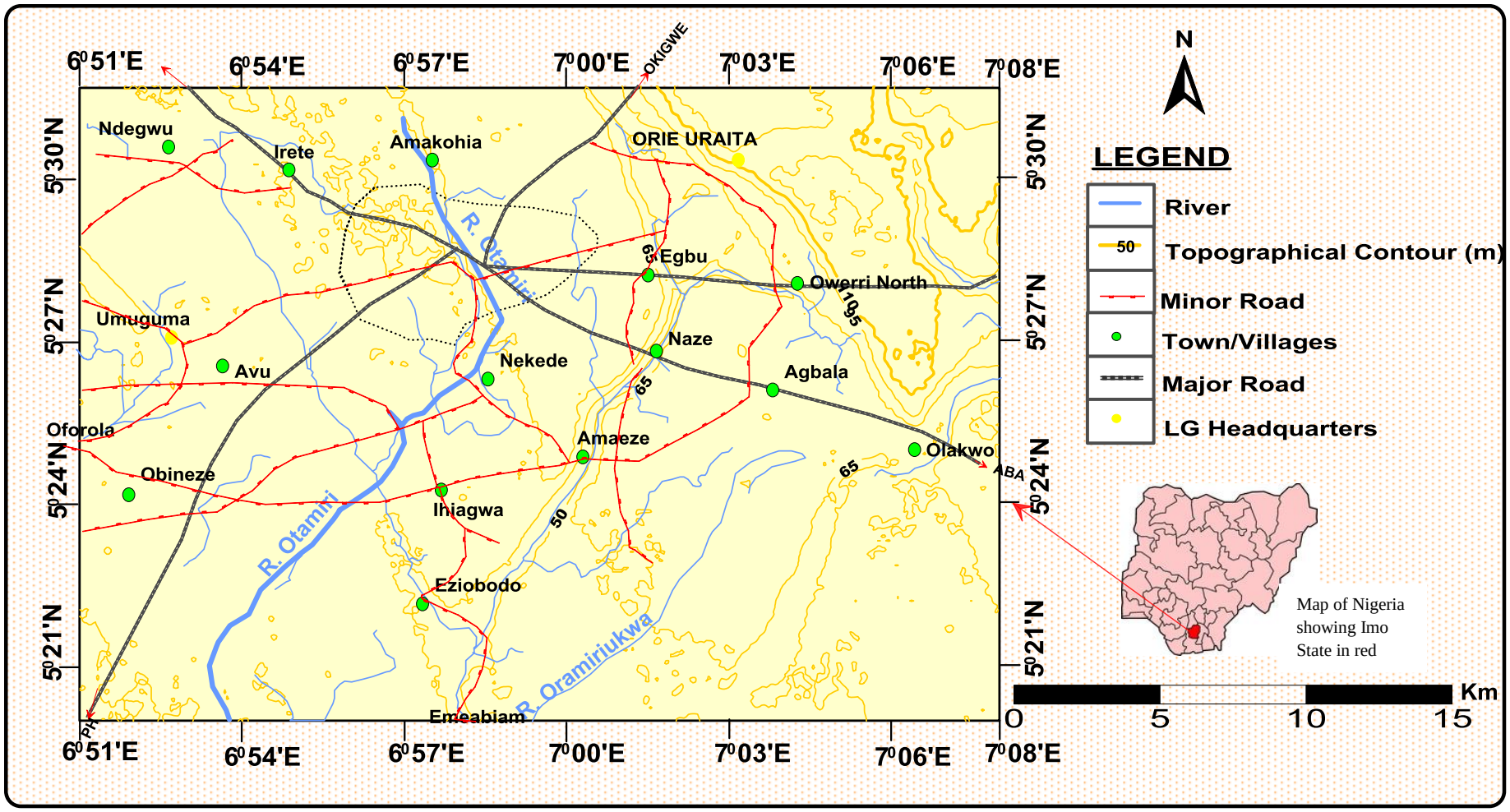


Fig. 1: Location Map of the Study Area (Carved from Department of Lands, Survey and Urban Development, Owerri, 1984)

The river runs south from Egbu, Owerri and through Nekede, Ihiagwa, Eziobodo, Olakwu, Umuisi, Mgbirichi and Umuagwo to Ozuzu in Etche, in the Rivers State, from where it flows to the Atlantic Ocean (Uma and Kehinde, 1992).

The Otamiri is joined by the Nworie River at Nekede in Owerri, a river about 9.2 km in length, subjected to intensive human and industrial activities, and used as a source of drinking water by the poor when the public water system fails. The topographical map of the study area shows that the highest point in the area is 121.92 meters while the lowest point is 45.72 meters.

1.7.2 Climate: Climate is a measure of the average pattern of variation in temperature, humidity, atmospheric pressure, wind, precipitation, atmospheric particle count and other meteorological variables in a given region over a long period of time. The area is marked by two main climatic regimes: the rainy and dry seasons. The wet season starts from April to October, during which the temperature varies from 23 to 26^{o}C. This season is associated with the prevalent moisture-laden southwest trade wind from the Atlantic Ocean. This rainy season is also characterized by double maximum rainfall during which the peaksoccur in July and September with a mean annual rainfall of 2152 (Short and Stauble, 1967). A high evapotranspiration rate induced by dry conditions further helps to increase water losses (Etu-Efeotor and Odigi, 1983). The dry season starts in November when the dry continental north-eastern wind blows from the Mediterranean Sea across the Sahara Desert and down to the southern part of Nigeria. Appendix 1A shows the annual rainfall for a period of 15 years (2000 to 2015) in the study area.

Humidity is usually low and clouds are absent during dry season. The effect of the harsh North easterly wind, also called harmattan, is also felt within the period. A mean annual temperature of

32^{o}C is typical of the area (Ezeigbo, 1987). Appendix 1Bshows the annual temperature data for a period of 14 years (2001 to 2015) in the study area.

1.7.3 Evaporation: Evaporation is the transfer of water from the earth into the atmosphere from surface water and soil. Reduction in the rate of evaporation constitutes a means of conserving water for agricultural, industrial and municipal uses. Appendix 1C shows the annual rate of evaporation for a period of 15 years (2000 to 2015) in the study area.

1.8.4 Vegetation and Land-use Pattern: Vegetation simply means the plant cover of the earth. Generally, the study area is dominated by rainforest vegetation whose density is substantially depleted by anthropogenic influences. Trees such as oil palm trees and Bamboo trees can be found in some major parts of the study area. The natural vegetation in the greater part of the area had also been replaced by derived savannah grassland interspersed with oil palm trees. The study area belongs to freshwater swamp forest, a subdivision of forest vegetation belt of Nigeria. This vegetation belt is typical of which trees are the most dominant species. Offodile (2002) reported that vegetation of the area is typically tropical rain forest. Varying and conflicting land uses such as farming, sand mining, car washing, waste disposal, recreational facilities, and engineering activities are common in the study area.

CHAPTER TWO

LITERATURE REVIEW

2Introductions

The demand for groundwater in virtually all parts of Nigeria is growing fast every time. This is as a result of rapid population growth and industrialization in the country. Geology of an area helps in determining the groundwater assessment of that area. This chapter reviews some related literatures with respect to regional geology, hydrogeology and groundwater quality assessment of the area.

2.1Regional Geology

The tertiary Niger Delta Basin of which the study area is a part of consists of major stratigraphic Formations, namely (from top to bottom): Benin, Agbada and Akata Formations (Short and Stauble, 1967). The Niger Delta basin is situated on the margin of the Gulf of Guinea in Equatorial West Africa, and extends from Calabar flank and Atlantic Ocean in the south (Reijer, 1996). Akata and Agbada Formations are the source and reservoir rocks respectively for petroleum in the Niger Delta.

The study area is underlain by the Benin Formation (Fig 2). It consists mainly of friable sands, conglomerates, very coarse sandstone and isolated gravel units and intercalation of shale/clay lenses of Pliocene to Miocene age (Horton, 1965; Short and Stauble, 1967; Ananaba, Onu and Iwuagwu., 1993). The sands and sandstones are coarse to fine-grained partly unconsolidated with thickness ranging from 0 to 2100meters (Avbovbo, 1978). The sediments represent upper deltaic plain deposits andthe environment of deposition is partly lagoonal and fluvio-lacustrine/deltaic

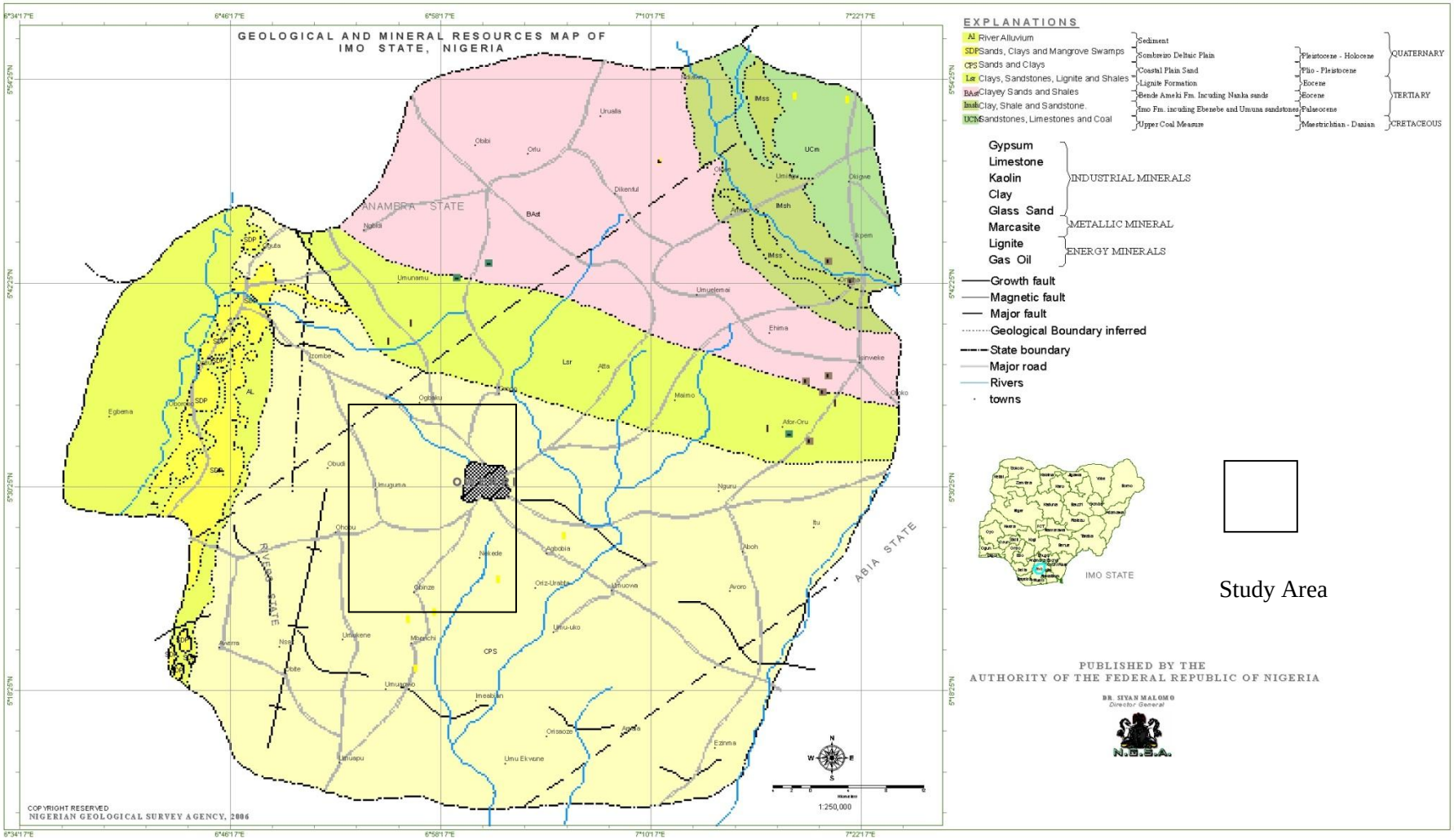


Fig 2: Geological and Mineral Resources Map of Imo State, Nigeria (After NGSA, 2006)

(Rayment, 1965).The formation which dips south-westward starts as a thin edge layer at its contact with Ogwashi-Asaba Formation in the northern part of the area (Rayment, 1965). The sandy unit which constitutes about 95% of the rock in the area is composed of over 96% of quartz (Onyeagocha, 1980). In many places within the area, the formation is overlain by a considerable thickness of earth (laterite) composed of iron-stained regolith formed by the weathering and subsequent ferruginization of the weathered materials. The Benin Formation within the Imo River Basin consists of unconsolidated yellow and white coastal plain sands with gravel beds, occasionally pebbly with grey sandy clay lenses (Nwachukwu*et al., 2010*). The Benin Formation comprises of a thick sequence of poorly consolidated to unconsolidated sandstones that are friable with sorting ranging from poorly to fairly sorted (Onyeagocha, 1980). The Benin Formation has lithologies consisting of sands, silt, gravel and clayey intercalations (Asseez, 1989). The top soil contains slight to moderate amount of humus and has a pH range of 4.5 to 4.9 (Chikezie, Eswaran, Asawalam and Ano, 2010). Figure 2 shows the geological and mineral resources of Imo state, Nigeria.

2.1.1 Stratigraphic Succession of Rocks: The stratigraphy of the south eastern Nigeria has been studied in detail by Uma and Egboka (1986). The stratigraphic succession of rocks in Imo State consists of Nsukka Formation, being the oldest formation and followed by Imo Shale, Ameki Formation, Ogwashi-Asaba Formation and Benin Formation (Uma and Egboka, 1986) (Table 1).

a)The Nsukka Formation: This was deposited during the Maastrichian - Upper Cretaceous age (Uma and Egboka, 1986). This formation consists essentially of dark shale, sandy shale, carbonaceous shales with thin coal seams. The grains are medium to coarse. It has some sandstone members reported to be up to 15meters. Nsukka Formation is the oldest formation with the thickness of more than 300meters (Offodile, 2002).

Table 1 Stratigraphic Succession of Rock in the Study Area (Uma and Egboka, 1986)

AGE	FORMATION	LITHOLOGY
Miocene-Recent	Benin Formation	Medium to coarse grained poorly consolidated with clay lenses and stringers.
Tertiary-Oligocene-Miocene	Ogwashi-Asaba Formation	Unconsolidated sand with lignite at various layers.
Eocene	Ameki Formation	Grey clayey-sand stone and sandy clay stone.
Paleocene	Imo Shale	Laminated clayey-shale.
Maastrichian- Upper Cretaceous	Nsukka Formation	Sand stone intercalated with shale and coal beds.

b)The Imo Shale: Imo Shale of Paleocene age was deposited during transgression period that followed the Cretaceous (Uma and Egboka, 1986). It developed as thick blue to greyish clay with a maximum thickness of about 1000meters. Uma and Egboka (1986) reported Imo Shale as laminated clayey-shale which is impervious and characterized by lateral and vertical variation in lithology. It dips at angles 17^{o} to 25^{o} to the south-west and the south (Uma, 1989). It includes three constituent sandstones: the Igbabu, Ebenebe and Umuna Sandstones outcropping at Imo river. The Umuna sandstone is composed of thick sandstone units and minor shales and is generally less than 70meters thick. The Ebenebe Sandstone occurs as a lens in the northwesternextremity. It is similar in lithology to the Umuna sandstone but is relatively thicker with a maximum thickness of 130meters (Uma, 1989).

c)The Ameki Formation: Overlying the Imo Shale is the Ameki Formation, which extends far south to the Okigwe area where most of it is covered by the Benin Formation. It was deposited

during Eocene age (Uma and Egboka, 1986) and consists essentially of greenish-grey clayey sandstone, shale, and mudstones with interbedded limestone. Uma and Egboka (1986) reported Ameki Formation as grey clayey-sandstone and sandy claystone. The lithologic units of the Ameki Formation fall into two general groups (Reyment, 1965; Whiteman, 1982 and Arua, 1986); an upper grey to green sandstone and sandy clay and a lower unit with fine to coarse sandstone and intercalations of calcareous shales and thin shaly limestone.

d)The Ogwashi-Asaba Formation: This was deposited during Tertiary-Oligocene-Miocene age (Uma and Egboka, 1986). It is made up of variable succession of clays, sands and grits with seams of lignite. Uma and Egboka (1986) reported this formation to be made up of unconsolidated sand with lignite at various layers.

e)The Benin Formation: This was deposited during Miocene-Recent age (Uma and Egboka, 1986). The Benin Formation consists of coarse-grained gravelly sandstones with minor intercalations of shales and clays. The sand units which are mostly coarse grained; pebbly and poorly sorted contain lenses of fine grained sands (Onyeagocha, 1980). The sands and sandstones are coarse to fine, partly unconsolidated with thickness ranging from 0 to 2100m (Avbovbo, 1978). Benin Formation is in part cross-stratified with the forset beds alternating between coarse and fine-grained sands. The petrographic study on several thin sections shows that quartz makes up more than 95% of all grains (Onyeagocha, 1980).

2.2 Hydrogeology and Groundwater quality Assessment

Ayoade (2003) described hydrogeology as the scientific study of groundwater with emphasis on the geology and its occurrence, movement and characteristics of groundwater. The mean thickness of the Benin Formation is about 800 meters and depth to watertable is about 18.3

meters below sea level (Avbovbo, 1978). The Benin Formation provides the aquifer for groundwater storage because of its high porosity and permeability. The incidence of high porosity and permeability, as well as shallowwatertable makes the groundwater in the area very vulnerable to pollution. The formation is generally water bearing and hence it is the main source of portable groundwater in the area (Nwankwo and Anyaogu, 2000). Therecharge is mainly by surface precipitation and nearly drainage sediments-deposition and groundwater flows are generally in the NW – SE trend, in line with the regional trend of the basin (Nwankwo*et al., 2000).* Recent investigation confirmed the presence of 40 to 70 counts of coliform per 100 ml of water in six out of ten sampled shallow wells around Owerri and this may have significant health implications (Nwachukwu, Feng and Alinnor; 2010). Offodile (2002) described the Benin Formation as the most aquiferous formation in Southern Nigeria with a transmissivity of 880 to 30,000 m^2/day, storativity of 1.53 to 3.16 x 10^{-3} and coefficient average porosity of 30 %. Akpokodje (1990) investigated the Benin Formation and reported unconfined to semi confined aquifers in certain places,Etu-Efeotor and Akpokodje (1990) identified three aquifers therein.Oteri (1988) evaluated saltwater intrusion in the Benin Formation using electric log interpretation, revealing occurrence of saltwater in freshwater aquifers at the upper zone of the Benin Formation between the depth of 30 meters and 947 meters.Offodile (2002) reported that Benin Formation area is generally flat lying with highest altitude not exceeding 180 meters above sea level and that pebble beds occur in places which has given rise to high yielding of boreholes. Offodile (2002) maintained that low yield at some areas in Benin Formation are attributed to finness and thinness of the aquifers, which are generally intercalated with clay shale and organic matter. The Benin Formation consists of predominantly freshwater continental friable sands and gravel that have excellent aquifer properties with occasional intercalations of

claystone/shales (Olobaniyi and Oweyemi, 2006). According to Etu-Efeotor (1981), Etu-Efeotor and Akpakodje (1990), Offodile (2002), Udom, Ushie and Esu (2002), the Benin Formation is highly permeable, prolific, productive and is the most extensively tapped aquifer in Niger Delta. According to Onyeagocha (1980), the rocks of Benin Formation are made up of about 95 to 99 % of quartz grains Na + K Mica 1 to 2.5 %, feldsper 0.5 to 1.0 % and dark minerals of 23 %. Multi-aquifer systems occur in the area and the upper aquifers are generally unconfined (Etu-Efeotor, 1981; Offodile, 2002; and Edet, 1993). The study area is drained by Rivers Otamiri, Nworie, Mbaa and Okitankwo with peak discharge occurring in September and October (Ezeigbo, 1987). These waters in the rivers are used for domestic and commercial water supply as well as for recreation, fishing and sand mining activities. Three main regional aquifers have been identified in the area by Maduagwu (1990) as;

a) The Coastal Plain sand (Benin Formation) Aquifer

b) The Bende Ameki Group (part of Anambra Basin) Aquifer

c) The AjaliFormation or False bedded Sandstones Aquifer

a)The Coastal Plain Sands (Benin Formation) Aquifer: The Coastal plain sands that cover all the area of study have annual replenishment of about 2.5 billion cubic meters (Leonard *et al*., 2010). It consists of alternating layers of sands, sandstones, and loams of clays. As the sandy component in most area forms more than 90% of sequence of layers, permeability, transmissivity and storage coefficients are high. The Static Water Level (SWL) ranges from 8 to 65meters depending on the location and the time of the year (Maduagwu, 1990). The Coastal sedimentary lowland is underlain by the Tertiary sediments of the deltaic plain, the coastal plain sand, Bende

Ameki and Imo shales. The high yearly average rainfall over the area of study ensures adequate groundwater recharge.

The depths to the aquifer vary from a few meters in the south to about 152.7meters with average depth of 45.7meters below the ground surface (Maduagwu, 1990).

Offodile (2002) reported that the Benin Formation aquifer has depth to watertable ranges between 3meters and 15meters below ground level but can be as deeper as 55 meters;an average specific capacity of 10,500lit/hr, (700g/hr) and the seasonal fluctuation of groundwater arebetween 2.1 and 3.6meters.

b)Bende Ameki Group (part of Anambra) Aquifer: The Bende Ameki group is composed mainly of sands intercalated with lignite and calcareous shale. The aquifer has a lowertransmissivity coefficient because of high percentage of shale. On the other hand, the depth of water table in the Bende Ameki is often considerable, reaching as much as 178.9meters (Maduagwu, 1990).

c)The Ajali Formation or False bedded Sandstones Aquifer: The Ajali Formation extends through the north eastern parts of the area and dips towards the south west. The rate of replenishment of groundwater is about 250 million cubic meters per year (Maduagwu, 1990). When comparedwith the Coastal plain sand and Bende Ameki group, it is the least prolific for ground water development. It consists of coarse sandstones with lenticular shales, beds of grit and pebbly gravel. The texture varies, but generally coarse. The aquiferous sands are friable, poorly sorted and typically whitish at depth (Offodile, 2002). Offodile (2002) reported a typical characteristic of boreholes in Ajali Formation as (Borehole A): Depth is 234meters, Drawdown is 6meters, Borehole yield is162m^3/hr and Static Water Level is 9.72 meters (Borehole B): Depth

is 247meters, Borehole Yield is 24m^3/hr, Static Water Level is 181.6meters, Drawdown is 1.89meters and Specific Capacity is 12.7m^3/hr.

Ahiarakwem*et al., (2014)* studied the variations in groundwater flow potential Benin Formation in Owerri and environs. The results indicated that hydraulic conductivities varies from 10^{-4} to 10^{-1} aquifer thickness from 36 to 50 meters, static watertablefrom 15 to 54 meters, transmissivity from 311.04 to 388, 800 m^2/day.

CHAPTER THREE

MATERIALS AND METHOD

3 Introductions

This chapter describes the study design, sampling methods and the techniques used in data collection and analysis. The field work for this project started in October 2012 and continued till April 2013.This was done in three stages. These included: desk study including; evaluation of field and laboratory analysis, field work and laboratory analysis

3.1 Methods of Investigation

3.1.1 Desk Study: This includesreviewing of existing related and relevant literatures such as bulletins, journals,collecting text books, geological and topographical maps.Data on rainfall and temperature (covering a period of fifteen (15) years were obtained from the Nigerian Meteorological Agency, Owerri. Relevant maps (topographical (on the scale of 1:50,000) and geological) were collected from Imo State Ministry of Lands and Survey and the Nigerian Geological Survey Agency, Owerri. Also, pumping test data and borehole logging details were collected from Anambra - Imo River Basin Development Authority.

The pumping test data collected from Anambra – Imo River Basin Development Authority done at Mbutu-AbohMbaise and Agbaja(Appendices 9 and 10) had already been calculated; and was based on Darcy's law which stated that the rate (Q) at which water flows through a porous medium is directly proportional to the length of the flow path and to the cross-sectional area (A) with a constant (K). Mathematically, the formula is expressed as: $Q \propto iA$

$$Q=KiA \qquad (1)$$

Where Q= discharge rate (m^3/day), K= hydraulic conductivity (m/day),i= hydraulic gradient= dh/dl i.e. loss of head (h) over the distance (l), A= cross sectional area perpendicular to the flow (m^2).The principle of constant discharge or rate (Q) of a pumping test involved applying a stress to an aquifer by extracting groundwater from a pumping well and measuring the aquifer response to that stress by monitoring drawdown as a function of time. These measurements were then incorporated into an appropriate well-flow equation as stated above to calculate the hydraulic parameters of the aquifer. Pumping test was done to determine how much groundwater can be extracted from the well based on long-term yield, and well efficiency, properties of aquifer(s), effect of pumping on the aquifer, suitable depth of pump and information on water quality and its variability with time. Discharge rate was kept constant throughout the test using flow meter and water level measurement taken at a stipulated time or at least every hour. After the pump was shut down, the water levels in the well started to rise again. These rises were measured using water level indicator, stop watch to record the time and it is termed recovery test. The measurement of recovery continued until the aquifer recovered to 95 % of its pre-pumping water level.

Hazen's method (Hazen, 1911) as given in equation 2, was used to calculate the hydraulic conductivity of the aquifer in the study area. D_{10}values determined from the sediment samples of Benin Formation using grain size analysis results are as follows: 0.63, 0.68, and 0.62. Figures 3, 4 and 5shows the grain size analysis graph of $d_{10}$from three borehole locations in the study area and Appendices 2A, 2C and 2E show the calculated valuesof grain size analysis from the three locations where the plotted graphs were deduced. One example is given below while the other examples are given in Appendix 3A

$$K=A\ (d_{10})^2, \qquad (2)$$

Where K= hydraulic conductivity (cm/sec)

d_{10} = particle size (mm) at 10% finer or 90% coarse

A = constant whose value is 1.0 for sand

Example

Hydraulic conductivity of Benin Formation aquifer in the study area

Therefore, $K = 1.0 \times (0.63)^2$

$= 1.0 \times 0.3936$

$K = 0.4 m/s$

$= 4 \times 10^{-1} m/s$

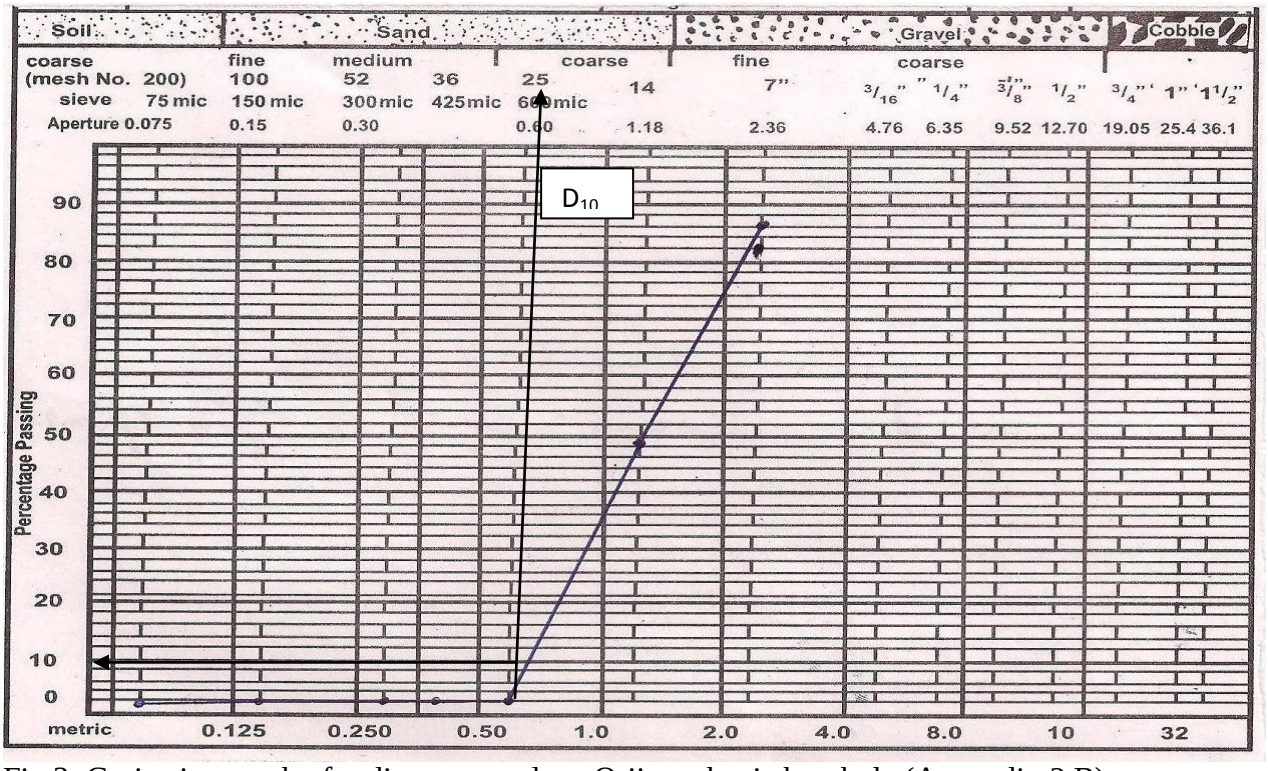


Fig 3: Grain size graph of sediment sample at Orji mechanic borehole (Appendix 2 B)

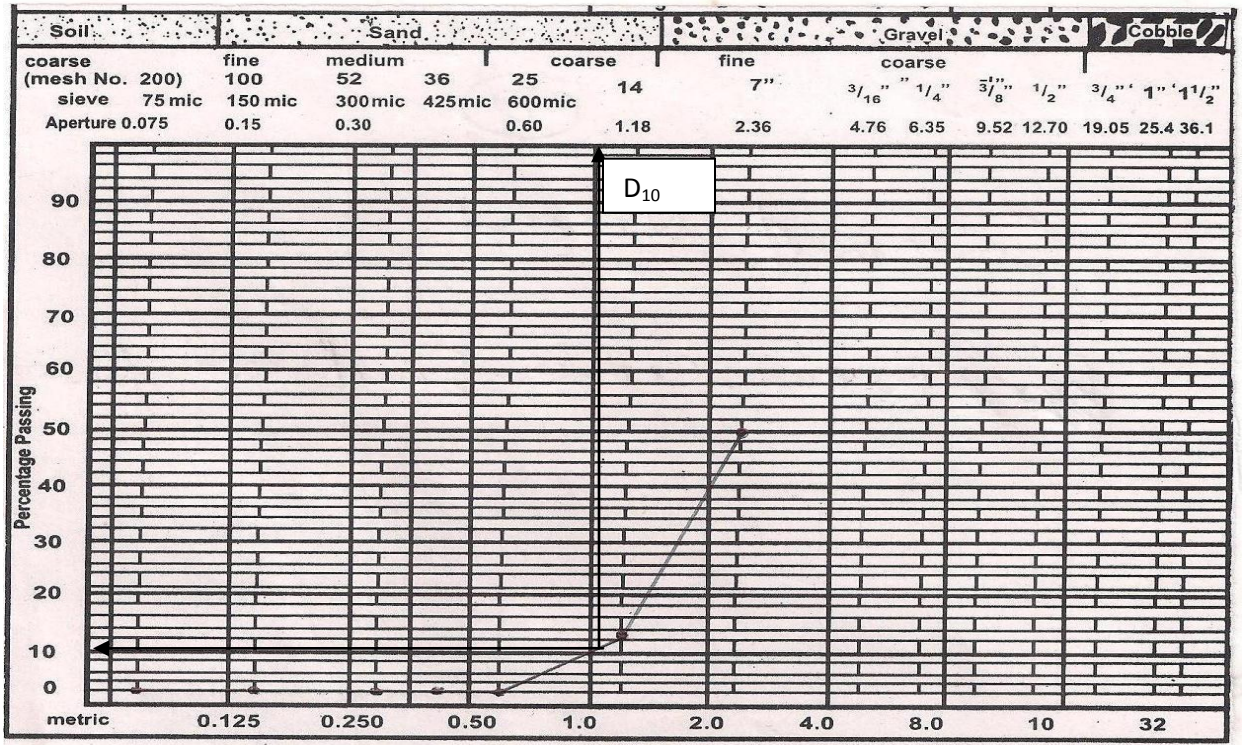


Fig 4: Grain size graph of sediment sample located at Concorde villa borehole (Appendix 2 D)

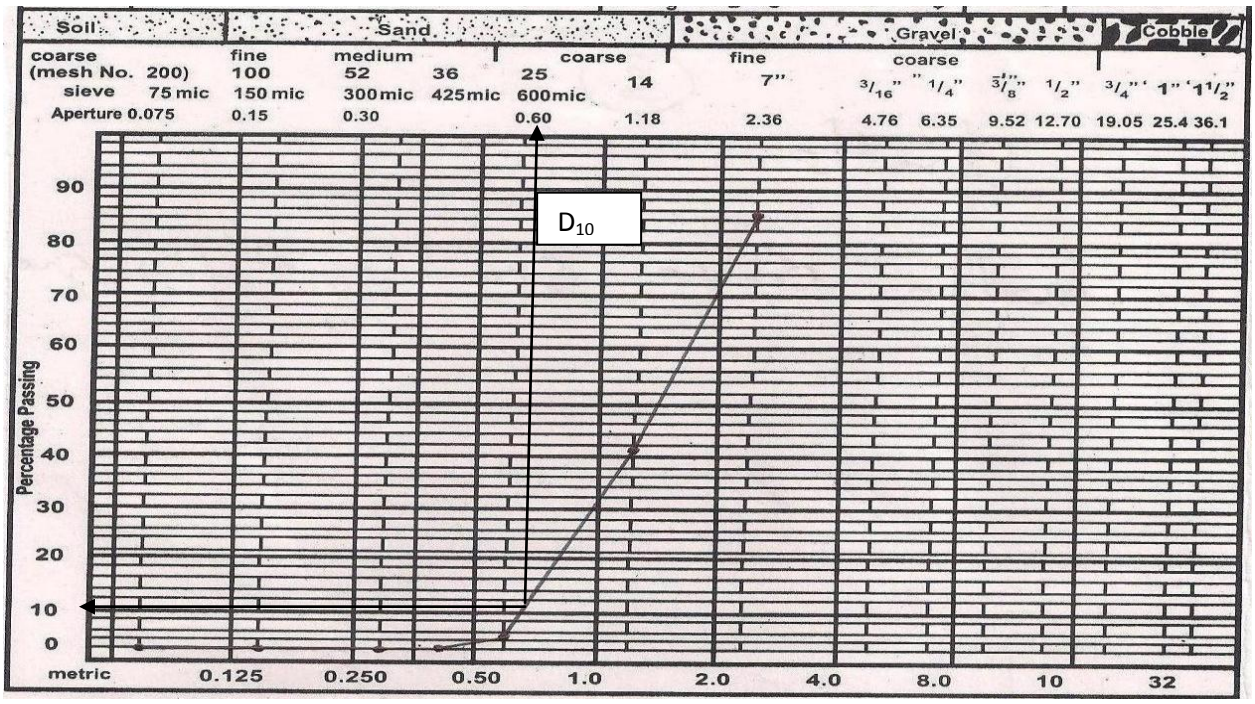


Fig 5: grain size graph of sediment sample located at Urattaborehole (Appendix 2 F)

Freeze and Cherry (1979) expressed transmissivity (T)m^2/d as given in equation 3and it was used to calculate the transmissivity of aquifer in the study area. Due to the cost of drilling wells to the maximum depth of the aquifer in the study area, screened thicknesses of aquifer as obtained from Anambra-Imo River Basin Development Authority were used to calculate the transmissivity of the aquifer in the area. The following were the screened thicknesses of Benin Formation aquifer at three locations in Owerri and environs; 25, 20and 20meters respectively for Umuokirika-Ahiazu, Nekede and Ogbe-Ahiazu boreholes(Appendices 6, 7 and 8). One example is given below while the other examples are given in Appendix 3B.

$T = Kb,$ (3)

Where K= Hydraulic conductivity

b = Saturated thickness of aquifer (screened thickness)

Example

Transmissivityin Benin Formation aquifer in the study area

Hydraulic conductivity of aquifer of Benin Formation in the area is 4×10^{-1}m/s

Therefore, T = 0.4m/s ×25m

Transmissivity (T) = 864,000m^2/d

Groundwater flow velocity (V) was calculated for the aquifer in the study area as given by Darcy's law, using the expression in equation 4.

$V = -Kí / n_e$ (4)

Where í = hydraulic gradient

n_e = is effective porosity

According to Ibe*et al*. (2007) hydraulic gradient (i) in coastal plain sand of Owerri ranges between 0.09 and 0.22. In this work, an average of this hydraulic gradient (i) range which is 0.16 was used to calculate the groundwater flow velocity (V). The effective porosity (n_e) was calculated using Fetter's (1994) range of values of hydraulic conductivity for unconsolidated deposit of gravel for various geological materials (between 20 and 35). In this work, an average of this effective porosity (n_e) for various geological materials which is 27.5 was used to calculate groundwater flow velocity (V). The average range of hydraulic gradient and effective porosity were used because theactual values that constituted the range from the workers mentioned were not gotten; and that the average of the range would still fall within the specified limits. Example is given below.

Example

$V = 0.5\ m/s \times (0.16)/27.5$

$= 2.7 \times 10^{-3} m/s$

Folk and Ward (1957) formulae as given in equations 5,6,7,8 were used in calculating grains particle size distribution, sediments characteristics in terms of sorting, kurtosis, skewness and then, the data obtained were used to plot particle size distribution curves.

$$\text{Mean} = \frac{\Phi_{16}+\Phi_{50}+\Phi_{84}}{3} \quad (5)$$

$$\text{Sorting} = \frac{\Phi_{84}-\Phi_{16}}{4} + \frac{\Phi 95 - \Phi 5}{6.6} \quad (6)$$

$$\text{Skewness} = \frac{(\Phi_{84}+\Phi_{16} -2\,\Phi_{50}) + (\Phi_{95}+\Phi_{5}-2\,\Phi_{50})}{2(\Phi_{84}-\Phi_{16}) + 2(\Phi_{95}-\Phi_{5})} \quad (7)$$

$$\text{Kurtosis} = \frac{(\Phi_{95} + \Phi_5)}{2.44(\Phi_{75} - \Phi_{25})}, \quad (8)$$

Where

Φ_5= phi value at 5^{th} percentile

Φ_{16}= phi value at 16^{th} percentile

Φ_{25}= phi value at 25^{th} percentile

Φ_{50}= phi value at 50^{th}percentile

Φ_{75}= phi value at 75^{th} percentile

Φ_{84}=phi value at 84^{th} percentile

Φ_{95}= phi value at 95^{th} percentile

3.1.1.2Evaluation of Field Data

3.1.1.3 Hydrogeological maps: The field data for groundwater available in the study area were plotted on topographical maps and the following hydrogeolgical maps were prepared.

(i) Groundwater contour maps (end of wet and peak of dry seasons)

and

(ii) The hydrogeological cross – section.

3.1.1.4Watertable contour maps: These are hydrogeological maps that show the watertable contours of the phreatic surface, recharge and discharge areas, discharge by effluent and recharge by influent, the flow direction and intensity of the groundwater flow in the study area, using data from the water level measurement and the coordinates obtained with the aid of the G.P.S from

the field. This process starts by gridding the entire map both latitudinal and longitudinally into three minute each. The maps were prepared for the end of wet and peak of the dry season. The maps were prepared by plotting the altitudesin meters above sea level (masl) of water levels measured ateach borehole site on a topographical map. The altitude of the water level in each of the wells was calculated by deducting the measured water level below the ground surface (depth to water level) from the altitudes of the well location. Lines were then drawn to join points of equal watertable elevation and numbers.

3.1.1.5Hydrogeological cross-section: This was constructed from the maps of watertablesfor both seasons. It is done by drawing line of cross-section A-B on watertable maps in such a way that it cuts across all the contours. The beginning and the end of the line of cross- section was indicated on a plane sheet, after which the plane sheet was placed on the watertable maps to mark out each contour value on the sheet. The contour values were used to graduate a vertical axis while the horizontal axis was drawn using line of the cross – section, on another plane sheet. Points of the contour values were marked out from the vertical axis, and finally hydrogeological cross section was drawn of the points.

3.1.2 FIELD WORK

3.1.2.1 Reconnaissance survey:The survey was made to locate wells (boreholes), to observe the groundwater condition of the area so as to know the apparatus for the field work.

3.1.2.2Water level measurement:Water level measurement, using plopper, involved the use of a concave metal cast attached to graduated tape of 150 meters, was done in boreholes from the ground surface for both the end of the wet season and the peak of the dry season. The tape was then lowered into the well until it made contact with the water inside the well, plopping noise

was heard when it hit the groundwater surface. At this point, the length of the tape was recorded as the depth to water levelbelow mean sea level.Measurements in the boreholes were carried in the morning(by 10 am) to allow groundwater recovery and to avoid the acceleration of drawdown in wells, as a result of early morning abstraction of groundwater by the residents for domestic use which generally begins at between 6 am to 8 am (information obtained from the residents).The depth to water level measurements were carried out in only thirteen (13) boreholes, as it was one of the limitations during the study.Reference marks were made at the point of measurement for easy location.

3.1.2.3 Water sampling: Physical parameters such as electrical conductivity measured in μs/cm, pH and Temperature were measured in situ with portable field equipment. At each sampling point, physical parameters such as temperature, electrical conductivity and pH were measured using thermometer, portable electrical conductivity cell and pH meter respectively. It was done by insertion of the probe into the water sample collected and recording of the reading as it stabilizes. This was done because their values might change significantly soon after collection and water sample could be degraded when exposed to the atmosphere. Data for the parameters were measured; time as well as location name and number were all recorded.

3.1.2.4 Sample collection and storage: A total of sixteen (16) groundwater samples taken mainly from boreholes and four (4) from riverswere collected from the study area. The samples were collectedfrom residential places and wider coverage of water sampling was done in the study area. Figure 6shows the water sampling locations and identification of the study area.

In the course of this work, water samples collection were done in line with the guidelines of Hem (1970) and American Public Health Association (APHA, 1992) to reduce the risk of sample

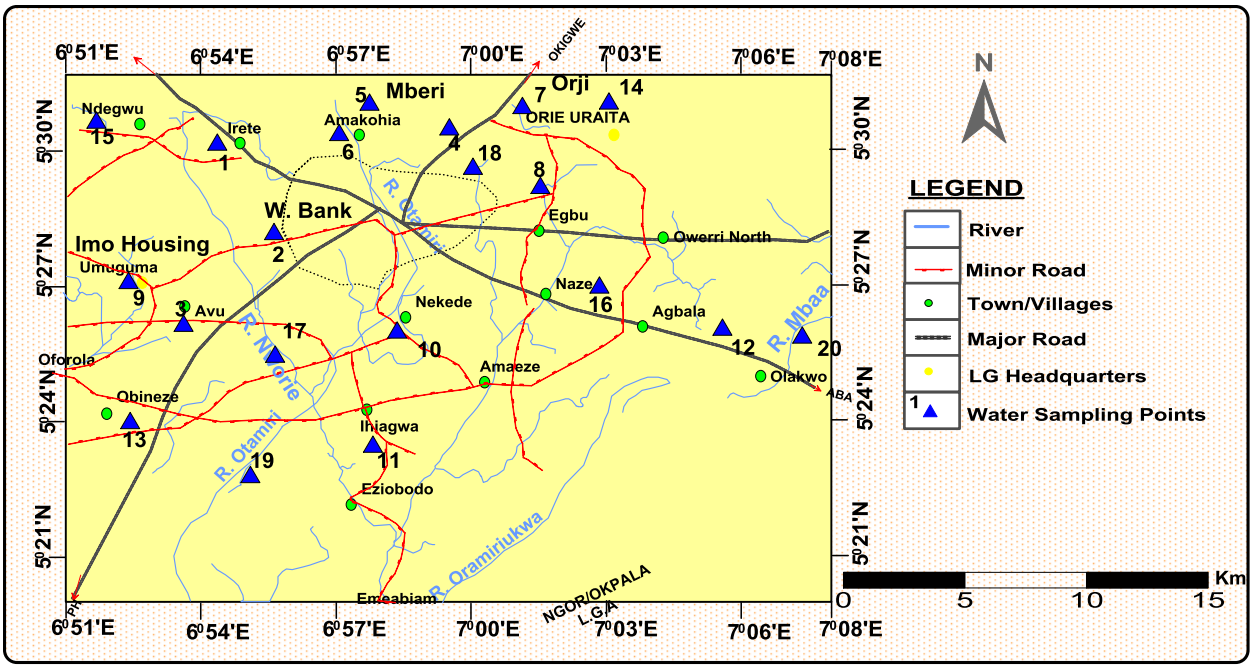


Fig 6: Water Samples Location and Identification Map in the Study Area

contamination, all water samples were collected in fresh sample containers (polyethylene bottles).The water samples were collected in forty (40) sample bottles which had been previously thoroughly washed and later rinsed three times with the water being sampled before filling the bottles to the brim in order to avoid biochemical reactions. Two separate samples were collected for each water point; one was for anionic determination while the second was for cationic determination. The samples collected for cationic determination were acidified with concentrated nitric acid (HNO_3)to reduce the adsorption of ions from solution and the formation of bonds between the container and the ions. Additional 20 water samples were taken from the same sources for bacteriological and microbial load analyses.In a bid to avoid the effects of extraneous materials from long distribution lines and possible long storage times in tanks that samples were collected directly from the aquifer. To get water from the aquifer, the well was pumped (using submersible pump system) for some minutes to discard stored water in the well and then the

water was sampled. Water samples were collected from streamsslowly with gentle stream, in order to avoid turbulence and air bubbles. Samples were labeled and preserved in ice-pack coolerkit before taken to laboratory for analysis.

3.1.2.5 Sediment Sample Collection: The sediment samples were collected from three different selected borehole locations (Orji mechanic, Concorde villa and Uratta, (representing parts of Owerri Municipal, Owerri-west Owerr-north Local Government Area and environs)withinthe same aquifer (Benin Formation) but at different depths. A representative of the sediment samples were obtained during the borehole drilling, immediately the driller observed rock cutting on the ground surface. The obtained sediment samples were drained of the water using sieve 0.075mm, placed on the sediment sample collection box and labeled. Thereafter, these sediment samples were transported to Arab contractors Nigeria Ltd soil laboratory, Owerri for grain size analysis.

3.1.2.6 Geological mapping: Geological mapping of the study area was done on an approximate scale of 1:50,000 as base map using appropriate and suitable field instruments such as 75 meters measuring tape and GPS. An extensive traversing using the many footpaths and roads available along Nworie and Otamiririvers paths where the outcrops are well exposed was done of the study area. Geological features observedwere the thicknesses of the beds, colours, texture and the boundaries, as the outcrops have been subjected to weathering and human activities.

3.1.3 The Laboratory Work

Twenty (20) water samples collected from the field in the study area were subjected to analysis to determine their chemical and microbial components.

Analysis of the collected water samples for their major cation and anion components was carried out in Ministry of Petroleum Resources and Environment (UNIDO Lab) Owerri. The major ions

analyzed and the methods used in analyzing them are as follows: sodium (Na^+) and potassium K^+ were analyzed by flame photometry, calcium (Ca^{2+}) and magnesium (Mg^{2+}) were determined by Atomic AbsorptionSpectrophotometry (AAS) and Fe^{2+} was determined by Spectrophotometry. Copper (Cu^{2+}), lead (Pb^{2+}), zinc (Zn^{2+}) and cadmium (Cd^{2+}) were determined by Extraction/Acetylene Flame method and mercury (Hg^{2+}) by Cold Vapour Atomic Absorption Spectrophotometry (CVAAS) method. Photometric method was used to determine sulphate(SO_4^{2-}) and nitrate (NO_3^-) using H18200 multiparameterBenchphotometer, Cl^- was analyzed by Argentometric method that is silver nitrate titration using potassium chromate as indicator and phenolphthalein/methyl orange. Titrimetric method was used to analyze bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}). Alkalinity was determined by sulfuric acid (H_2SO_4) titrimetric method, hardness was determined by EDTA titrimetric method. Turbidity was analyzed by using HACH laboratory Turbidimeter model 2100N. Colour of the samples was analyzed withLovibond Comparator and Total Dissolved Solids (TDS) was determined using H19835 Auto Ranging meter HANNA instruments.

The descriptions, principles and procedures of the methods used are presented belowin accordance with the procedures described byAPHA(1971) and HACH Chemical Company (1978).

3.1.3.1ANALYSIS OF PHYSICAL PROPERTIES OF WATER SAMPLES

3.1.3.2COLOUR DETERMINATION BY LOVIBOND COMPARISM METHOD

Colour in natural waters result from metallic salts, organic matter and other dissolved or suspended organic materials from decaying vegetation and certain inorganic matter. This is called an apparent colour caused by scattering of light by suspended particles.

True colour on the other hand results from absorption by coloured material present in water of certain wavelength of light. Only true colour remains in water after removing turbidity in the process of treatment.

Measurement of colour intensity as regards this analysis is based on visual comparison with standards using Lovibond comparator.

Principle of the method: Colour is measured with Lovibond comparator in True Colour Units, so called TCU, or Hazen Units. One TCU is produced by 1mg/l of platinum in form of chloroplatinic acid, in the presence of 2 mg/l of cobalt chloride.

Procedure for analysis: A test tube is filled with 10ml of water sample and 10ml of distilled water is filled in another test tube. The two test tubes are then inserted inside a Lovibond comparator and colour is estimated using the standard disc provided for the test(Colour disc). The values of colour recorded from the disc will then be read from the book index (the complete Lovibond analytical tests).

3.1.3.3 Turbidity Determination by using turbidimeter

Principle: It is based on the principle of Nephelometric measurement of the turbidity with automatic range selection and Signal Average On. When Signal Average is on, the Turbidimeter's microprocessor compiles a number of readings and averages the result. The average value is calculated and displayed approximately once every second.

Procedure for Analysis: A representative sample of water is collected in a clean container. The sample is filled into the sample cell to approximately 30ml. the sample cell is carefully handled by the top and caped. The sample cell is held by the cap and wiped to remove water spots and

finger prints. A thin bead of silicon oil is applied from the top to bottom of the cell – Just enough to coat the cell with a thin layer of oil. This oil is spread uniformly using the oiling cloth provided and its excess is wiped off to an extent that the cell will appear nearly dry with little or no visible oil. EPA filter is inserted in the sample cell and the sample cell is then placed on the Turbidimeter cell compartment and the lid is closed. Manual or automatic range is selected by pressing the RANGE key. Appropriate signal averaging setting is turned on by pressing the SIGNAL AVG key. An Appropriate Ratio Setting is selected on by pressing the RATIO key with appropriate FNU unit selected bypressing the UNITS key. The measurements displayed or the results are read and recorded or printed by pressing the PRINT key.

3.1.3.4 Alkalinity Determination by H_2SO_4 Titrimetric Method: Alkalinity of water is the capacity of that water to accept hydrogen ions(H^e). It is usually imparted by the bi-carbonate(HCO_3^-), Carbonate (CO_3^-), hydroxide (OH^-) ion components of the natural or treated water.

Principle: - The basic principle of this titrimetric method is such that a sample of water is titrated with standard acid solution e.g. H_2SO_4 (0.02N) using suitable indicators like phenolphthalein and methyl-orange. Phenolphthalein is used to determine that portion of alkalinity contributed by all the hydroxide and half of the carbonation, corresponding to a pH of 8.2 at the end of titration

Methyl-orange is used to determine the all alkalinity forms corresponding to pH of 4.3 at the end of titration.

Procedure for analysis: Exactly 100ml of water sample is measured in to a conical flask and three (3) drops of phenolphthalein indicator is added to the sample. After the addition, no pink

coloration is produced, then three drops of methyl-orange indicator is added to the same sample in the flask and the sample becomes yellow. After the sample becomes yellow, 0.02N of Sulphuricacid from burette is added to the sample until the first change is noted from yellow to orange to indicate the end point of the titration. The ml of acid used is recorded and the concentration of total alkalinity is thus calculated as:

$$Total\ Alkalinity = \frac{B \times N \times 50{,}000}{Ml\ of\ sample}(as\ mg.CaCO_3)$$

$: B = ml\ of\ titration\ for\ sample\ to\ reach\ meth - orange\ end\ point.$

$$N = Nornality\ of\ acid = 0.02N$$

3.1.3.5 Hardness Determination by EDTA Titrimetric method

Hardness is the traditional measure of capacity of water to react with soap. Hard waters require more soap to produce lather than soft waters because certain materials in the water react with soap, causing a precipitation which appears as a scum or curd on the water surface. Total hardness of a sample is of two types (i) Temporary hardness which is the portion of total hardness that is deposited when water is boiled (ii) Permanent hardness is the remaining hardness after the temporary hardness is deposited. This means that total hardness is made by salts of main alkaline earth elements, magnesium and calcium.

Principle of the method: Principally, it is based on the titration of a quantity of water sample with Ethylene Diamine Tetra Acetic acid (EDTA) using Eriochrome Black T as an indicator which gives blue colouration at the end point as well as a buffer solution which adjust the sample pH to 10.

Procedure for analysis: The water sample is shaken thoroughly and a 25 ml of it is taken and diluted to 50ml with distilled water. Two (2) ml of buffer solution is added to it to adjust its pH to 10 and immediately 2 drops of Erochrome Black T indicator is added to it. Thesolution is then titrated with EDTA within five (5) minutes interval. A blue colour is seen, which is the end point, after which the titer is read and recorded.

Calculation

$$Mg/l\ CaCO_3 = \frac{A \times B \times 1000}{Ml\ of\ Sample}$$

$Where\ A = Ml\ of\ Titrant$

$B = MgCaCO_3\ to\ 1.00ml\ EDTA\ titrant$

3.1.3.6 Total Dissolved Solids (TDS) Determination by Instrumental method

Total Dissolved Solids (TDS) also known as mineralization of water is the term used to describe inorganic salts and small amounts of organic matter present in solution in water.

A high content of dissolved mineral salts may affect the taste of drinking water and have a laxative effect.

Principle of the method: Total Dissolved Solid (TDS)'s measurement with H19835 Auto Ranging meter HANNA instrument is based on insertion of the instrument in the water sample and the corresponding reading is taken and recorded from a displaying screen in the instrument.

Procedure for analysis: The H19835 Auto Ranging meter is inserted into the water sample. This Hanna instrument has ability of measuring three parameters depending on whichparameter

is selected or switch on to. Then meter was switched on to the Total Dissolved Solids (TDS) parameter where the reading of TDS measured is recorded in mg/l each sample water.

3.1.4 Analysis of Chemical Characteristics of Water Sample

3.1.4.1 Determination of Sodium (Na^+) and $(K+)$ by flame photometer or flame photometry method

Flame photometry is a method used in determining the concentration of some cations in group I and II (alkaline and alkaline earth metals) of the periodic table that have low ionization energy, of which Sodium (Na^+) and Potassium (K^+) are among.

Principle of the method: The basic principle of flame emission is such that a sample in liquid form (water) is presented to a nebulizer which delivers a quantity of the sample as a fine aerosol on to a mixing chamber where it is combined and mixed with fuel. This mixture (aerosol and fuel) is directed to a burner for ignition and burning. The flame is positioned in a simple optical chamber where the emission from the flame is collected and directed through an optical filter system and on to a light detection device. The intensity of the light falling on the detector is measured and displayed on a meter.

Procedure for analysis: The fuel supply of the flame photometer is turned on at source and the "power" switch is depressed to switch on the 410. The "power on" LED will start and an ignition cycle will commence. If the "flame on" LED is not illuminated at the end of the ignition, set the filter selection to the required element of interest. The nebulizer inlet-tube is inserted in a beaker containing approximately 100ml of diluents and 15 minutes is allowed for the operating temperature to stabilize. This will ensure a stable burner temperature when solutions are aspirated.During the warm up period, a set calibration solutions is prepared to cover the required

measurement range. 30ppm for Sodium (Na^+) and 10ppm for potassium (K^+)were used as the highest standard concentration in order to obtain maximum linearity corning recommend. The diluents are aspirated into the flame and the "blank" control of the instrument is adjusted so that the display read zero while aspirating diluents. The highest concentration standard is aspirated and each of the remaining calibration standards is aspirated for 20 seconds (Starting with the lowest concentration to avoid carry over). 10 seconds is again allowed between measurements and 20 seconds is allowed for a stable reading than "coarse" and "five" controls are adjusted for a convenient reading. e.g. 20 Na can be set to read 20.0. Samples, standard and blank are aspirated at 20 seconds per sample to check the drift.

3.1.4.2 Determination of Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) by Atomic Absorption Spectrophotometry (AAS) method

Principle of the method: The principle is based on the absorption of radiant energy of various wavelengths by atoms present in the sample in their ground states. The atoms of elements strongly absorb radiation at certain characteristic wavelengths that coincide with the emission lines of spectral wavelengths of the particular element.

Procedure for analysis: Sample solution is aspirated through a nebulizer and sprayed as a fine aerosol in to the mixing chamber where it is mixed with fuel and oxidant gases. The mixture is then carried to the head of a flame or burner for sample vaporization and atomization. The sample is then passed through the light beam which is a hollow – cathode lamp. These cathode lamps are designed to emit the atomic spectrum of a particular element and the specific lamps are selected for use depending on the element to be determined. For example, if calcium is to be measured, a calcium lamp is selected to be used. The atomic vapour of the sample absorbs some

of the energy from a cathode lamp used as a radiant source. The energy absorbed and the remaining energy are passed into the monochromator which selects and isolate the wavelengths of energy of elements of interest. The wavelength of light isolated by the monochromator is then directed to the detector, which serves as the 'eye' of the instrument. This detector is a photo-multiplier tube; produce an electrical current dependent on the light intensity.

The electrical current is then amplified and processed by the instrument electronics to produce a signal, which is a measure of the light attenuation occurring in the sample cell. This signal is further processed to produce instrument readout directly in concentration units.

3.1.4.3Determination of Mercury(Hg^{2+})by Cold VapourAtomic Absorption Spectrophotometry (CVAAS) method

Principle of method: The method involving reduction of Hg^{2+} ions in sample test solution with stannous chloride to generate elemental mercury vapour (Hg^0); and the introduction of mercury vapour into photo-absorption cell for the measurement of absorbance at 253.7nm.

Procedure for analysis: Gently transfer a fixed volume, V ml (normally 10 ml) of blank test solution, standard test solution, and sample test solution into the reaction vessel in the mercury analyzer and apply the stopper. Add 1 ML of 10% SnCl solution with the accessory dispenser and push the start button. The diaphragm pump will run and generated elemental mercury vapour will be circulated through the 4-way cock between the reaction vessel and the acidic gas trap for 30 seconds to homogenize the concentration in the gas phase, while the acidic gas generated from the test solution is then collected in the alkaline solution. After 30 seconds, the 4-way cock will turn automatically by 90^o, allowing the introduction of the elemental mercury vapour into the photo-absorption cell through the ice bath for measurement of absorbance. The readings of

the recorder will increase sharply and decrease with a sharp peak. When the reading of the recorder begins to decrease, open the cock on the lower part of the reaction vessel to discard the solution inside, close it again, and allow it to aerate until it returns to the baseline. Push the rest button to start the next measurement.

3.1.4.4Determination of copper(Cu^{2+}), lead (Pb^{2+}), zinc (Zn^{2+}) and cadmium (Cd^{2+})by Extraction/Acetylene Flame method

Principle of the method: The method consists of chelation with ammonium pyrrolidinedithiocarbamate (APDC) and extraction into methyl isobutyl ketone (MIBK), followed by aspiration into an air-acetylene flame.

Procedure for analysis: After final adjusting of burner position, aspirate water-saturated MIBK into flame and gradually reduce fuel flow until is similar to that before aspiration of solvent. Select atleast three concentrations of standard metal solutions to bracket expected sample metal concentration after extraction, in the optimum concentration range of the instrument. Adjust 100ml of each standard and 100ml of a metal-free water blank to pH of 3 by adding 1 *N* HNO_3 or 1 *N*NaOH. Transfer each standard solution and blank to individual 200 ml volumetric flasks, add 1ml of APDC solution, and shake to mix. Add 10 ml MIBK and shake vigorously for 30 second. Let contents of each flask separate into aqueous and organic layers, then carefully add water down the side of each flask to bring the organic layer into the neck and accessible to the aspirating tube. Aspirate organic extracts directly into the flame and record absorbance.

3.1.4.5Determination of Iron II (Fe^{2+}) by a spectrophotometry method

Principle of the method: The technique is based on measuring iron content of a sample with the use of iron-vacu-vials ampoule to mix the sample and the sample reading is taken in a spectrophotometer.

Procedure for analysis: The water sample was filled in the sample cup to the 25ml mark. The vacu-vial ampoule is placed in the sample cup and its tip is snapped by pressing the ampoule against the side of the cup. The ampoule will fill leaving a small bubble to facilitate mixing. The content of the ampoule is thenmixed by inverting it several times, allowing the bubble to travel form end to end. The ampoule is dried and 1 minute waiting is exercised for colour development. The vacu-vial ampoule is then placed in the spectrophotometer and the concentration of iron present in the sample is read or measured.

3.1.4.6Determination of Chloride (Cl^-) by Argentmetric method

Principle of the method: The simplest and most widely used method for the estimation of chlorides in water is Argent metric method. This method is based on the titration of a halide. Such as Chloride (Cl^-) with standard Silver nitrate ($AgNO_3$) in the presence of Potassium chlorate (K_2CrO_4) as indicator. The end point of the titration is indicated when the solution changes from pure yellow to reddish brown. This is caused by the start of the precipitation of insoluble reddish brown silver chromate when all the chloride has reacted with Silver nitrate solution.

The reactions involved in the process are:

$$NaCl \quad \times \quad AgNO_3 \rightarrow AgCl_4 \times NaNO_3$$

(In water) (Std-solo) (In-soluble white ppt)

$AgNO_3 \times K_2CrO_4 \rightarrow Ag_2CrO_4 \times 2KNO_3$ (In-soluble reddish brown ppt)

Procedure for analysis: A 100ml of water sample is exactly measured in to a conical flask of 250ml and 1.0 ml of potassium chromate indicator solution is added to it.The sample in the flask is then titrated with standard silver nitrate solution of 0.0141N until there is a perceptible colouration end point. The concentration of chloride is calculated from this below expression.

The expression goes thus:

$$Cl\ (Mg/l) = \frac{A \times N}{Ml\ of\ sample\ taken\ for\ analysis}$$

Where: $A = Ml\ of\ titration\ for\ sample,\ N = Normality\ of\ Silver\ nitrate\ solution\ (N = 0141)$

3.1.4.7Determination of Carbonate and Bi-Carbonate by Titrimetric Method

Principle of the method: This technique is based on titration of water sample with standard solution of Sulphuric acid (H_2SO_4) in the presence of phenolphthalein and methyl orange as indicators. The end point of the titration will be indicated when the colour of the solution changes from orange – yellow to red.

Procedure for analysis: Carbonate $(\boldsymbol{CO_3^-})$0.0ml of water sample is measured in a conical flask and 2-5 drops of phenolphthalein indicator is added to it. The solution is then titrated with 0.02N H_2SO_4 till the pink colour disappears. The volume of acid used is recorded and the concentration of CO_3^- is calculated as:

$$\frac{2 \times Normality\ of\ Acid\ \times Volume\ of\ water\ used\ \times 100}{Aliquot\ taken\ (mls\ of\ acid\ used)}$$

Bicarbonate(HCO_3^-): To the same solution as above 2-5 drops of methyl –orange is added and then titrated until the colour changes which indicates the end point of the titration. The volume of acid used is recorded.

$$\frac{2 \times Normality\ of\ Acid\ \times Volume\ H_2O\ \times 100}{Aliquot\ taken\ (mls\ of\ acid\ used)}$$

N.B: 2 = constant values given

3.1.4.8Determination of sulphateSO_4^{2-} and Nitrate (NO_3^-) by photometric method

Determination of Sulphate (SO_4) by precipitation method using photometer

Principle: This method is based on precipitation of Sulphate(SO_4^{2-}) with barium chloride crystals in which the light absorbance of the suspension is measured.

Procedure for analysis:A suitable sulphate method is selected. A cuvette is filled with 10ml of unreacted sample and its cap is replaced after filling. The cuvette is placed into the instrument andthe lid is closed. The ZERO key is pressed and the display shows "O" when the meter is zeroed and ready for measurement. The content of one packet of H193 751 – O indicator reagent is added to it. The cap of the cuvette is replaced after the addition and it is inverted gently to mix for 1 minute (about 30 inversions). The cuvette is reinserted into the instrument (H18300 multiparameter Bench Photometer). TIMER key is pressed and 5 minutes waiting is exercised and then, READ key is pressed. When the timer ends, the meter will perform the reading. Hence the instrument displays concentration on mg/l of SO_4^{2-}

3.1.4.9Determination of (NO_3^-) Nitrate by Cadmium reduction method using Bench photometers

Principle: this method is based on adaptation of the cadmium reduction method. This method explains the reaction between nitrate and the reagent which causes an amber tint in the sample.

Procedure for analysis: A suitable nitrate method is selected. A cuvette is filled with 6ml of the sample up to half of its height using the pipette and its cap is replaced after filling. The cuvette is then placed in to the holder and the lid is closed. The ZERO key is pressed and ready for measurement. The cuvette is removed from the instrument and content of one packet of H193728-0 reagent is then added to it. The cuvette's cap is replaced and immediately shaken vigorously for 10 seconds. The mixing continues by inverting the cuvette gently for 50 seconds, while taking care not to induce air bubbles.

Powder will not completely dissolve and time as well as way of shaking could sensitively affect the measurement. The cuvette is then reinserted into the instrument taking care not to shake it. The TIMER key is pressed for 4 minutes and 30 seconds waiting, after which the READ key is pressed. When the timer ends, the meter will perform the reading. The instrument displays the results in mg/l of nitrate-nitrogen. The key CHEM FRM is then pressed to convert the result in mg/l of nitrate (NO_3^-).

3.1.5Water samples bacteriological Analysis

Twenty (20) water samples collected from the field were analyzed of their microbial components at the Ministry of Petroleum Resources and Environment Owerri (UNIDO lab). The water samples were analyzed for coliforms (E.coli) and total microbial load using culturing method.

E.coli count is the most useful test for detecting faecal contamination of water supplies in water quality analysis. The technique adopted in this work is membrane filtration method.

3.1.5.1 Membrane filtration technique: A 100ml water sample is filtered through a membrane filter. The membrane, with the coliform organisms on it, is then cultured on a pad of sterile selective broth containing lactose and an indicator. After incubation, the number of coliform colonies was counted. This gives the presumptive number of E.coli in the 100ml water sample.

3.1.6Sediments grain size analysis

Sediment samples collected from the field at three selected boreholes of the same aquifer (Benin Formation) were analyzed at Arab Contractors soil laboratory. Grain size analysis was conducted using mechanical sieve shaker and in nest of standard sieves with the coarsest on the top and the finest at the bottom, covered with lid on top and pan as receiver. Sediment samples were oven-dried and 500 grams of each was weighed on a scale. Thereafter, the sample was soaked in water for 45 minutes to wash off clay or silt sticking on the grains using sieve 0.075mm. The washed sample was oven-dried again, weighed and put on top of the coarsest sieve already fitted on a sieve shaker. The sieve shaker with the content shakes at least ten (10) minutes. The portion of the sediment sample retained on each sieve is weighed and the percentage of sediment sample retained on each sieve is calculated on the basis of total weight of the washed sediment sample. From these results, the sediments percentage passing each standard sieve is calculated. The values obtained from this analysis were used to plot graph of grain size against sieve sizes and also used to identify the effective grain size d_{10} of the aquifer samples. Effective grain size d_{10} is the size corresponding to 10% of the aquifer samples being finer and 90% coarser.

CHAPTER FOUR

RESULTS AND INTERPRETATIONS

4 Geology of the Study Area

The study area is underlain by the Benin Formation or Coastal Plain sand which is a major lithostratigraphic unit in the Niger Delta Basin. The Benin Formation outcrops at the gravel mines along Otamiri and Nworie rivers located at Nekede, Egbeada to Amakohia were mapped and it revealed that it has been subjected to weathering and anthropogenic activities. It contains three lithological layers of (from top) medium sand with alternating occurrence of clay, coarse gravel beds and coarse sand (Plates 1, 2 and 3). The first layer consist of reddish-brown medium sand with alternating clay and thickness ranging from 3 to 5 meters, second layer consists of brownish-white coarse gravel with thickness ranging from 2 to 6 meters, the third layer consist of whitish coarse sand with exposed thickness ranging from 3 to 4 meters.

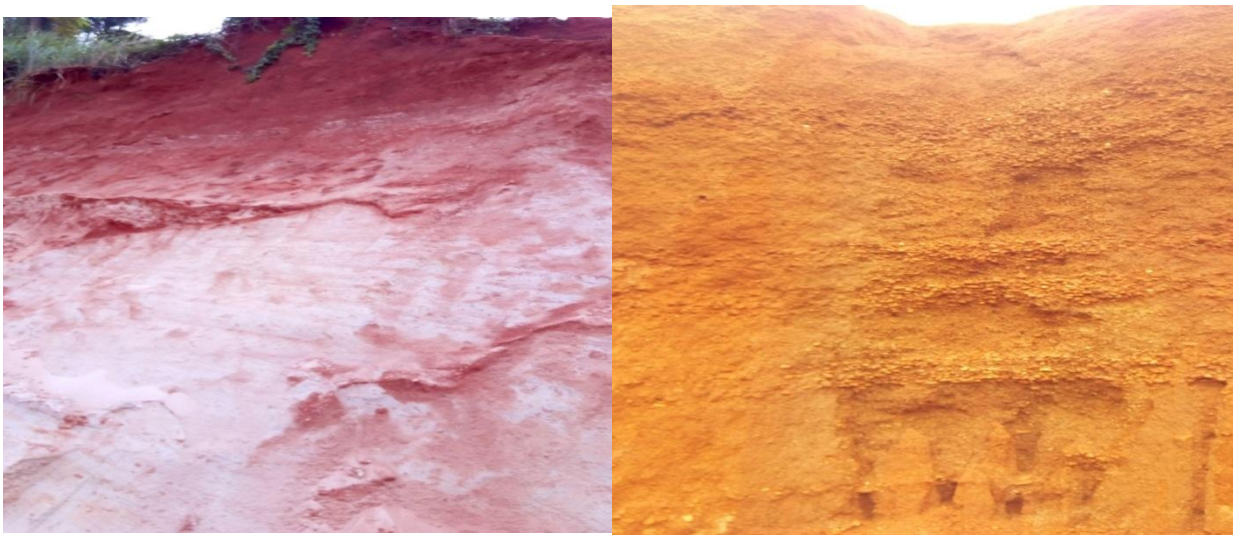


Plate 1: Outcrops of Benin Formation at Nekede Gravel Mines Showing Reddish-brown Medium Sand with alternating Clay, brownish-white Gravel Beds and whitish Coarse Sand in the Study Area

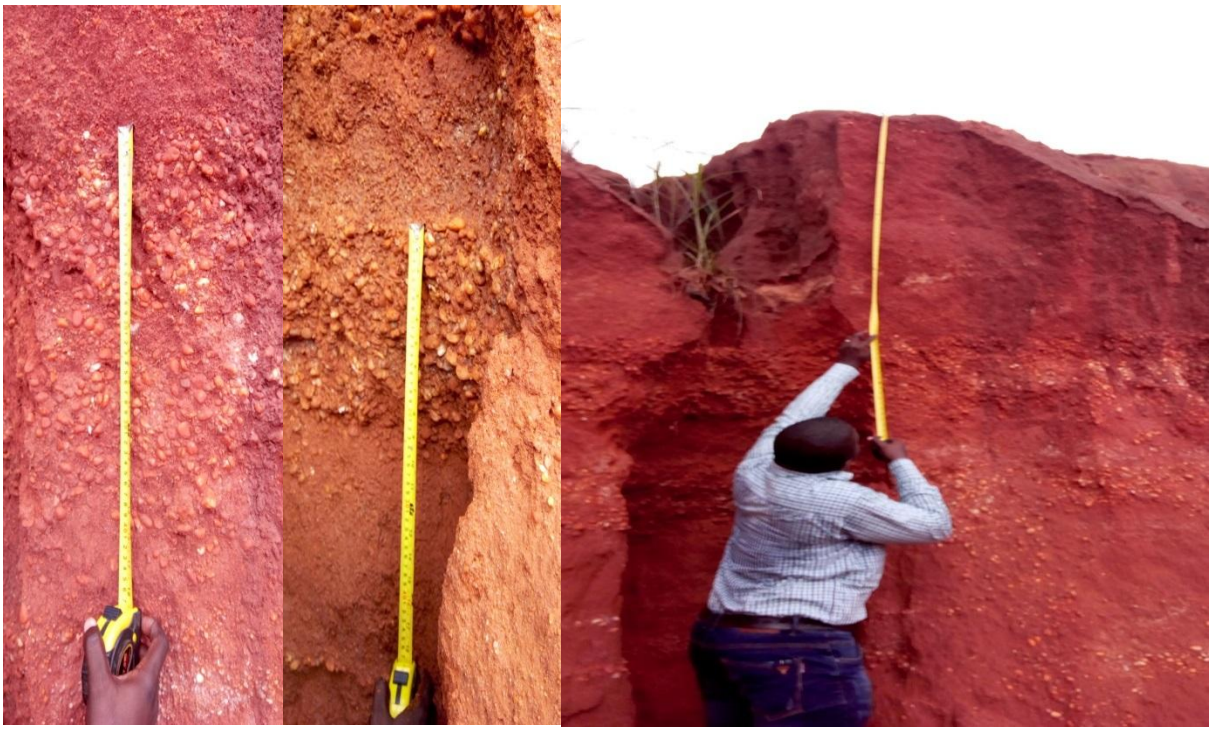


Plate 2: Outcrops of Benin Formation at Egbeada-Amakohia Gravel Mines Showing Reddish-brown Medium Sand with alternating Clay and Brownish-white Gravel Beds in the Study Area



Plate 3: Outcrops of Benin Formation at Nekede Gravel Mines Showing Typical Aquifer (Whitish Coarse Sand) of Coastal plain Sand in the Study Area



Plate 4: Mined Gravel of Benin Formation besideOtamiri River in the Study Area



Plate 5: Sand Mine of Benin Formation beside Otamiri River in the Study Area

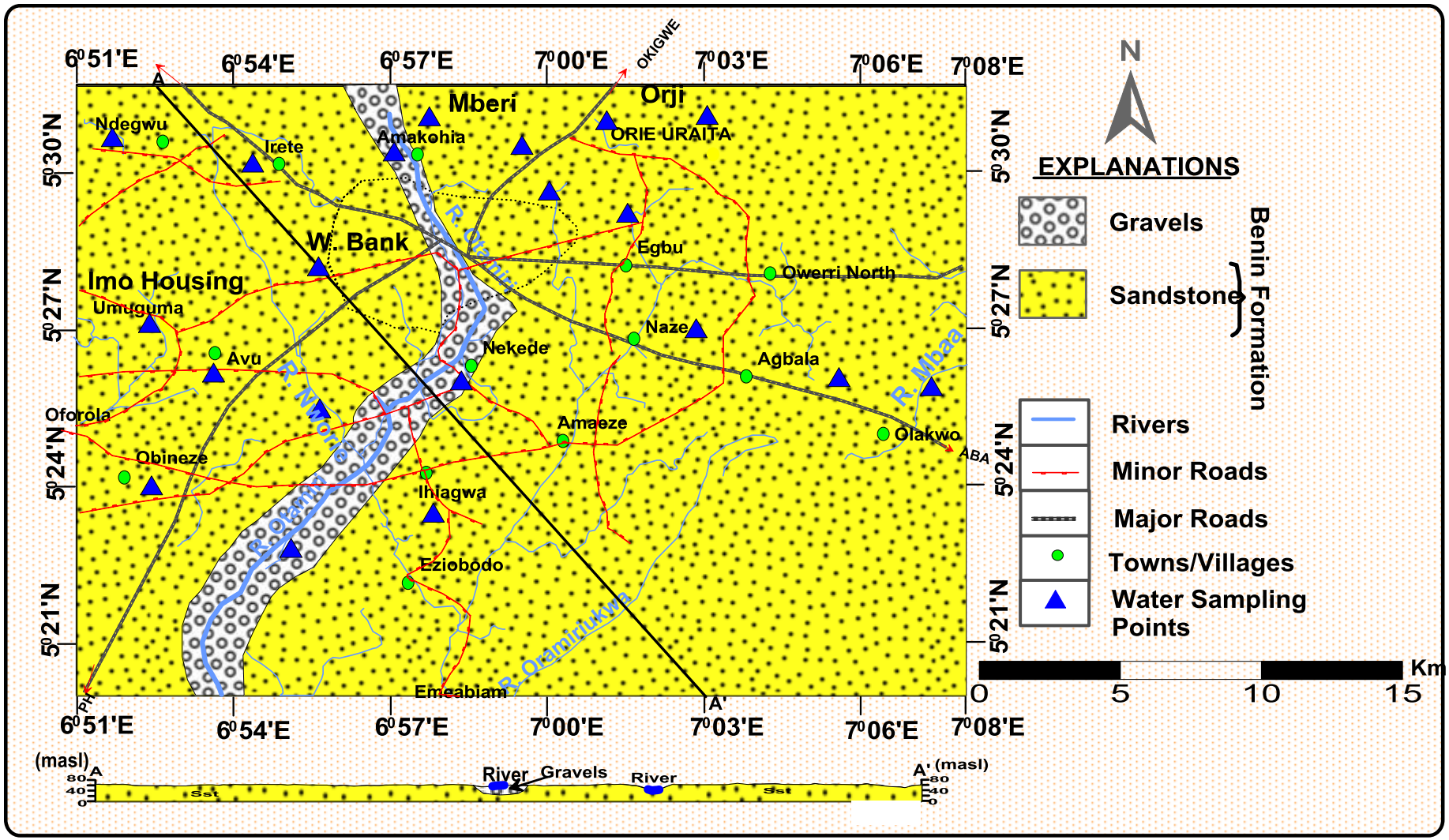


Fig 7: Geological Map of the Study Area Showing Outcrop of Sand and Gravel beds along Otamiri and Nworie Rivers

4.1 Determination of Watertable Elevation

Water level measurements were specifically taken to provide data for groundwater contour maps of the area as described in Table 2. The map produced contains watertable contour, boreholes with groundwater level in below mean sea level (bmsl), groundwater flow directions, areas of recharge and discharge, effluent and influent recharges.

4.1.1Watertable Contour and Groundwater Flow: Watertable contours as shown on the map in figures 8 and 9, deduced cone of depression areas near some wells, as a result of over withdrawal of groundwater by the residents which when continued could result to collapse of the well. Close spacing of contour lines on the groundwater contour maps of the study area indicated areas of low permeability while well-spaced lines indicated areas of likely more permeable. The spacing of groundwater contour maps gives a good indication of variation in aquifer permeability values.

The minimum watertable below mean sea level on the maps of the study area is located at Amakohia-Uratta; and the depths are 36.8meters at peak of dry season and 37.8meters at end of wet season, while maximum watertable below mean sea level in the area is located at Egbu; and the depths are 95metersat the end of wet season and 91.8 meters at the peak of dry season. The groundwater contour maps show convergent and divergent wells; hence groundwater predominant directions of flow are northwest, northeast and south. The groundwater flow arrow lines on the maps indicated groundwater flow directions and patterns; groundwater concentrated areas, discharge and recharge areas, as well as variation in aquifer permeability.

Table 2: Well characteristics from accessible boreholes in the study area (Source: field data 2012/2013)

S/No	Location	Coordinate	Water level measurement					Elevation (amsl)	Watertable		Remarks
			Wet season	Average wet season	Dry season	Average dry season	Groundwater fluctuation		Wet season	Dry season	
1	Irete	05°30'02'' N 06°53'04'' E	17.7 17.5	17.6	19.7 19.9	19.8	2.2	70	52.4	50.2	Borehole
2	Umuguma-Avu	05^{0}27.5'02'N' 06^{0}55.5'00''E	N/A	N/A	N/A	N/A	N/A	75	N/A	N/A	Borehole
3	Avu	05^{0}25.9'00''N 06^{0}52.5'0.5''E	N/A	N/A	N/A	N/A	N/A	72	N/A	N/A	Borehole
4	Ubomiri	05°30.5'0.3'' N 06°57'0.1'' E	44.9 44.9	44.8	47.1 47.5	47.3	2.5	113	68.2	65.7	Borehole
5	Mbieri	05°30.5'00'' N 06°58.5'00'' E	47.4 47.6	47.5	50.1 50.3	50.2	2.7	142	95	91.8	Borehole
6	AmakohiaUratta	05°30.4'00'' N 06°56.5'01'' E	29.0 29.4	29.2	30.1 30.3	30.2	1	67	37.8	36.8	Borehole
7	Orji	05°30'57'' N 07°01'11'' E	52.0 52.8	52.4	54.8 55.2	55.0	2.6	125	73	70	Borehole
8	Egbu	05°29'12.5'' N 07°01'31.4'' E	33.6 33.2	33.4	34.4 34.8	34.6	1.2	93	59.6	58.4	Borehole
9	Umuguma (Imo housing)	05^{0}26.5'0.5''N 06^{0}52.05'0.1''E	N/A	N/A	N/A	N/A	N/A	70	N/A	N/A	Borehole
10	Nekede	05°25.5'02'' N 06°57.05'01'' E	20.0 19.6	19.8	21.3 21.3	21.3	1.5	65	45.2	44	Borehole
11	Ihiagwa	05°23'52.2'' N 06°57'44'' E	20.0 19.6	21.0	20.8 21.2	21.0	1.2	67	46	46	Borehole
12	Agbala	05°25'56.7'' N 07°05'38.2 E	22.5 22.1	23.5	23.2 23.8	23.5	1.2	88	65	64.5	Borehole
13	Obinze	05°23.2'00'' N 06°51.5'0.25'' E	19.3 19.5	20.7	20.6 20.8	20.7	1.3	62	41.3	41.3	Borehole
14	Uratta	05°31'04.2'' N 07°02'57.8'' E	55.9 55.7	57.1	57.3 56.9	57.1	1.3	132	75	75	Borehole
15	Ndegwu	05°30.5'0.5'' N 06°51.5'0.3'' E	20.7 20.9	23.2	23.1 23.3	23.2	2.3	79	55.8	55.8	Borehole
16	Naze	05°26.04'0.5'' N 07°2.03'0.3'' E	27.3 27.3	28.5	28.4 28.6	28.5	1.2	74	45.5	45.5	Borehole
17	Nworie river	05^{0}25.04'0.1''N 06^{0}55.04'0.1''E	N/A	N/A	N/A	N/A	N/A	57	N/A	N/A	River
18	Okitankwu river	05^{0}28.04'0.1''N 07^{0}0.15'00''E	N/A	N/A	N/A	N/A	N/A	47	N/A	N/A	River
19	Otamiri river	05^{0}22.01'0.2''N 06^{0}55'00''E	N/A	N/A	N/A	N/A	N/A	42	N/A	N/A	River
20	Mbaa river	05^{0}25.04'0.14''N 07^{0}6.5'0.45''E	N/A	N/A	N/A	N/A	N/A	49	N/A	N/A	River

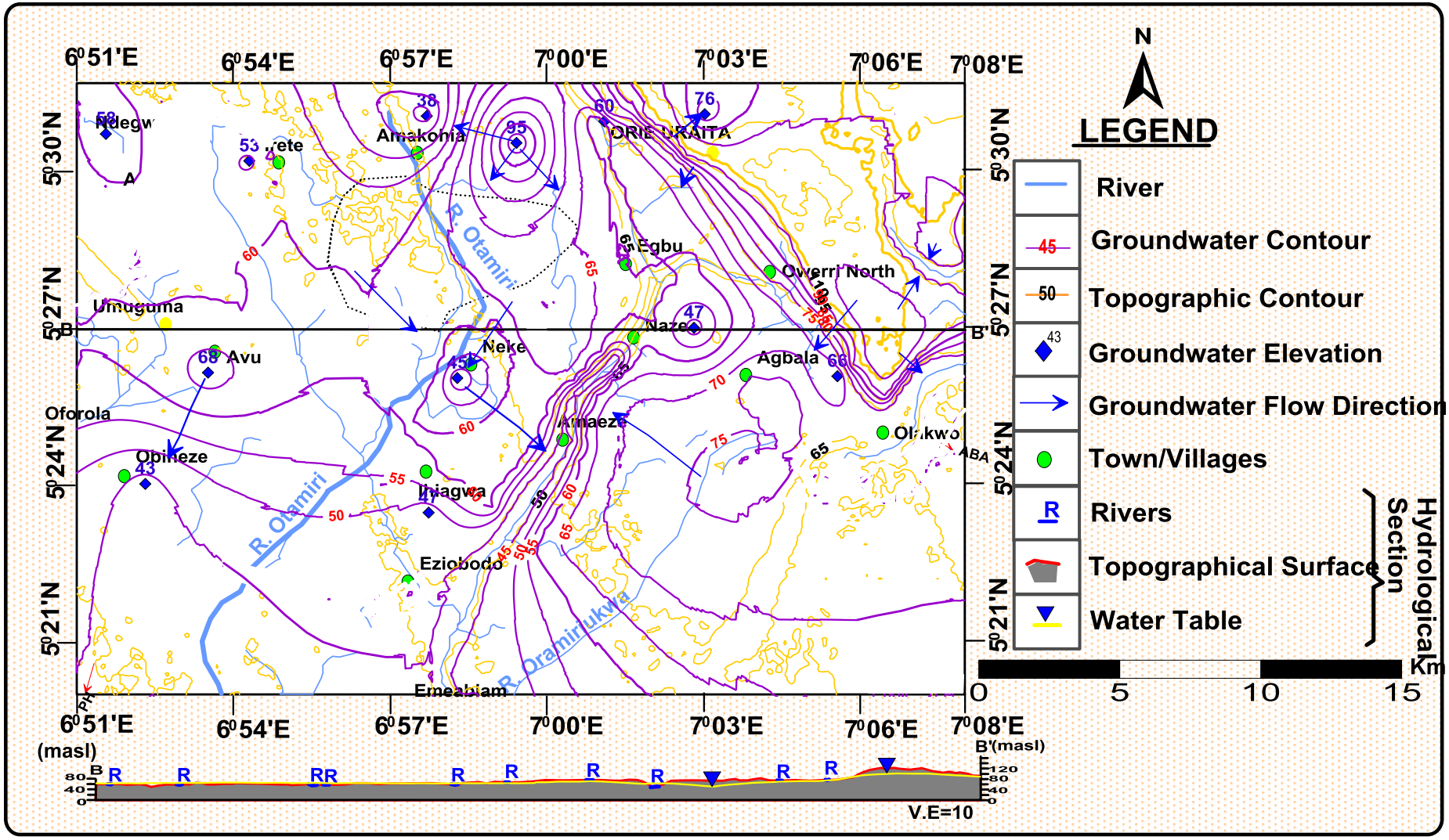


Fig 8: Groundwater Contour Map of the Study Area (End of Wet Season)

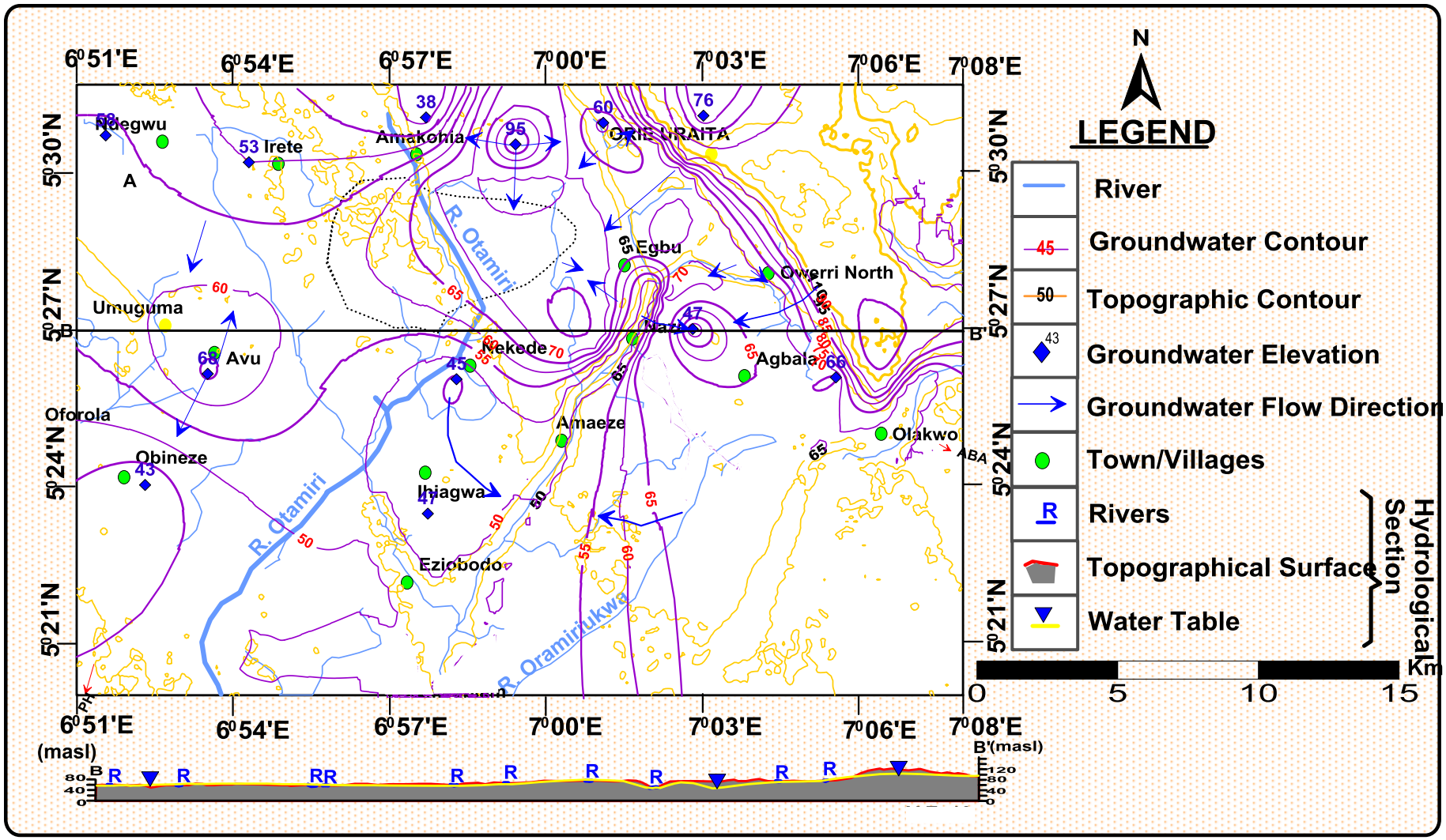


Fig 9: Groundwater Contour Map of the Study Area (Peak of Dry Season)

4.1.2 End of Wet Season: The watertable contour map at the end of wet season was based on the water level measurements in thirteen (13) selected boreholes done in October, 2013. At the end of wet season, lowest water level below sea level in the study area was 55.8 meters and the highest was of 17.6 meters with an average of 31.55 meters (Table 2).

4.1.3 Peak of Dry Season: The water level at the peak of dry season was measured in April, 2012 in the study area. The lowest groundwater level below sea level was 57.1 meters and the highest was 19.8 meters with an average of 33.26 meters. The groundwater fluctuation in the study area at end of wet season and the peak of dry season ranges from 1 to 2.7 meters with an average of 1.71 meters (Table 2).

4.1.4 Recharge in the Study Area: Since the topography of the study area is almost a plane surface as shown on the cross-section of the groundwater contour maps, surface runoff is low. This encourages recharge of groundwater by direct infiltration from rain water; which passes through the unsaturated zone into the saturated zone which in turn stores water. The maps also show the influent zones (arrow lines pointing away from the rivers (Figs 8 and 9), where recharge of groundwater is from the rivers and streams in the study area. The streams diverge through the porous media of coastal plain sand to recharge the groundwater in the area.

During the wet season, the recharge of the watertable aquifer was identified easily because the levels of water in boreholes rose up to an average of 1.71 meters in the wells higher above the levels during the dry season. This identification is usually few hours after each heavy down pour or at the end of wet season as seen in variation in fluctuation ofwatertable in the study area (Table 2). The directions of the arrow lines on the maps show predominantly towards the

recharge areas from the discharge areas, and these would be useful in urban planning and in choosing of waste disposal sites in the study area.

4.1.5 Discharge in the Study Area: The discharge from aquifers in the study area either occurs

artificially or naturally. Discharge through boreholes in the area of study is artificial by residential abstraction by means of submersible pump system, mostly for domestic use. Abstraction is always high in the morning and weekends (confirmed by different residents in the study area) as residents abstract water for bathing, washing and for other domestic activities. Natural groundwater discharge in the study area as seen on the maps occurs through effluent (arrow lines pointing towards the rivers (Figs 8 and 9), where the groundwater releases water into the rivers and streams through porous media. Groundwater discharge also occurs naturally during harmattan (dry season).

4.2 Aquifer of the study area

4.2.1 The Coastal Plain Sands (Benin Formation) Aquifer: The Coastal plain sand (Benin Formation) covers all the area of study. The study revealed that shallow aquifers found in the area are mostly unconfined and made up of unconsolidated sedimentary materials, which is why it is believed that the aquifer bears freshwater with high yield potentials. The study revealed that there is occurrence of thick freshwater bearing aquifer in almost all the location ranging between 20 to 25 meters below sea level (Appendices 6, 7 and 8), in most cases saturated during wet season. The study also discovered various types of aquifer ranging from shallow, intermediate and deep within the study area. The reliable aquifer in the area can be tapped at the depths between 56 to 120 meters below sea level (inference from borehole data in Appendices 6, 7 and 8). The depth of borehole at Umuokirika-Ahiazu is 150 meters; depth to aquifer is between 120

to 145 meters, with a thickness of 25 meters. Depth of borehole at Nekede is 80 meters; depth to aquifer is between 56 to 76 meters with thickness of 20 meters. The depth of borehole at Ogbe-Ahiazu is 120 meter; depth to aquifer is between 100 to 120 meters with thickness of 20 meters. The soils encountered during boreholes logging were fine sand, silt sand and clay. The yield of the boreholes in Owerri and environs as determined from pumping test obtained from Anambra-Imo River Basin Development Authority included Agbaja borehole yield of 432 m^3/day, drawdown of 3 meters and water level of 30.4 meters. Mbutu-AbohMbaise borehole yield is 840 m^3/day; drawdown of 1.5 meters and water level of 8 meters (Appendices 9 and 10). Average transmissivity of aquifer in the study area is 864,000 (m^2/day) and average hydraulic conductivity is 4×10^{-1} m/s.The high yearly average rainfall over the area of study ensures adequate groundwater recharge through infiltration from unsaturated zone to zone of saturation.

4.3Hydraulic Parameters of Aquifer in the Study Area

Properties of Aquifer in the Study Area

Table 3: Aquifer properties of the study area

Sample location (Benin Formation)	Screened Aquifer Thickness (d) (m)	Hydraulic Conductivity(k) (m/s)	Transmissivity T (m^2/day)	Groundwater Flow Potential
1 Umuokirika-Ahiazu	**25**	**4×10^{-1}**	**864,000**	**High**
2 Nekede	**20**	**5×10^{-1}**	**864,000**	**High**
3 Ogbe-Ahiazu	**20**	**4×10^{-1}**	**864,000**	**High**

4.3.1 Hydraulic Conductivity (K)**:** Hydraulic conductivity (m/s)value of aquifer in the study area ranges between 4×10^{-1} m/s and 5×10^{-1} m/s with an average of 4×10^{-1} m/s(Table 3) indicating easy transmission of groundwater in the aquifer.

4.3.2 Transmissivity (T)**:** Transmissivity(m^2/day) average value of aquifer in the study area is 864,000 m^2/day(Table 3). These values are indicative of very good aquifer in conformity with the hydraulic conductivity values.

4.3.3 Groundwater Flow Velocity: Groundwater velocity in the study area is 2.5×10^{-3} m/s. It also shows aquifer of good performance

4.4Grain Size Evaluation of the Area

Table 4: Data from sediments grain size of the study area
(Source: laboratory data, 2012)

S/No	Location	Co- ordinate °'" Latitude N Longitude E	Sorting	Skewness	Kurtosis	Interpretation	Mean	Remarks
1	Orji Mechanic	-	0.36	-0.33	1.43	Well sorted, negatively skewed (coarse skewed) and leptokurtic	-1.2	Benin Formation (unconfined)
2	Concorde Villa	-	0.63	-0.13	1.36	Moderately sorted, negatively skewed (coarse skewed) and leptokurtic	-1.8	Benin Formation (unconfined)
3	Uratta	-	0.65	-0.45	1.00	Moderately sorted, negatively skewed (coarse skewed) and mesokurtic	-1.28	Benin Formation (unconfined)

The results of sediment samples collected from the field at three selected borehole locations within Owerri and environs (Orji mechanic, Concorde villa and Uratta) is classified as medium to coarse sand and gravel. The maximum size of sediment's grain was retained in standard sieve

is 2.36 mm. Figures 3, 4 and 5 show the graphical classification of grain sizes of the study area. Appendices 2A, 2C and 2E show the details of sieve analysis tests as done in the laboratory.

The aquifer sediment grains are well to moderately sorted and negatively skewed. A geological formation comprising of well sorted sand and gravels tends to form more permeable aquifer. The strata would be efficient for storing or transmitting groundwater, which are the fundamental functions of aquifers. If the skew of the sediment is negative, it implies that grains are coarse and that the aquifer can store and transmit water. Table 4 above shows the aquifer sediment's properties while appendices 2B, 2D and 2F shows particle size distribution curves for determination of sorting, skewness and kurtosis.

4.5 Evaluation of Total Water Reserves (Water Budget)

The study had evaluated the inflow-outflow (water balance) of water reserves in Owerri, adopting the classification of Total water reserves, as classified by Schoeneich, (2007).

Table 5: Classification of total water reserve (Source: Schoeneich, 2007).

	TOTAL WATER RESOURCES (tWR)	
	Utilisable Water Resources (uWR)	Non-Utilisable Water Resources (nWR)
Total Static Water Resources (tWRs)	Utilisable Static Water Resources (uWRs)	Non-Utilisable Static Water Resources (nWRs)
Total Dynamic Water Resources (tWRd)	Utilisable Dynamic Water Resources	Non-Utilisable Dynamic Water Resources (nWRd)

4.5.1 Total Static Water Resources in the Study Area (tWRs): The groundwater static water resources (gWRs) are calculated as:

$$gWRs = A \times T \times V. \quad (9)$$

Where “A” = area of aquifer (groundwater deposit),

“T” = mean weighted thickness of water saturation part of the aquifer, and “V” = coefficient of voidity expressed as decimal fraction (dimensionless).

In the case of the study area, only that aspect of groundwater resources (gWRs) is calculated using the formula: gWRs = A × T ×V. The thickness of the saturated part of the aquifer is between 20 and 25 meters with mean of 21.7 meters (21.7 meters thickness was used for this calculation) as deduced from Appendices 6, 7 and 8.

To calculate the static groundwater resources (gWRs) of the area: (gWRs = A×T×V), equation 9 is introduced.

The area of Owerri is = 683.33 km^2. (Using the dimension of the topographical map studied as calculated in Appendix 4).

A = area of the aquifer covered by Owerri (converting km^2 to m^2) = 683.33 $km^2 \times 10^6$= 683,330,000 m^2.T = thickness of water saturated part of the aquifer = 21.7 meters (Appendices 6, 7 and 8 as inference) andV = coefficient of voidity (or mean maximum % porosity) =20 % to 35 % as expressed by Fetter (1994) for range of gravel and sand expressed as decimal fraction. In this work, average of the range (27.5 % or 0.275) was used to calculate the total static groundwater resource of the study area.

Therefore a static groundwater resource in the area is;

gWRs = A×T× = 683,330,000 $m^2 \times$ 21.7 m × 0.275 = 4,077,771,775 m^3/a.

4.5.2 Total Dynamic Water Resources of the Study Area (tWRd): These are equal to the volume of water flowing in a unit of time through a water deposit (surface body or aquifer) and

are normally expressed in cubic meters per year (m^3/ year). The total annual rainfall of Owerriranges between 60 mm to 4262.2 mm with a mean average of 2161.1 mm/a (inference from NIMET, 2015 report).To calculate the dynamic groundwater resources of Owerri,

WRd=A×D = Pv (volume of rainfall) (10)

Therefore, area (A) = 683,330,000 m^2 × 2.1611 m/a or 2,161.1 mm/a (depth of rainfall D) = 1,476,744,463 m^3/a (i.e. volume of rainfall).

Therefore, volume of base flow (total dynamic groundwater resources of Owerri) is 1,476,744,463 m^3/a× 0.41 (coefficient of base flow corresponding to 2,161.1 mm/a depth of rainfall, as shown in Fig 10) = 605,465,229.83 m^3/a as dynamic groundwater resources of Owerri.

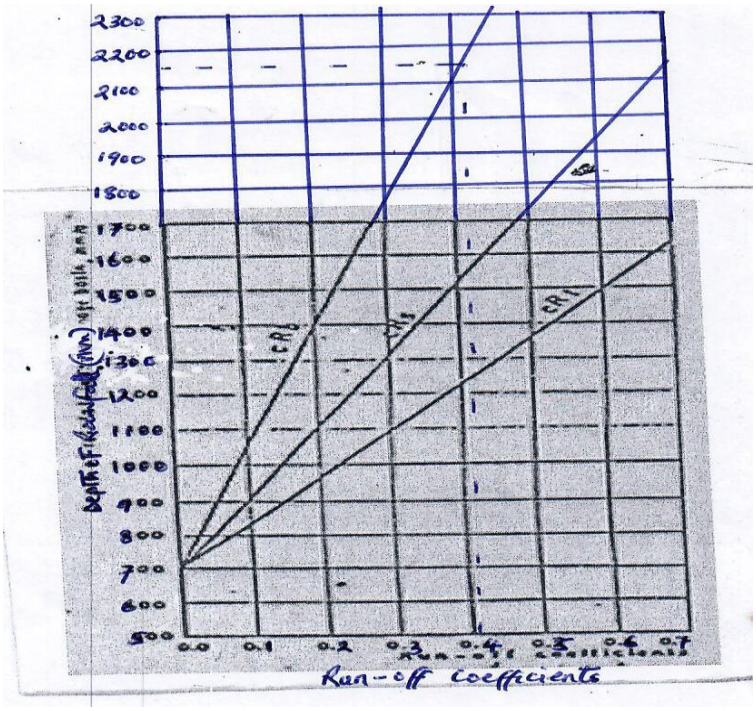


Figure 10: Correlation between depth of rainfall and runoff coefficient in drainage basins (Adapted after, Schoeneich, 2007).

Legend: cRt = total runoff coefficient; cRs = surface runoff coefficient; cRb = base flow coefficient.

4.5.3 Utilizable Dynamic Water Resources of the Study Area (uWRd): The Utilizable Dynamic Water Resources of Owerri(study area) was found based on the following assumptions: out of the total dynamic water resources of the study area, 11 % is set aside for losses due to dry season and 30 % is set aside for unaccountable water loss due to wastages and environmental degradation. Therefore Utilizable Dynamic Water Resources will be 59 % of the Total Dynamic Water Resources (tWRd) of the study area, which is uWRd = 605,465,229.83 m^3/a× 59 % = 35,722,448,559.9 m^3/a

4.6 Water Demand and Consumption

4.6.1 Population of Water Consumers in Owerri (study area): According to 2006 National Population Census which stated the population of each Local Government Area as Owerri municipal 125,337, Owerri north 176,334 and Owerri west 101,754 summed at 403,425 populations of the people in living in Owerri (Table 6). According to the bureau for statistics, the population growth rate of Owerri in 2006 population census is 3.2% (0.032 %). The study area falls within the residential water consumption category. The projected population of Owerri (projected from 2006 to 2015) was used to calculate the population projection in Owerrifrom 2015 to 2065 (50years) using the formula:

$P\ e^{r\ n}$ (Kpedekpo, 1982) (11)

Where P = present population, *e* is exponential, r is population growth rate, and n is the projected year. This is because the population of Nigeria is expected to stabilize by the year 2050. For a viable water resources management plan of an area, the planning horizon should be at least 30 year.

Table 6: 2006 Population Census of Owerri by Local Governments. (Source: National Population Commission, Owerri).

Name	Status	Population Census 26-11-1991	Population Census 21-3-2006
Owerri municipal	L.G.A	---	125,337
Owerri North	L.G.A	---	176,334
Owerri west	L.G.A	---	101,754
Total			403,425

4.6.2 Water Demand in Owerri: Therefore Owerri population (as projected from 2006 to 2015, 9years) is, using equation 12: 403,425 people (2006) $e^{0.032 \times 9}$ = 403,425 $e^{0.288}$ = 538,071 projected population of people of Owerri in 2015. Therefore, the projected population by 2065 (50years) is 538,071 people (2015) $e^{0.032 \times 65}$ = 538,071 $e^{2.08}$ = 4,306,972.593 people in 2065. Water consumption in Owerri by the people is mainly urban residential. The 50 lpcd including wastages is considered for urban dwellers in this work, in line with Schoeneich's 50 lpcd, in his work on water resources management in Nigeria. Therefore, for Owerri, the present water demand is = 50 lpcd or 0.05 m^3/d × 538,071 people = 26,903.55 m^3/d or 9,846,699.3m^3/a.

In 50 years from 2015 (2015-2065), the projected water demand for Owerri will be: 4,306,972.593 people × 0.05 m^3/d = 215,348.62965 m^3/d or 78,817,598.4519m^3/a. It is expected that in 50 years from 2015, well advanced industrializations will be established and this perhaps will take or use 20% of the projected water demand in the study area, (Iwd) which is 20% of 78,817,598.4519 m^3/a = 15,763,519.6903 m^3/a. This gives a total of 78,817,598.4519 m^3/a + 15,763,519.6903 m^3/a = 94,581,118.1422 m^3/a (i.e. projected water demand + 20% of the water demand for industrialization).Therefore, at the ultimate planning horizon (50 years from 2015), the estimated water demand that will be allocated to industrialization is = 15,763,598.6903 m^3/a.

Owerri (study area) has a total dynamic groundwater resources of 605,465,229.83 m^3/a, to meet the present and future water demand of people in the area. During the time of planning, the area will have a large water resources surplus of 35,722,448,559.9 m^3/a - 94,581,118.1422 m^3/a = 35,627,867,441.8 m^3/a (i.e. uWRd – projected water demand).

This study of water budget for Owerri shows that the area will havea water surplus of35,627,867,441.8 m^3/a, at the projected and planning horizon.

Table 7: Summary of Water Budget for Owerri (study area)

Water Resources	Total volume (m^3/a)
Total Static Water Resources (tWRs)	4,077,771,775 m^3/a.
Total Dynamic Water Resources (tWRd)	605,465,229.83 m^3/a
Utilizable Dynamic Water Resources (uWRd)	35,722,448,559.9 m^3/a
Projected Water Demand for the people (2015-2065)	78,817,598.4519 m^3/a
Projected water demand for industrialization (Iwd)	15,763,519.6903 m^3/a
Projected water demand + water demand for industrialization (Pwd+Iwd)	94,581,118.1422 m^3/a
Result = uWRd – (Pwd + Ir)	35,627,867,441.8 m^3/a
Surplus	35,627,867,441.8 m^3/a

4.7 Hydrochemistry and Water Quality

The physicochemical and microbial data ranges of thewater samples acquired from field and laboratory; its concentrations in milligram per liter (mg/l) are presented in Tables 8 and 9.

4.7.1 Physical Qualities of Water in the Area

4.7.1.1 Colour: Colour range of the water samples of the study area is 5 Hazen unit to 10/15 Hazen unit, depicting clear to not clear. Presence of colour in the water is sometimes objectionable and could be as a result of dissolved organic material decaying in the surface water, excessive concentration of inorganic iron and the nature of the formation (lateritic).

Table 8: Range ofvalues of physico-chemical and microbial analysis from the study area and WHO guidelines for drinking water. (Adapted from World Health Organization, 2006)

Parameter	Range	Mean	WHO Standard (2006)	
			PL	MPL
Colour(Hazen)	5-15	8.5	5	15
Temperature(°C)	20-28.3	26.6	-	-
Turbidity	1-50	13.13	5	25
pH	6.2-10.7	7.66	6.5	8.5
Conductivity (µs/cm)	0.03-0.44	0.135	200	400
TDS (mg/l)	6-67	34.64	600	1000
Total hardness (mg/l)	2.0-12.8	7.94	200	500
Na^{+}(mg/l)	3.33-7.6	4.886	20	200
K^{+}(mg/l)	0.2-10.1	1.918	200	-
Ca^{2+}(mg/l)	2.4-8.3	4.117	75	200
Mg^{2+}(mg/l)	1.02-3.44	1.726	50	150
Fe^{2+}(mg/l)	0.001- 0.59	0.292	0.3	1.0
HCO_3^{-}(mg/l)	9.64-28.6	20.025	<100	600
Cl^{-}(mg/l)	0.04-21.0	3.856	250	500
SO_4^{2-}(mg/l)	1.0-4.2	2.319	250	500
NO_3^{-}(mg/l)	0.01-4.06	0.815	25	50
Pb^{2+}(mg/l)	0.001-0.01	0.0055	1.0µg/l	<0.02
Cd^{2+}(mg/l)	0.029-0.16	0.0628	3.0µg/l	0.003
Cu^{2+}(mg/l)	0.06-2.88	0.819	1.0	5.0
Zn^{2+}(mg/l)	0.01-2.51	0.736	3.0	5.0
Hg^{2+}(mg/l)	0-0.001	0.001	0.5µg/l	0.001
Total microbial Load	5-120	31.1	<100	
Total Coliform	4-262	36	<10	

PL = Permissible Limit
MPL= Maximum Permissible Limit

4.7.1.2 Temperature: Temperature of the water sample of the study area varies between 20°C and 28.3°C with a mean of 26.6°C. Both high and low temperature of water can influence several other parameters and can alter the physical and chemical properties of water.

4.7.1.3 Conductivity: Conductivity values range from 0.03µS/cm and 0.44 µS/cm, with an average of 0.0235µS/cm, indicating very low salinity hazard. Conductivity is a measure of the total dissolved ionic constituents in water which varies with temperature. There are few salts that become less soluble at warmer temperature while some salts become more soluble in higher temperature and thus will affect conductivity. Conductivity increases is dependent on the salts present in solution.

Table 9: Result of the physico-chemical and bacteriological analysis of water samples of the study Area. (Source: field and laboratory data, 2012. Analyzed at Ministry of Petroleum UNIDO Lab. Owerri)

Sample No / Parameters	1 Irete 06°53'04'' E 05°30'02'' N	2 Umuguma – Avu 06°55.5'00'' E 05°27.5'02' N'	3 Avu 06°52.5'0.5' 'E 05°25.9'00'' N	4 Ubomiri 06°57'0.1'' E 05°30.5'0.3' ' N	5 Mbieri 06°58.5'00'' E 05°30.5'00'' N	6 Amakohia-uratta 06°56.5'01'' E 05°30.42'00' ' N	7 Orji 07°01'11'' E 05°30'57'' N	8 Egbu 07°01'31.4'' E 05°29'12.5'' N	9 Umuguma-Imo housing 06°52.05'0.1''E 05°26.5'0.5''N	10 Nekede 06°57.05'01'' E 05°25.5'02'' N	11 Ihiagwa 06°57'44'' E 05°23'52.2'' N	12 Agbala 07°05'38.2 E 05°25'56.7'' N	13 Obinze 06°51.5'0.25' ' E 05°23.2'00'' N	14 Uratta 07°02'57.8'' E 05°31'04.2'' N	15 Ndegwu 06°51.5'0.3'' E 05°30.5'0.5'' N	16 Naze 07°2.03'0.3'' E 05°26.04'0.5' ' N	17 Nworie River 06°55.04'0.1' 'E 05°25.04'0.1' 'N	18 Okitankwo River 07°0.15'00'' E 05°28.04'0.1' 'N	19 Otamiri River 06°55'00''E 05°22.01'0.2' 'N	20 Mbaa River 07°6.5'0.45''E 05°25.04'0.14'' N
Color(Hazen)	10	10	15	5	5	5	10	5	5	5	10	5	10	15	5	5	10	15	10	15
Temperature (°C)	27	27	28.3	26	27	28	26.4	27.4	28	27.2	29	27	26	27	28	29	20	20	20	26
Conductivity (□s/cm)	0.04	0.1	0.07	0.05	0.2	NA	0.03	NA	NA	NA	NA	0.21	0.12	0.03	0.44	0.21	0.2	NA	0.07	0.12
PH	6.4	9.9	5.6	6.8	10.2	6.4	6.2	6.3	6.2	7.3	6.3	8.3	7.3	7.2	6.8	6.5	10.4	10.2	10.7	7.5
Turbidity	2.2	5	0	0	10	12	4.8	5.2	3	5	2.3	16	4.2	11	40	1	20	43	28	50
Total Hardness(mg /l)	11.2	12.8	12.6	4.6	11.8	11.5	12.6	11.6	4.0	3.0	1.02	4.6	12.8	11.5	2.0	4.4	2.2	4.7	6.2	4.5
TDS (mg/l)	10	6	38	15	26	16.3	11	36	24.7	64.1	21.7	20	52.1	32.2	38.7	39	60	62.5	67.2	52.5
Ca^{2+} (mg/l)	2.8	3.5	7.6	7.8	4.1	2.88	2.89	2.89	8.3	3.6	4.5	7.6	2.7	2.4	4.6	2.8	3.5	2.4	2.7	2.88
Mg^{2+}(mg/l)	1.02	1.26	1.5	1.24	1.11	3.3	1.23	2.13	1.05	1.08	1.05	1.28	1.5	3.44	1.22	1.11	3.4	1.7	2.88	2.02
Na^{+}(mg/l)	4.59	5.35	3.95	3.32	4.36	4.27	4.21	7.6	5.34	3.92	4.32	3.3	4.21	4.28	6.2	5.5	5.4	5.5	5.68	6.4
K^{+} (mg/l)	1.1	0.85	2	1.74	0	0	1.9	2	2	0.9	0.3	1.15	0.5	0.6	0.4	0.2	6.8	4.4	1.42	10.1
Fe^{2+}(mg/l)	0.38	0.49	0.17	0.59	0.001	0.39	0.38	0.19	0.26	0.41	0.13	0.38	0.49	0.59	0.17	0.13	0.08	0.09	0.15	0.38
HCO_3^-(mg/l)	17.5	18.4	20.75	9.64	18.5	18.5	18.2	17.6	20.4	19.0	18.5	17.5	19.2	20.7	19.5	18.5	28.5	26.4	28.6	24.6
SO_4^{2-}(mg/l)	2.8	2	0	1	3.2	1.8	3	3.8	2.1	4.2	1.1	1	1.02	1.05	1.01	2.8	4	3	4	3.5
Cl^- (mg/l)	1.4	1.7	2.5	5.08	0.04	1.6	1.4	1.6	1.7	1.6	16.5	2	3	0.06	1.7	1.8	3.04	4.2	5.2	21
NO_3^- (mg/l)	0.08	0.07	0.09	3.08	4.06	0	0.1	0	0.05	0.04	0.08	0.04	0.09	0.02	0.01	0.01	2	2.1	2.2	2.2
Pb^{2+} (mg/l)	0	0.001	0	0.005	0	0.001	0.008	0	0	0	0	0.003	0.004	BDL	BDL	0.01	0.003	0.006	0.009	0.01
Hg^{2+} (mg/l)	BDL	DBL	0.001	BDL	BDL	BDL	0.001	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.001	BDL	0.001	BDL
Cd^{2+} (mg/l)	0.15	0.16	0.14	-	-	0.12	0.16	0.02	0.01	0.03	0.05	0.03	0.16	-	-	0.041	0.043	0.052	0.061	0.029
Cu^{2+} (mg/l)	0.07	0.06	0.57	0.44	0.76	0.35	0.14	0.25	0.43	0.26	0.56	0.83	0.51	0.73	0.25	0.14	2.88	2.19	2.60	2.33
Zn^{2+} (mg/l)	0.18	0.21	0.08	0.13	0.17	0.06	0.02	0.18	0.01	2.51	1.95	2.10	2.05	2.18	0.78	0.58	0.47	0.68	0.22	0.06
Total microbial load	15	20	46	ND	ND	31	ND	6	15	48	49	ND	17	ND	ND	5	115	120	62	73
Total coli form	5	10	13	ND	ND	15	ND	ND	5	20	18	ND	6	ND	ND	4	224	262	74	64

4.7.1.4Hydrogen exponent (pH): pH is a measure of the acidity or alkalinity of groundwater. pH values of the water samples of the study area range from 6.2 to 10.7. The mean average values ofpH8.5mg/l in the study area is said to be strongly alkaline (pH > 8.2), though it is used for drinking, domestic and industrial purpose.Low pH may be caused by decaying vegetation and presence of acidic substances of peaty origin.

4.7.1.5Odour: Majority of the water samples wereodourless, though some objectionable odour was observed in some surface water. It shows a possible bacteriological pollution of the surface water in the study area.

4.7.1.6 Total Dissolved Solid (TDS): Total Dissolved Solids (TDS) values range from 6mg/l to 67mg/l, with an average of 36.5mg/I. This shows that water in the area is excellent for drinking and for other purposes. TDS test of water was done to provide a qualitative measure of the amount of dissolved ions. The source of TDS can include all of the dissolved cation and anion.

4.7.2 Chemical Qualities of Water of the Study Area

4.7.2.1 Total Hardness (calcium and magnesium ions in mg/l): Total Hardness value ranges from 2.0mg/l to 12.8mg/l, with an average of 0.74mg/I. When water passes through or over deposits such as limestone, the level of Ca^{2+}, Mg^{2+} and HCO^{3-} ions present in water can greatly increase and cause the water to be classified as hard water. High level of Ca^{2+} and Mg^{2+} can cause scaly deposits in plumbing, appliances, and boilers. These two ions also combine chemically with soap molecules, resulting in decreased cleansing action. On the contrary, calcium is an important component of cell walls of aquatic plants and of the bones or shells of aquatic organisms. Magnesium is an essential nutrient for plants, and is a component of chlorophyll.

4.7.2.2 Calcium (Ca^{2+}) ion: Calcium (Ca^{2+}) ion varies in concentrations from 2.4 (mg/l) to 21.0 (mg/l) with an average value of 3.856 (mg/l). Calcium ion released into the groundwater in the study area may be traced to lime in cement used for building constructions and agricultural fertilizers.

4.7.2.3 Magnesium (Mg^{2+}): Magnesium (Mg^{2+}) ion concentrations vary from 1.02 mg/l to 3.44 mg/l and average concentration of 1.726 mg/l. Magnesium concentration in groundwater of the study area may be as a result of agricultural activities, such as the use of artificial fertilizers, indiscriminate disposal of animal dumps and land use (gravel mining). High magnesium and calcium concentrations make the groundwater hard or very hard and undesirable due to potential incrustation build-up in pipelines and household appliances. This needs to be taken into consideration practically when considering the construction of a central water supply.

4.7.2.4 Sodium (Na^{+}): Sodium (Na^{+}) ions occurred in concentrations that ranges from 3.3 (mg/l) to 7.6 (mg/l) with a mean of 4.885 (mg/l). The low sodium situation of waters in the study area is an indicative of low input of this cation from anthropogenic sources such as agricultural activity. Over abstraction of groundwater in some areas studied may have resulted to greater drawdown, causing saltwater-freshwater interface. This process may have increased the concentration of sodium ion a little.

4.7.2.5 Potassium (K^{+}): Potassium (K^{+}) ion concentrations vary from 0.2 mg/l to 10.1 mg/l and average concentration of 1.918 mg/l.Potassium concentration in groundwater of the study area may be traced to fertilizer uses, breakdown of both human and animal waste products and from natural water-rock interaction. In few locations in the study area (such as water samples 5 and 6) potassium concentration was not determined (negligible).

4.7.2.6 Iron (Fe^{2+}): Iron concentration falls within the range of 0.001 mg/l to 0.59 mg/l. This relatively high iron concentration may be attributed to possible infiltration of petroleum products from the petrol stations within these areas and discharge from automobile workshops. Water-rock interaction may also have attributed to relatively high concentration of iron through weathering and dissolution processes resulting in production of iron oxides which is present in laterites found in the area. Also, the source could be traced to the oxidation of iron minerals by oxygenate recharge water as a result of shallow and open nature of ground water system in the area. This relatively high iron content may cause staining in laundry, incrustation in metal pipes for reticulation and scaling in pipes. The excessive iron is also capable of spreading and polluting nearby aquifer in areas where there is an existing interconnectivity between surface and groundwater systems.

4.7.2.7 Zinc (Zn^{2+}): Zinc concentration in the study area falls within the range of 0.01 mg/l to 2.51 mg/l. Zinc concentration may be traced from the same sources that attributed relatively high iron in the study area, especially leakage of underground petrol storage tanks and automobile waste disposal sites.

4.7.2.8 Mercury (Hg^{2+}): Mercury concentration of water samples fall within the range of BDL to 0.001mg/l. About 80 percent of water samples are found to be good for drinking while 20 percent of the water samples are found high concentrated. However, mercury is not acceptable at any level of concentration in drinking water. The concentration of mercury in water sample collected at Orji mechanic can be linked to indiscriminate litter of automobile waste such as grease, engine oil, car electrical panels etc. Mercury concentration analyzed in water samples collected from the rivers may as well be traced to anthropogenic activities such as the use of

fertilizers and insecticides in the nearby farmland, cassava processing in and within the rivers, laundry activities.

4.7.2.9 Copper (Cu^{2+}): Copper concentration in water samples fall within the range of 0.06 mg/l to 2.88 mg/l. About 80 % of the samples are good for drinking while 20 % are found high concentrated. Copper concentration found in some areas increased especially in the rivers. It may be traced to sewage effluents from the residential buildings and landfill.

4.7.2.10 Cadmium (Cd^{2+}): Cadmium concentration in water samples fall within the range of 0.029 mg/l to 0.16 mg/l. 100 % of the water samples are highly concentrated. High cadmium in the area could be as a result of unregulated household effluents within the urban residential areas, effluents from the industrial plants at industrial layout Irete community, which drain into Otamiri and Nworie rivers. It is suspected as well that oil spills ranging fromfuel tanker accidents, leakages from the petrol station's underground tanks and oil pipeline burst attributed to high cadmium in ground and surface water in the area.

4.7.2.11 Lead (Pb^{2+}): Lead concentration in water samples fall within the range of 0.001 mg/l to 0.01 mg/l. About 10 % of the water samples are highly concentrated while 90% of the samples are good for drinking and other purposes. Lead concentration within some areas may be traced to infiltration of petroleum products from nearby fuel stations, waste from automobile workshops and effluents from residential and industrial sites.

4.7.2.12 Chloride (Cl^-): Chloride concentration in water samples ranges from 0.04 mg/l to 21.0 mg/l with a mean of 3.856 mg/l. Concentration of rainwater by evapotranspiration and evaporation of seawater (Atlantic Ocean) that enters aquifer as rainfall recharge may be the source of chloride in the area.

4.7.2.13 Sulphate (SO_4^{2-}) and Nitrate (NO_3^-): Sulphate and nitrate concentration of water samples range between 1.0 mg/l to 4.2 mg/l, 0.01 mg/l to 4.06 mg/l, respectively. Sulphate in water may be from agricultural and household fertilizers in the area or from natural processes (rainfall). Too much sulphate may have laxative effects.

Generally, nitrate content in water samples show very low values, with undetectable values in some samples. The concentration of nitrate in water samples may be from household fertilizers and excretes of animals and humans. The low concentration of nitrate in the area suggests the usefulness of the water for drinking and domestic use while high level of nitrate in water meant for irrigation is good.

4.7.2.14 Bicarbonate (HCO_3^-): The bicarbonate concentration in water samples show range between 9.64 mg/l and 28.6 mg/l with an average of 20.25 mg/l. The Bicarbonate ion is sourced from the atmospheric carbondioxide dissolved by rain water and carbondioxide present in the humus soil, absorbed by water during percolation. The most important effect of bicarbonate ingestion is the change in acid-base balance as well as blood pH and bicarbonate concentration in biological fluids.

4.7.3 Microbial analysis

The total microbial load and total coliform in the water samples ranges from 5 to 120 with an average of 31.1 while total coliform ranges from 4 to 262 with an average of 36. Some the water samples in the area contained colonies with undetectable values in some samples. The total microbial and total coliform in water samples became extreme in surface water samples in the study area. It shows that the rivers and aquifer in some locations are contaminated at sampling points by faecal coliform bacteria, especially the E-coli which is an indicator micro organism for

other pathogens that may be present in faeces. The source of this contamination may be attributed to indiscriminate animal dumps in and around the surface water and leakages from underground sewage pits. The water in the areas affected indicated poor quality for domestic water supplies.

4.7.4 Salinity Hazard and Sodium Absorption Ratio (SAR)

The water sample's conductivity ranges from 0.03 (µS/cm) to 0.44 (µS/cm) with an average of 0.135 (µS/cm) and average sodium hazard of 0.52 meq/l, indicated that waters are excellent for agricultural purposes. Figure 11, plot of sodium hazard (SAR) against salinity hazard shows a low (S1) sodium hazard of waters in the area.

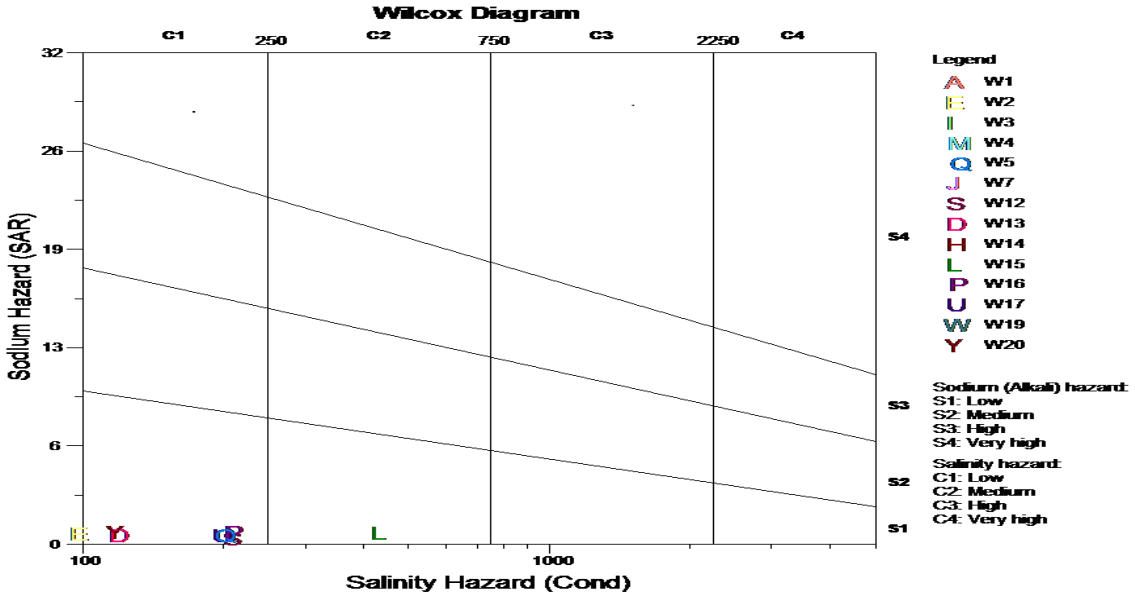


Fig 11: Wilcox quality classification of irrigation waters using water samples collected (after Wilcox, 1948)

Table 10: Hydrochemical Data in meq/l for the Study Area (Owerri)

Sample Number	K^+(meq/l)	Na^+(meq/l)	Ca^{2+}(meq/l)	Mg^{2+}(meq/l)	$\frac{(Ca^{2+}+Mg^{2})}{2}$	$Na^+/\sqrt{(M_g + Ca)/2}$
1	0.03	0.20	0.14	0.08	0.11	0.61
2	0.02	0.23	0.17	0.10	0.14	0.62
3	0.05	0.17	0.38	0.12	0.25	0.35
4	0.04	0.14	0.39	0.10	0.25	0.28
5	0	0.19	0.20	0.10	0.15	0.49
6	0	0.19	0.14	0.27	0.21	0.41
7	0.05	0.18	0.14	0.10	0.12	0.51
8	0.05	0.33	0.14	0.18	0.16	0.83
9	0.05	0.23	1.41	0.09	0.25	0.46
10	0.02	0.17	0.17	0.09	0.13	0.47
11	0.01	0.19	1.22	0.10	0.16	0.48
12	0.03	0.14	0.38	0.10	0.24	0.29
13	0.01	0.18	0.13	0.12	0.13	0.50
14	0.02	0.19	0.13	0.28	0.20	0.42
15	0.01	0.27	0.23	0.10	0.17	0.66
16	0.01	0.24	0.14	0.10	0.12	0.69
17	0.17	0.23	0.17	0.28	0.23	0.48
18	0.11	0.24	0.12	0.14	0.13	0.67
19	0.04	0.25	0.13	0.24	0.19	0.57
20	0.26	0.28	0.14	0.17	0.16	0.70

4.7.5 Classification of water in the study area (Owerri)

The order of abundance of cations is Na > Ca > Mg > K and anions is HCO_3>Cl^-. The dominant water is alkaline bicarbonate water (HCO_3-Na-Ca-Mg-K) amounting to 85 % of the total water samples collected.There are two (2) types of water in the area. These are:

(i) Na - Ca - Mg - HCO_3

(ii) Mg – Na - Ca - K- HCO_3-Cl

The dominance of alkali bicarbonate water type could be attributed to the infiltration of carbondioxide rich rainwater derived from the atmosphere and input of alkali salts from anthropogenic sources. Figures 12 and 13 show the predominance of alkali bicarbonate water type in the area.

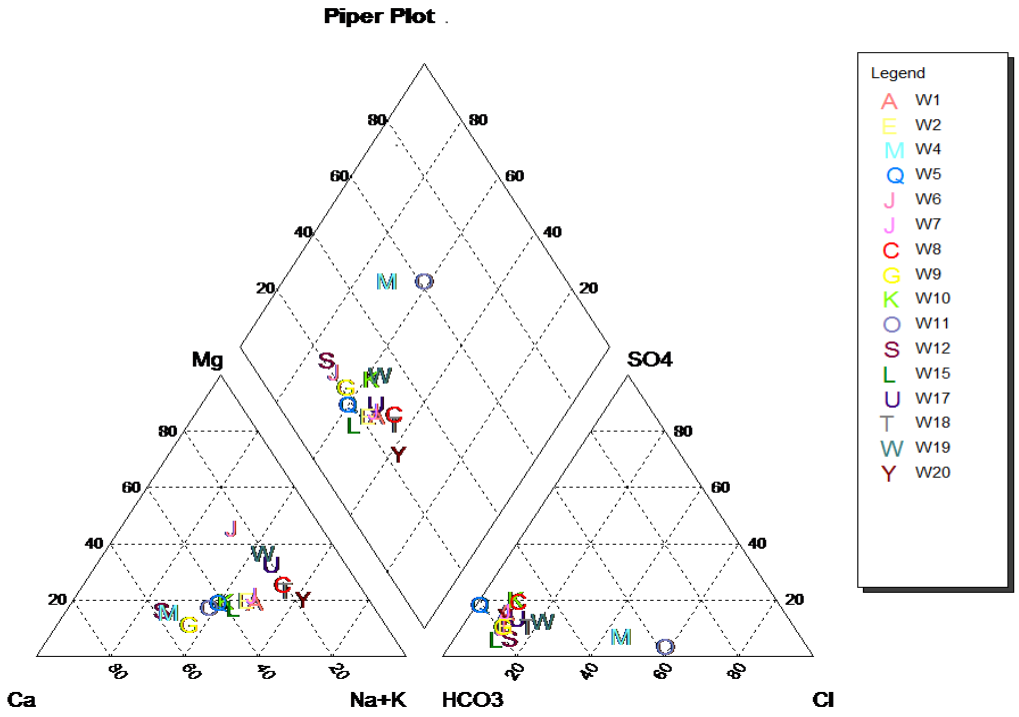


Fig 12: Piper trilinear diagram showing the water types in the study area (Adapted after Piper, 1944)

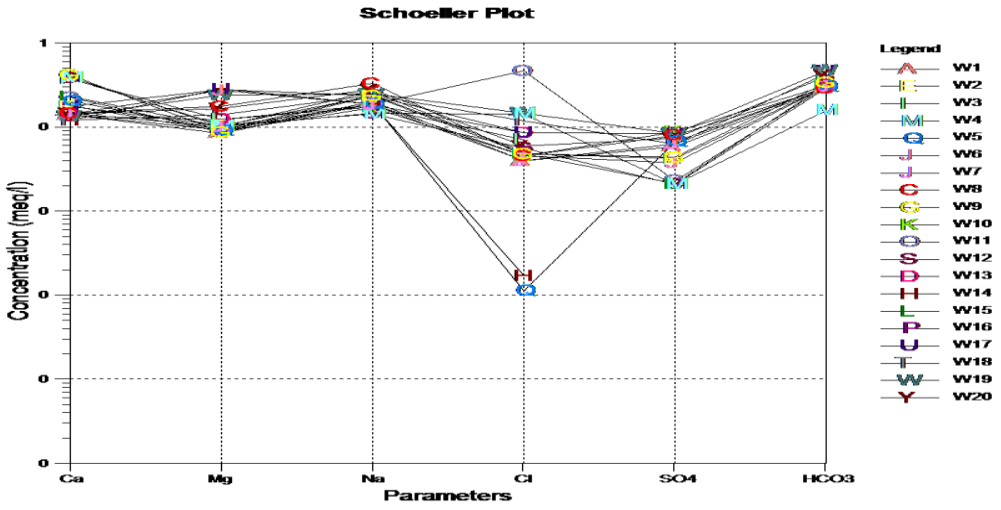


Fig 13: Schoeller semi logarithmic diagram showing the relative abundance of cations and anions in the study area (Adapted after Schoeller, 1962)

CHAPTER FIVE

5 DISCUSSIONS

This Chapter looks at the various field and laboratory acquired data with respect to vivid discussion on these data, in terms ofgeology and groundwater occurrence, water quality and usability according to World Health Organization (WHO) standards as well as types of waters observed in the area using piper trilinear diagram.

The geology of the study area (Benin Formation or Coastal plain sand) consisting of medium sand with alternating clay, coarse gravel and sand, covers all the area of study and has groundwater annual replenishment of about 2.5 billion cubic meters (Leonard *et al*., 2010). The aquifer grain sizes of Benin Formation as calculated using Folks and Wards' (1957) equations, scales and verbal terms of grain size parameters (well to moderately sorted: 0.36, 0.63 and 0.65) and (negatively skewed: -0.33, -0.13 and -0.45) had made it possible to store and transmit water. If the skew of the sediment is negative, it implies that grains are coarse and that the aquifer can store and transmit water (Folks and Wards, 1957). Table 11 shows verbal terms and scales for grain size parameters.

Table 11: Folk and Ward's (1957) Verbal Terms and Scales for Grain Size Parameters

Standard deviation (Sorting)	**Description**
< 0.35	Very well sorted
0.35 - 0.5	Well sorted
0.5-0.71	Moderately well sorted
0.71-1.0	Moderately sorted
1.0 - 2.0	Poorly sorted
2.0-4.0	Very poorly sorted
> 4.0	Extremely poorly sorted
Skewness	
>0.30	Strongly fine skewed
0.30 - 0.10	Fine skewed
0.10- (-0.10)	Near Symmetrical
-0.10-(-0.80)	Coarse skewed
< 0.30	Strongly coarse skewed

Kurtosis	
<0.67	Very platykurtic
0.67 - 0.90	Platykurtic
0.90- 1.11	Mesokurtic
1.11- 1.50	Leptokurtic

Watertable in the study area is high in some areas ranging from37.8 to 95 meters and 36.8 to 91.8 meters below mean sea level respectively, with groundwater fluctuation of 1.17 meters (end of wet and peak of dry seasons). These shows that annual groundwater recharge in the area is high with low discharge (Table 2).Where groundwater contours as shown in the maps (Figures 8 and 9) are more widely spaced, the converse is true, and the aquifer is likely to be more permeable (Brassington, 1998).

Aquifer yields in the study area are between 432 m^3/day and 840m^3/day, drawdown between 1.5 to 3 meters.Offodile (2002) reported that Benin Formation gives copious yields up to 1080 m^3/day and that borehole data in Benin Formation area revealed the same sequence of continuous sandy pebbly formation. He described the borehole yields and watertable in parts of Benin Formation which bordered the area of study as; Portharcourt borehole yield (1404 m^3/day) and watertable (16.8 m), Elele borehole yield (360 m^3/day) and watertable (11.4 m), Umuechem borehole yield (432m^3/day) and watertable (12.3 m), Imo river yield (216 m^3/day) and watertable (6.9 m).

Hydraulic conductivity of aquifer in the area ranges from 4×10^{-1} to 5×10^{-1}, transmissivity average is 864,000 m^2/day and groundwater flow velocity is 2.5×10^{-3} m/s.Ahiarakwem*et al., (2014)* calculatedgroundwater flow potential trend in Owerri, stating ten (10) properties of aquifer in the study area as shown in Table 12 below.

Table 12: Groundwater Flow Potential Trend in Owerri (Ahiarakwem*et al., 2014)*

Location	Aquifer thickness (m)	Hydraulic Conductivity (m/s)	Transmissivity (m^2/day)	Groundwater flow potential
Futo 5	45	10^{-1}	388,800	High
Nekede 1	44.8	10^{-1}	387,072	High
Ihiagwa 4	39	10^{-1}	336,960	High
Aba Rd. 6	50	10^{-2}	43,200	High
Njoku Sawmill	49	10^{-2}	42,336	High
Concorde	40	10^{-2}	34,560	High
Aladinma	50	10^{-2}	4,320	High
Naze	38	10^{-4}	3,283.2	High
Amazu	45	10^{-4}	388.8	Moderate
Uratta 3	36	10^{-4}	311.04	Moderate

The hydraulic parameters in the study area indicated easy transmission of groundwater in the aquifer. Freeze and Cherry (1979) stated the range of values of hydraulic conductivity for unconsolidated deposits of gravel as 10^{-2} and 1 (m/s) (Table 13). The hydraulic conductivity of the aquifer in study area is within this range.

Table 13: Freeze and cherry's (1979) Range of Values of Hydraulic Conductivity of geological material

Consolidated Deposits	**K (m/s)**
Karst Limestone	10^{-8}- 10^{-2}
Permeable Basalt	10^{-7}- 10^{-3}
Igneous and Metamorphic rocks (fractured)	10^{-10}-10^{-4}
Limestone and Dolomite	10^{-10}-10^{-5}
Sandstone	10^{-10}-10^{-6}
Igneous and Metamorphic (Unfractured)	10^{-13}-10^{-8}
Unconsolidated Deposits	
Shale	10^{-12}-10^{-8}
Unweathered marine clay	10^{-10}-10^{-8}
Glacial till	10^{-12}-10^{-5}
Silt, Loess	10^{-10}-10^{-5}
Silty sand	10^{-8}-10^{-3}
Clean sand	10^{-5}-10^{-2}
Gavel	10^{-2}-1

Offodile (2002) described the aquifer transmissivity in Benin Formation ranging from 880 to 30,000 m^2/day. Kampsax-Kruger (1985) rating of transmissivityrange for very good water transmissivity capacity is 1 x 10^{-2}< T (Table 14). The transmissivity of the aquifer in the study area falls within this range.

Table 14: Kampsax-Kruger's (1985) rating of transmissivity values

Transmissivity Range	Water Transmissivity Capacity
$T<1x10^{-3}$	Poor
$1x10^{-3}<T < 5 x 10^{-2}$	Medium
$5x 10^{-3} < T <1x10^{-2}$	Good
$1x10^{-2} < T$	Very Good

Gheorge's (1978) standard for groundwater transmitting potential range of T > 500 m^2/d (Table 15), shows that the aquifer potential in the study area's transmitting potential is high. Kransny (1993) classification of transmissivity (m^2/d) also shows that the class of transmissivity magnitude is II, meaning that the designation of transmissivity magnitude is high and withdrawal is of lesser regional important (Table 16).

Table 15: Gheorge's (1978) standard for aquifer transmissivity

TRANSMISSIVITY RANGE	**TRANSMITTING POTENTIAL**
T greater than 500m^2/day	High potential
T between 50 - 500m^2/day	Moderate potential
T between 5 - 50m^2/day	Low potential
T between 0.5 - 5m^2/day	Very low potential
T less than 0.5m^2/day	Negligible potential

Table 16: Kransny's (1993) classification of aquifer transmissivity

Coefficient of Transmissivity (m^2/ day)	Class of Transmissivity Magnitude	Designation of Transmissivity Magnitude	Groundwater supply potential
100	I	Very high	Withdrawal is of great regional importance
100	II	High	Withdrawal is of lesser regional importance
10	III	Intermediate	Withdrawal of local water supply (small Communities, Plants)
1	IV	Low	Small Withdrawal for local water supply (private consumption)
0.1	V	Very low	Withdrawal for local water supply with limited consumption.
	VI	Imperceptible	Source for local water supply are difficult (if possible) to ensure

Colour range of the water samples in the study area is 5 Hazen unit to 10/15 Hazen unit and falls within the range of WHO (2006) permissible and maximum permissible limits of 5 and 15 Hazen unit, which made it good water for drinking, domestic and agricultural purposes.

Temperature of the water sample of the study area varies between 20^{o}C and 28.3^{o}C with a mean of 26.6^{o}C.Conductivity values range from 0.03µS/cm and 0.44 µS/cm, with an average of 0.0235µS/cm, indicating very low salinity hazard.

pH values of the water samples of the study area range from 6.2 to 10.7. According to the World Health Organization (2006), health effects are most pronounced in pH extremes. The mean average values ofpH8.5mg/l in the study area is said to be strongly alkaline (pH > 8.2).Drinking water with an elevated pH (above 11) can cause skin, eye and mucous membrane irritation. pH values below 4 can also have corrosive effects. WHO (2006) warns that elevated pH above 11 can worsen existing skin conditions.

Majority of the water samples wereodourless except objectionable odourobserved in some surface water.

Total Dissolved Solids (TDS) values range from 6mg/l to 67mg/l, with an average of 36.5mg/I. TDS in the study area is far below WHO (2006) permissible limits of 600 mg/l for drinking water.

Total Hardness value ranges from 2.0mg/l to 12.8mg/l, with an average of 0.74 mg/l and far below the WHO (2006) permissible limits of 200 mg/l, indicating soft and good water quality.

Calcium (Ca^{2+}) ion varied in concentrations from 2.4 (mg/l) to 21.0 (mg/l) with an average value of 3.856 (mg/l) and fall below WHO (2006) permissible limit of 75mg/l. Calcium in the body mediates muscle contraction and exocrine, endocrine, and neurocrine function. Ninety eight (98 %) of calcium present in human body is found in the bones. Calcium deficiency in the body may cause mental status changes, tetanus and bone damage etc. While excess of it may cause constipation, bone pain, kidney stones etc.

Magnesium (Mg^{2+}) ion concentrations vary from 1.02 mg/l to 3.44 mg/l and average concentration of 1.726 mg/l and fall below WHO (2006) permissible limit of 50mg/l. According to Todd (1980), a higher concentration of magnesium in household water has a laxative effect, especially on a new user of the supply.

Sodium (Na^{+}) ions occur in concentrations that range from 3.3 (mg/l) to 7.6 (mg/l) with a mean of 4.885 (mg/l). The WHO (2006) permissible limit for sodium ion is 200 mg/l. The low sodium ion concentration recorded in all the locations in the study area generally agrees with Todd (1980) contention that the concentration of sodium in groundwater is commonly less than 100 mg/l. High concentration of sodium of more than 200 mg/l makes water unsuitable for domestic

use (unacceptable taste), causes foaming in the presence of suspended matter, and accelerating scale formation and corrosion in boiler (Todd, 1980; Udom, 1999).

Potassium (K^+) ion concentrations vary from 0.2 mg/l to 10.1 mg/l with average concentration of 1.918 mg/l, falling below WHO (2006) permissible limit of 200mg/l.

Iron concentration falls within the range of 0.001 mg/l to 0.59 mg/l. About 45 % of the water samples of the study area fall below the WHO (2006) permissible limit of 0.3 mg/l, while 55 % fall above the permissible limit, but not greater than the maximum permissible limit of 1.0 mg/l. Oxidation of iron minerals by oxygenate recharge water as a result of shallow and open nature of ground water system in the area may cause high iron concentration.Onyeagocha (1980) stated that in many places within the area, the formation is overlain by a considerable thickness of earth (laterite) composed of iron-stained regolith formed by the weathering and subsequent ferruginization of the weathered materials. This relatively high iron content may cause staining in laundry, incrustation in metal pipes for reticulation and scaling in pipes. Iron is an essential element in human nutrition, but high iron concentration in water may result to anaemia (Henry and Heinke, 1996).

Zinc concentration in the study area falls within the range of 0.01 mg/l to 2.51 mg/l and fall below the WHO (2006) permissible and maximum permissible limits of 3.0 and 5.0 mg/l. Zinc can be injurious to fishes and infants. When their mothers have absorbed large concentrations of zinc, the children may be exposed to it through blood or milk of their mothers (Henry and Heinke, 1996). However, when people absorb too little zinc they can experience a loss of appetite, decreased sense of taste and smell, slow wound healing and skin sores. Zinc-shortages can even cause birth defects (Chapman, 1992).

Mercury concentration of water samples fall within the range of BDL to 0.001 mg/l. About 80 % of water samples fall below the WHO (2006) maximum permissible limit of 0.001 mg/l while 20 % of the water samples fall within WHO maximum permissible limits 0.5 μg/l. High exposures to inorganic mercury may result in damage to the gastrointestinal tract, the nervous system, and the kidneys (Chapman, 1992).

Copper concentration in water samples fall within the range of 0.06 mg/l to 2.88 mg/l. About 80 % of the samples fall below the WHO (2006) permissible limit of 1.0 mg/l while 20 % fall above. Copper concentration found in some areas increased especially in the rivers. The human body has a natural mechanism for maintaining the proper level of copper. However, children under one year old have not yet developed this mechanism and, as a result, are more vulnerable to the toxic effects of copper such as liver sluggishness, chronic fatigue, inflammation and slow metabolism (Henry and Heinke, 1996).

Cadmium concentration in water samples fall within the range of 0.029 mg/l to 0.16 mg/l. 100 % of the water samples fall above the Maximum Permissible Limit of 0.003 mg/l. Cadmium concentration in the body is first transported to the liver through the blood and can lead to diarrhea, stomach pains and severe vomiting, reproductive failure and even infertility (Henry and Heinke, 1996). Pre-use treatment for cadmium such as distillation system, addition of alum and iron salts to filtration system may aid in cadmium removal. This pre-use treatment for cadmium is strongly recommended for all water sources affected in the study area.

Lead concentration in water samples fall within the range of 0.001 mg/l to 0.01 mg/l. About 10 % of the samples fall above the WHO (2006) Maximum Permissible Limit of <0.02 mg/l while 90% of the samples fall below. High lead exposure can cause seizures, mental retardation, and

behavioural disorder. Faetuses, Infants, and children are especially susceptible to low doses, resulting to central nervous system disorders. It may also be a factor in high blood pressure and heart diseases (Henry and Heinke, 1996). Pre-use treatment for lead such as Reverse Osmosis Systems and filtration are recommended for all water sources affected in the study area.

Chloride concentration in water samples ranges from 0.04 mg/l to 21.0 mg/l with a mean of 3.856 mg/l, falling below WHO (2006) permissible limit of 250 mg/l. Rainfall is the main reason for intense change in Chloride as it changes water potentiality abruptly along profile (Chen *et al., 2002*). The chloride concentrations in the area are comparatively low because of the fact that chloride does not show any correlation with the components of pore water derived from mineral breakdown (Spears and Reeves, 1975).

Sulphate and nitrate concentration of water samples range between 1.0 mg/l to 4.2 mg/l, 0.01 mg/l to 4.06 mg/l, respectively. The sulphate and nitrate concentration levels in the study area fall below the WHO (2006) recommended permissible limit of 250 mg/l and 25 mg/l for drinking water. Nitrate values over 50 mg/l are dangerous to babies as it could lead to the problem of infantile cyanosis or "baby disease" which could result to death (Chapman, 1992).

The bicarbonate concentration in water samples show range between 9.64 mg/l and 28.6 mg/l with an average of 20.25 mg/l, falling below WHO (2006) permissible limit of <100 mg/l. Water which contains bicarbonate (>600 mg/I) may have an effect on acid-base.

The total microbial load and total coliform in the water samples ranges from 5 to 120 with an average of 31.1 while total coliform ranges from 4 to 262 with an average of 36. Some the water samples in the area are below while some are above WHO (2006) permissible limit of < 100 colonies and < 10 colonies respectively with undetectable values in some samples. The rivers

and aquifer in some locations are contaminated at sampling points by faecal coliform bacteria, especially the E-coli which is an indicator micro organism for other pathogens that may be present in faeces. The water in the areas affected indicated poor quality for domestic water supplies.

For agricultural/irrigation purpose, after Wilcox's (1984) diagram shows that the water samples in the study area are of low salinity hazard (Fig 11) and < 250 µS/cm (Table 17), indicating that the waters are excellent for irrigation. Table 17 shows the range of electrical conductivity values for different salinity hazard classes.

Also, the sodium hazard is low in groundwater of the area; hence the groundwater is excellent for irrigation. The low value of Sodium hazard (average of 0.52 meq/l) in groundwater of the area is based on its calculation from Sodium Absorption Ratio (SAR)which is expressed as: Sodium Absorption Ratio: $\mathbf{Na^{+}/\sqrt{(M_g + Ca)/2}.}$ Where Na, Mg and Ca are measured in milliequivalents per litre(Table 10).

Table 17: Suitability of Water for Irrigation, in respect of Salinity Hazard (After Wilcox, 1948)

Salinity Hazard	**Range of Electrical conductivity (µS/cm)**
Low	Less than 250
Medium	250 to 750
High	750 to 2250
Very high	Greater than 2250

The groundwater from the study area is classified by using Piper's diagram (Piper, 1944). The Piper trilinear plot of the water chemistry (Fig 12) is a graphical presentation of percentage equivalent of the major cations and anions. Here cations, are expressed as percentage of total cations in meq/l, plot as a single point on the left triangle; while anions similarly plot on the right

triangle. These two points are then project in the central diamond-shaped area. This single point is thus uniquely related to the total ionic distribution. Two (2) types of waters were determined in the area. These are:

(iii) Na - Ca - Mg - HCO_3

(iv) Mg – Na - Ca - K- HCO_3-Cl

The Piper's diagram (Piper, 1944) is in line with Schoeller (1962) semi-logarithmic diagram (Fig 13), both indicating predominance of alkali bicarbonate water type.

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATIONS

6Summary and Conclusion

The study area is underlain by the Benin Formation. The rock contains medium sand with clay intercalation and gravel beds. Groundwater resourcesof Owerri have beendone using data on water level measurement, grain size analysis, physicochemical analysis and microbial analysis.The results of water level measurement revealed certain attributes: areas of highwatertable (Amakohia-Uratta,Obinze, Ihiagwa, Nekede and Naze) ranging from 36.8meters to 45.5meters with an average of 42.9 meters below mean sea level and lowwatertable (Mbieri, Ubomiri, Irete,Ndegwu, Uratta, Orji, Agbala andEgbu) ranging from 50.2meters to 95meters with an average of 59.4 meters below mean sea level, hence major areas of groundwater recharge and discharge established.The predominant directions of groundwater flow are northwest, northeast and south directions. The watertable average fluctuation in the area is 1.71 meter below mean sea level.

Unconfined aquifer was identified in the study area with a reliable tapping depth; ranging from 56 to 120 meter below mean sea level. The aquifer grain size is classified as medium to coarse sand and gravel, well to moderately sorted (0.36, 0.63and 0.65) and negatively skewed (coarse grains) (-0.33, -0.13, -0.45). Average of borehole yields is 636 m^3/day, aquifer thickness is 21.7 metersand drawdown is 2.3 meters. Hydraulic properties of aquifer in the area were calculated and the averagesof results obtained showed hydraulic conductivity (4×10^{-1} m/s), transmissivity (864,000 m^2/d), and groundwater flow velocity (2.5×10^{-3}m/s). These indicated aquifer of good performance.

Some important water quality problems identified in some parts of the study area were concentrations of lead (Pb) ranging from 0.001 to 0.01mg/l, mercury (Hg) BDL to 0.001mg/l, and cadmium (Cd) 0.029 to 0.16mg/l. These may have adverse pathogenic consequences. The microbial tests of ground and surface water sources had also shown the presence of faecalcoliform, especially Ecoli. The order of abundance of cations in the water are sodium >calcium >magnesium >potassium while anions range in abundance from bicarbonate > chloride. The average electrical conductivity value of 0.135μS/cm indicated low salinity hazard in the groundwater of the area. The dominant water type is alkaline bicarbonate water (Na - Ca - Mg - HCO_3) amounting to about 85% of water samples collected from groundwater and surface water. The average values of the Sodium Absorption Ratio (SAR) (0.52meq/l) indicated prevalence of good water for irrigation purposes.

Total dynamic groundwater resources of the area is 4,077,771,775 m^3/a. The current maximum water demand for an estimated population of 538,071(2015) people in the study area is 9,846,699.3 m^3/a. The projected population of 4,306,972.593 people in the next 50 years from 2015 and at the growth rate of 3.2 % in the study area would make water demand for the people to be 78,817,598.4519 m^3/a. The projected water demand for people and industrialization (2015 to 2065) would be 94,581,118.1422 m^3/a. During this time of planning, the study area will have a large water resources surplus of 35,627,441.8 m^3/a, since utilizable dynamic groundwater resources (uWRd) is 35,722,448,559.9 m^3/a, at the projected 50 years (2015 to 2065), including advanced industrialization. However, groundwater available for supply that will meet the current and/or projected demand in Owerri (study area) is adequate, with surplus of 35,627,867,441.8 m^3/a.

6.1Recommendations

1. There is need for regular appraisal of the available water resources by water managers and planners to ascertain the quality of the resource. Though the availability of the resources is relatively assured, quality sustainability should be a priority

2. Pre-use treatment programs shall be incorporated in cases of water resources development in the study area.

3. Proper understanding of the lithology and groundwater flow direction of the area is of importance before selecting waste disposal and industrial sites, especially in densely populated urban areas.

4. Environmental Impact Assessment should be done before setting up any category of industry in the area. Both surface and sub-surface investigations shall be done (among others) if water safety is considered a priority.

5. Adequate legislative measures should be in place to ensure that environmental standards are observed while embarking on various private, commercial and industrial activities in the area.

6. Public enlightenment efforts need to be enhanced in the entire area, especially in densely populated urban area, to improve on personal and public hygienic lives of the people. Efforts in this direction can reduce the problems of microbial pollution/contamination in public water supply sources.

7. Care should be taken to make sure that the rate of groundwater exploitation does not exceed the recharge rate, which could have grave environmental consequences.

8.An impounding reservoir is needed to be constructed downstream the Owerri municipal or Owerri west drainage basin within the study area to reduce groundwater abstraction thereby saving the environment from degradation.

6.2Contributions to Knowledge

1. It would help hydrogeologists and water related disciplines in the State to know the nature and occurrence of groundwater in the area.

2. It has helped in the production of current hydrogeological maps of the study area

3. Providing account or estimate of calculated water budget of the study area (Owerri).

4. Serve as a reference to researchers for further research(s)

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APPENDIX

Appendix 1A: Values of Rainfall at Owerri

Source: Nigerian meteorological Agency, 2015

Rainfall	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total	Average	Yearly mean	Stdey
Month															
Jan	39.1	5.5	0	0	6.1	35.5	78.5	0	0.9	21.9	0	187.5	17.0	191.7	197.2
Feb	0	62	27.9	59.3	32.4	58.4	48.4	7.4	0	58.5	62.6	416.9	37.9	191.7	1218.0
Mar	53.2	206.4	90.4	109.6	67.4	102.6	108.1	57.7	256.4	40.1	34.1	1126	102.3	191.7	9873.1
Apr	354.2	172.2	241.7	114.1	258.8	194.3	104.1	62.1	238.2	152.2	164.2	2056.1	186.9	191.7	33825.9
May	47.3	140.8	265.6	176.5	268.9	359.8	157.3	260.9	165.4	282.2	297.5	2422.2	220.2	191.7	47175.8
Jun	391.8	385.4	387.3	227	298.2	367	349.9	397.3	230.8	304.3	255.2	3594.2	326.7	191.7	104811.1
Jul	382.7	301.7	391.5	526.5	327	380.6	397.6	485.4	328.8	328.3	252	4102.1	372.9	191.7	136839.5
Aug	356.4	348.7	358.7	384	384.4	302.4	232.1	509	362.8	569.9	453.8	4262.2	387.4	191.7	147819.3
Sept	344	430.8	293.5	535.2	305.1	232.9	537.6	303	446.3	210.9	258.4	3897.7	354.3	191.7	123437.2
Oct	246.5	213.4	372.4	176.6	260.3	199.8	303.3	180.2	183.3	270.1	306.6	2712.5	246.5	191.7	59336.5
Nov	116.5	22.6	40.9	47.4	56.7	13.9	33.3	42.7	14.8	73.1	18.4	480.3	43.6	191.7	1653.5
Dec	5.5	14.8	0	6.7	12.3	0	0	9.6	10.1	0	1.6	60.6	5.5	191.7	6.2
Total													**2301.6**		**666193.6**

Rainfall	2011	2012	2013	2014	2015	Total	Average	Yearly mean
Month								
Jan	25	55	27	0	35.1	142.1	28.42	
Feb	141.1	114.1	102.1	0	225.1	582.4	116.48	
Mar	55	71	88.5	0	331.5	546	109.2	
Apr	604	420.1	395.4	10	158	1587.5	317.5	
May	420.2	320.2	315.3	71	455.5	1582.2	316.44	
Jun	188.1	359.3	387.1	288.1	569	1791.6	358.32	
Jul	815.3	956.1	855.1	109.5	115.5	2851.5	570.3	
Aug	604.2	537.5	605.4	489	120.8	2356.9	471.38	
Sept	388.2	528.3	503.1	909	66	2394.6	478.92	
Oct	446.1	226.2	310.2	439	75.5	1497	299.4	
Nov	98.5	108.5	186.2	125	55	573.2	114.64	
Dec	71	71	56.3	0	50	248.3	49.66	
Total							**2751.74**	

Appendix 1B: Values of Evaporation in Owerri

Source: Nigerian Meteorological Agency, 2015

Evaporation mm	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total	Average	Yearly mean	stdey
Months															
Jan	3.7	4.9	6.1	4	3.7	6.2	3.9	4.8	5	3.9	4.6	50.8	4.618182	2.8	3.305785124
Feb	6	5.8	5.3	4.1	4.8	3.4	5.2	5.7	5.3	4.1	6	55.7	5.063636	2.8	5.124049587
Mar	5.1	3.3	3.3	3.5	3.5	3.1	4.1	3.3	3.3	3.5	5.1	41.1	3.736364	2.8	0.87677686
Apr	3	3.3	3.1	3.3	3	3.1	3.2	3.5	3.1	3.3	3	34.9	3.172727	2.8	0.13892562
May	2.7	2.4	2.5	2.5	2.6	2.6	0	0	2.5	2.5	2.7	23	2.090909	2.8	0.502809917
Jun	1.8	2	1.9	1.8	2	2.2	1.8	2.1	1.9	1.8	1.8	21.1	1.918182	2.8	0.777603306
Jul	1.4	1.8	1.4	1.7	1.9	1.8	1.6	1.4	1.4	1.7	1.4	17.5	1.590909	2.8	1.461900826
Aug	1.4	1.2	1.3	1.4	1.4	1.3	1.6	1.3	1.3	1.4	1.3	14.9	1.354545	2.8	2.089338843
Sept	1.7	1.7	1.7	1.6	1.8	1.7	1.8	1.7	1.7	1.7	1.7	18.8	1.709091	2.8	1.190082645
Oct	1.8	2.3	1.8	2.1	1.7	2	2.4	1.8	1.8	1.8	2	21.5	1.954545	2.8	0.714793388
Nov	2.3	2.8	2.9	2.5	2.7	2.9	3	2.9	2.9	2.3	2.9	30.1	2.736364	2.8	0.004049587
Dec	4.5	4	5.5	5.2	4.8	4.7	4.2	5.5	5.5	4.5	4.8	53.2	4.836364	2.8	4.14677686
Total												382.6	34.78182		120977.4876

Evaporation mm	2011	2012	2013	2014	2015	Total	Average	Yearly mean
Months								
Jan	0	1.96	1.10	1.50	1.40	5.96	1.192	
Feb	0	1.4	0.4	1.30	1.10	4.2	0.84	
Mar	0	1.57	1.4	2.3	0.90	6.17	1.234	
Apr	0	1.46	0.95	1.9	1.00	5.31	1.062	
May	0	1.25	1.00	0.70	0	2.95	0.59	
Jun	0	1.00	0.60	1.00	0.90	3.5	0.7	
Jul	0	0.73	1.20	0.70	2.3	4.93	0.986	
Aug	0	0.74	0.90	0.50	1.97	4.11	0.822	
Sept	0	0.69	1.50	1.50	2.1	5.79	1.158	
Oct	0.95	1.38	0.70	3.2	1.4	7.63	1.526	
Nov	0.10	1.00	1.10	1.10	1.2	4.5	0.9	
Dec	0.50	2.14	1.9	1.20	1.6	7.34	1.468	
Total							12.478	

Appendix 1C: Values of Temperature at Owerri

Source: Nigerian meteorological Agency, 2015.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Temp(0^0)												
2010												
Maxi	34.1	34.8	34.5	33.8	32	30.7	29.6	29.5	29.5	30.9	31.8	33.6
Mini	22.1	23.8	24	23.8	23.7	23.5	22.6	22.3	22.3	22.4	22.8	20.6
Total	56.2	58.6	58.5	57.6	55.7	54.2	52.2	51.8	51.8	53.3	54.6	54.2
Mean	28.1	29.3	29.25	28.8	27.85	27.1	26.1	25.9	25.9	26.65	27.3	27.1
StdDev	789.61	858.49	855.56	829.44	775.62	734.41	681.21	670.81	670.81	710.22	745.29	734.41
2009												
Maxi	33.1	33.3	33.8	32.5	32.1	30.8	29.1	28.5	30.2	30.4	31.7	34.1
Mini	22.1	23.2	24	23.2	23	22.9	22.8	22.8	22.8	22.6	21.7	21.5
Total	55.2	56.5	57.8	55.7	55.1	53.7	51.9	51.3	53	53	53.4	55.6
Mean	27.6	28.25	28.9	27.85	27.55	26.85	25.95	25.65	26.5	26.5	26.7	27.8
StdDev	761.761	796.06	835.21	775.62	759.00	720.92	673.40	657.92	702.25	702.25	702.25	772.84
2008												
Maxi	33.8	0	34	32.2	31.1	30	29.1	29.4	29.9	31.3	33	33.1
Mini	20	0	22.8	22.7	23.1	22.6	22.2	22.6	22.6	22.9	23.3	21.7
Total	53.8	0	56.8	54.9	54.2	52.6	51.3	52	52.5	54.2	56.3	54.8
Mean	26.9	0	28.4	27.45	27.1	26.3	25.56	26	26.25	27.1	28.15	27.4
StdDev	723.61	0	806.56	753.50	734.41	691.69	657.92	676	689.06	734.41	792.42	750.76
2007												
Maxi	34.1	34.8	34.5	33.8	32	29.9	29.1	28.5	30.2	30.4	31.7	34.1
Mini	19.5	23.2	24.2	23.3	23.2	22.9	22.7	22.5	22.4	22.1	22.3	21.8
Total	53.6	58	58.7	57.1	55.2	52.8	51.8	51	52.6	52.5	54	55.9
Mean	26.8	29	29.35	28.55	27.6	26.4	25.9	25.5	26.3	26.25	27	27.95
StdDev	718.24	841	861.42	815.10	761.76	696.96	670.81	650.25	691.69	689.06	729	781.20
2006												
Maxi	34.1	34.8	33.2	33.6	32.3	31	29.2	29.5	29.5	30.9	32.3	33.5
Mini	23.8	23.9	23.2	23.9	23.3	22.7	22.9	22.5	22.4	22.2	22.2	19.5
Total	57.9	58.7	56.4	57.5	55.6	53.7	52.1	52	51.9	53.1	54.5	53
Mean	28.95	29.35	28.2	28.75	27.8	26.85	26.05	26	25.95	26.55	27.25	26.5
StdDev	838.10	861.42	795.24	826.56	772.84	720.92	678.60	676	673.40	704.90	742.56	702.25
2005												
Maxi	33.1	33.3	33.8	32.5	32.1	30	29.1	29.4	29.9	31.3	33	32.8
Mini	19.7	24	23.9	23.9	23	23	22.7	22.4	23.2	22.7	23.4	22.2
Total	52.8	57.3	57.7	56.4	55.1	53	51.8	51.8	53.1	54	56.4	55
Mean	26.4	28.65	28.85	28.2	27.55	26.5	25.9	25.9	26.55	27	28.2	27.5
StdDev	696.96	820.82	832.32	795.24	759.00	702.25	670.81	670.81	704.90	729	795.24	756.25
2004												
Maxi	33.3	33.3	33.8	32.5	32	31.1	29.1	28.5	30.2	30.4	31.7	34.1
Mini	21.1	22.7	24	23.6	22.9	22.5	22.4	22.4	22.9	22.9	22.7	22.2
Total	54.4	56	57.8	56.1	54.9	53.6	51.5	50.9	53.1	53.3	54.4	56.3
Mean	27.2	28	28.9	28.05	27.45	26.8	25.75	25.45	26.55	26.65	27.2	28.15
StdDev	739.84	784	835.21	786.80	753.50	718.24	663.06	647.70	704.90	710.22	739.84	792.42
2003												
Maxi	33.8	32.9	34	32.2	31.1	30	29.1	29.4	29.9	31.3	33	33.1
Mini	21.1	23.5	23.8	23.3	23.3	22.9	22.5	22.8	22.5	22.8	23.3	21
Total	54.9	56.4	57.8	55.5	54.4	52.9	51.6	52.2	52.4	54.1	56.3	54.1
Mean	27.45	28.2	28.9	27.75	27.2	26.45	25.8	26.1	26.2	27.05	28.15	27.05
StdDev	753.50	795.24	835.21	770.06	739.84	699.60	665.64	681.21	686.44	731.70	792.42	731.70
2002												

Maxi	34.2	35.6	33.6	32.7	32.6	0	29.8	29.3	30.3	30.8	33	34.5
Mini	22.7	23.7	25.2	24.4	23.6	0	23.5	23.5	23.3	23.5	24.4	23.5
Total	56.9	59.3	58.8	57.1	56.2	0	53.3	52.8	53.6	54.3	57.4	58
Mean	28.45	29.65	29.4	28.55	28.1	0	26.65	26.4	26.8	27.15	28.7	29
StdDev	809.40	879.12	864.36	815.10	789.61	0	710.22	696.96	718.24	737.12	823.69	841
2001												
Maxi	34.3	35.9	33.8	33.9	32.3	30.9	29.6	28.3	30	31.8	32.9	34.4
Mini	22.8	24.1	24.5	24.5	24	23.5	22.9	23.1	23.2	23.7	24.5	24.9
Total	57.1	60	58.3	58.4	56.3	54.4	52.5	51.4	53.2	55.5	57.4	59.3
Mean	28.55	30	29.15	29.2	28.15	27.2	26.25	25.7	26.6	27.75	28.7	29.65
StdDev	815.10	900	849.72	852.64	792.42	739.84	689.06	660.49	707.56	770.06	823.69	879.12
2011												
Maxi	33.1	33.3	33.8	32.5	32.1	30.8	29.1	28.5	30.2	30.4	31.7	34.1
Mini	22.1	23.2	24	23.2	23	22.9	22.8	22.8	22.8	22.6	21.7	21.5
Total	55.2	56.5	57.8	55.7	55.1	53.7	51.9	51.3	53	53	53.4	55.6
Mean	27.6	28.25	28.9	27.85	27.55	26.85	25.95	25.65	26.5	26.5	26.7	27.8
StdDev	761.761	796.06	835.21	775.62	759.00	720.92	673.40	657.92	702.25	702.25	702.25	772.84
2012												
Maxi	33.8	35	34	32.2	31.1	30	29.1	29.4	29.9	31.3	33	33.1
Mini	20	24.3	22.8	22.7	23.1	22.6	22.2	22.6	22.6	22.9	23.3	21.7
Total	53.8	59.3	56.8	54.9	54.2	52.6	51.3	52	52.5	54.2	56.3	54.8
Mean	26.9	34.5	28.4	27.45	27.1	26.3	25.56	26	26.25	27.1	28.15	27.4
StdDev	723.61	731.3	806.56	753.50	734.41	691.69	657.92	676	689.06	734.41	792.42	750.76
2013												
Maxi	34.1	34.8	34.5	33.8	32	29.9	29.1	28.5	30.2	30.4	31.7	34.1
Mini	19.5	23.2	24.2	23.3	23.2	22.9	22.7	22.5	22.4	22.1	22.3	21.8
Total	53.6	58	58.7	57.1	55.2	52.8	51.8	51	52.6	52.5	54	55.9
Mean	26.8	29	29.35	28.55	27.6	26.4	25.9	25.5	26.3	26.25	27	27.95
StdDev	718.24	841	861.42	815.10	761.76	696.96	670.81	650.25	691.69	689.06	729	781.20
2014												
Maxi	34.1	34.8	33.2	33.6	32.3	31	29.2	29.5	29.5	30.9	32.3	33.5
Mini	23.8	23.9	23.2	23.9	23.3	22.7	22.9	22.5	22.4	22.2	22.2	19.5
Total	57.9	58.7	56.4	57.5	55.6	53.7	52.1	52	51.9	53.1	54.5	53
Mean	28.95	29.35	28.2	28.75	27.8	26.85	26.05	26	25.95	26.55	27.25	26.5
StdDev	838.10	861.42	795.24	826.56	772.84	720.92	678.60	676	673.40	704.90	742.56	702.25
2015												
Maxi	33.1	33.3	33.8	32.5	32.1	30	29.1	29.4	29.9	31.3	33	32.8
Mini	19.7	24	23.9	23.9	23	23	22.7	22.4	23.2	22.7	23.4	22.2
Total	52.8	57.3	57.7	56.4	55.1	53	51.8	51.8	53.1	54	56.4	55
Mean	26.4	28.65	28.85	28.2	27.55	26.5	25.9	25.9	26.55	27	28.2	27.5
StdDev	696.96	820.82	832.32	795.24	759.00	702.25	670.81	670.81	704.90	729	795.24	756.25

Appendix 2A: particle Size Distribution Analysis Result for Sediment Sample at Orji Mech

Sample 1: Benin Formation

Screen Type: A.S.T.M

Shaker Type: Electric

Sieve Time: 5 minutes

Weight of sample: 500g

Visual Classification of Soil: sand, trace of fine Gravel

SAMPLE LOCATION: Orji Mechanic

S/N	PHI (Φ)	SIEVE SIZE(mm)	SIEVE WEIGHT(mm)	WEIGHT + SAMPLE	WEIGHT RETAINED	% WEIGHT RETAINED	CUMM % WEIGHT RETAINED	WEIGHT PASSING	% WEIGHT PASSING
1-2	2	384.5	453.7	69.2	13.91	13.91	428.12	86.09	
2-1	1.8	353.8	538.9	185.1	37.21	51.12	312.22	48.88	
3-0.25	0.6	334.5	572.4	237.9	47.83	98.95	259.42	1.05	
40.5	0.425	309.4	313.7	4.3	0.86	99.81	493.02	0.19	
5 2.75	0.3	294.5295	0.5	0.1	99.91	496.82	0.09		
63.25	0.212	280.7	280.9	0.2	0.04	99.95	497.12	0.05	
73.75	0.15	275.3	275.4	0.1	0.02	99.97	497.22	0.03	
84	0.063	262	262.02	0.02	0.004	99.974	497.3	0.026	
	Total497.32	**99.974**							

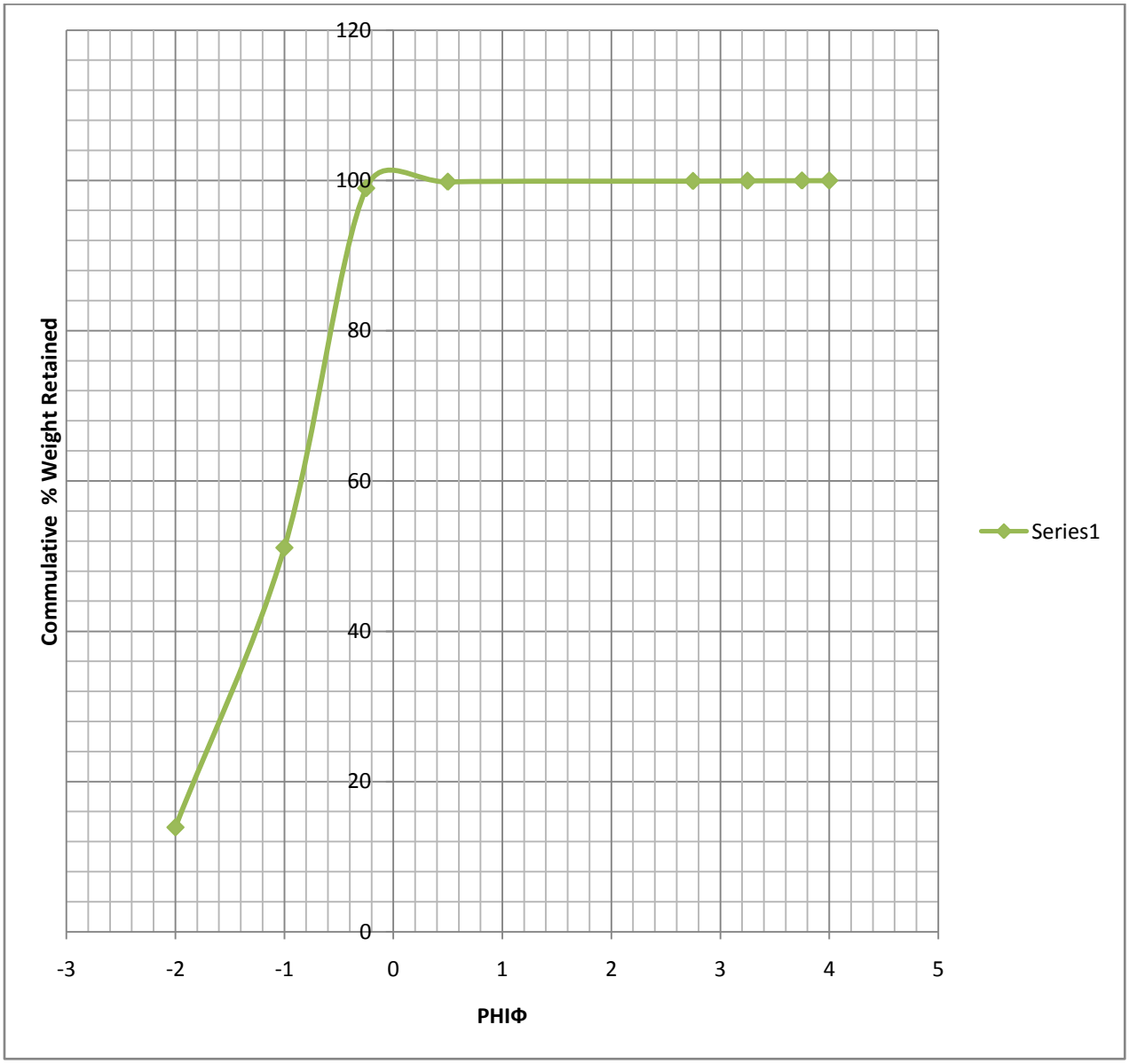
Sieve loss=500g-497.32=2.68g

Phi (Φ) Data from graph

Φ5 = -2.32 Φ16 =-1.88 Φ25=-1.57 =Φ50 -1.09

Φ75 = -0.75 Φ84 =0.63 Φ95=-0.5

Appendix 2B: Particle Size Distribution Curve for Sediment Sample at Orji Mechanic



Appendix 2C: particle Size Distribution Analysis Result for Sediment Sample at Concorde villa

Sample 2: Benin Formation

Screen Type: A .S.T.M

Shaker Type: Electric

Sieve Time: 5 minutes

Weight of sample: 500g

Visual Classification of soil: sand, trace of fine gravel.

SAMPLE LOCATION: Concorde villa

S/n	PHI (Φ)	SIEVE SIZES (mm)	SIEVE WEIGHT (mm)	WEIGHT + SAMPLE	WEIGHT RETAINED	% WEIGHT RETAINED	CUMM % WEIGHT RETAINED	WEIGHT PASSING	% WEIGHT PASSING
1 -2	2	384.5	630.4	245.9	49.66	49.66	249.2	50.34	
2	-1 1.8	353.8	537.3	183.5	37.06	86.72	311.6	13.28	
3-0.25	0.6	334.5	396.2	61.7	12.46	99.18	433.4	0.82	
40.5	0.425 309.4	312.1	2.7	0.54	99.72	492.4	0.28		
52.75	0.3	294.9	295.2	0.7	0.14	99.86	492.4	0.14	
63.25	0.212	280.7	281	0.3	0.06	99.92	494.9	0.08	
73.75	0.15	275.3	275. 5	0.2	0.04	99.96	494.9	0.04	
84	0.063	262	262.1	0.1	0.02	99.98	495	0.02	
Total						495.1	99.98		

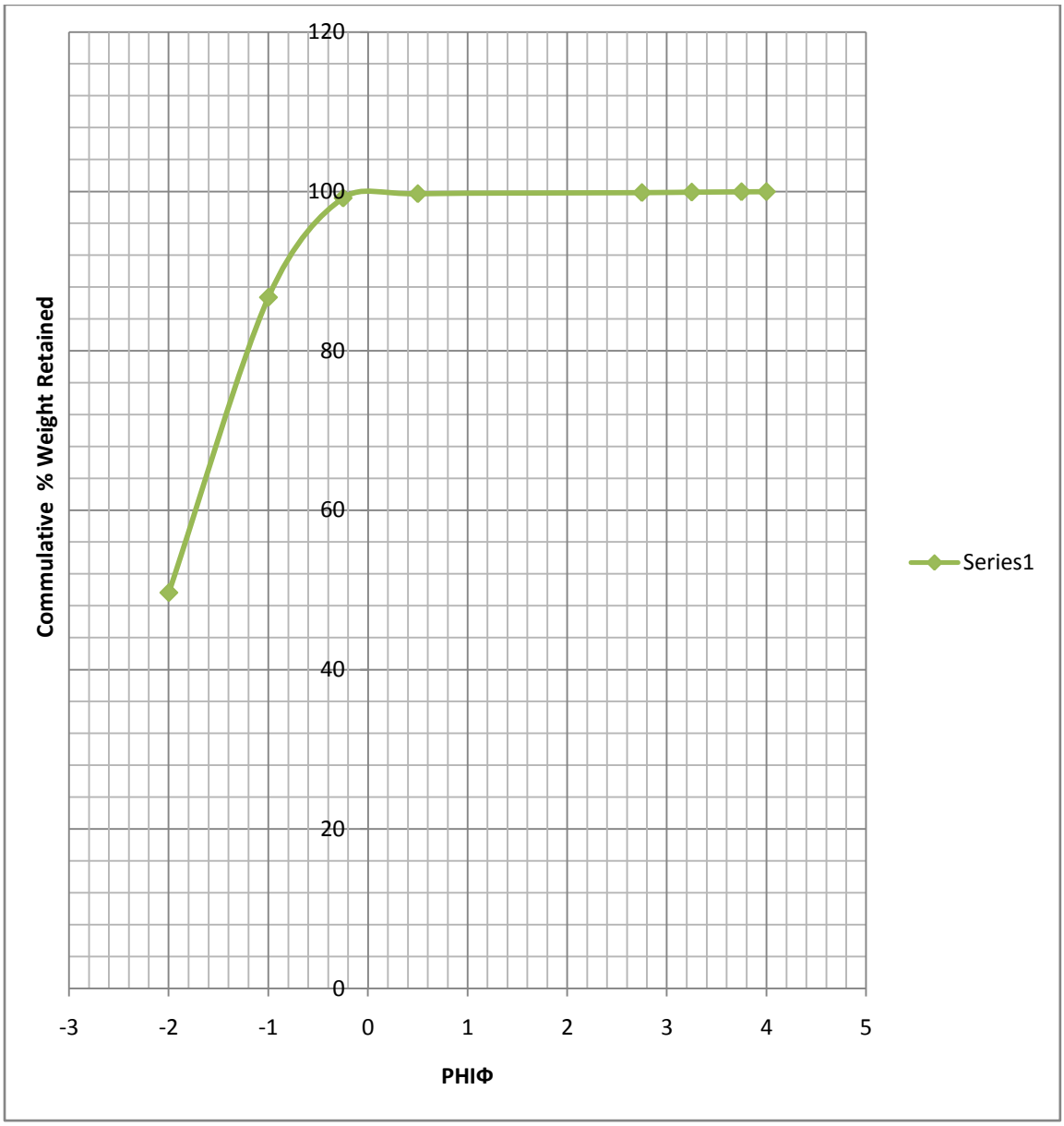
Sieve Loss= 500g- 495. 1g = 4.9g

Phi (Φ) Data from Graph

Φ = -2.67 Φ_{16} = -2.45 Φ_{25} =-2.28 Φ_{50}= -1.85

Φ_{75} = -1.25Φ_{84} = -1.09 Φ_{95} =-0.75

Appendix 2D: Particle Size Distribution Curve Sediment Sample at Concorde villa



Appendix 2E: Particle Size Distribution Analysis Result for Sediment Sample at Uratta

Sample 3: Benin Formation

Screen Types: A.S.T.M

Shaker Type: Electric

Sieve Time: 5 minutes

Weight of Sample: 500g

Visual Classification of Soil: Sand, trace fine Gravel

SAMPLE LOCATION:Uratta

S/n	PHI (Φ)	SIEVE SIZE(mm)	SIEVE WEIGHT (mm)	WEIGHT + SAMPLE	WEIGHT RETAINED	% WEIGHT RETAINED	CUMM % WEIGHT RETAINED	WEIGHT PASSING	% WEIGHT PASSING
1-2	2	384.5	460.2	75.7	15.22	421.6	84.78		
2 -1	1.8	353.8	573.5	219.7	44.17	59.39	469.3	40.61	
3	-0.25	0.6	334.5	520.2	185.7	37.24	96.73	311.6	3.27
4	0.5	0.425	309.4	321.1	11.7	2.35	99.08	485.6	0.92
5	2.75	0.3	294.5	297.2	2.7	0.54	99.62	494.6	0.38
6	3.25	0.212	280.7	281.6	0.9	0.18	99.8	496.4	0.2
7	3.75	0.15	275.3	275. 6	0.3	0.06	99.86	497	0.14
84		0.063	262	262.6	0.6	0.12	99.98	496.7	0.02
Total						**497.3**	**99.98**		

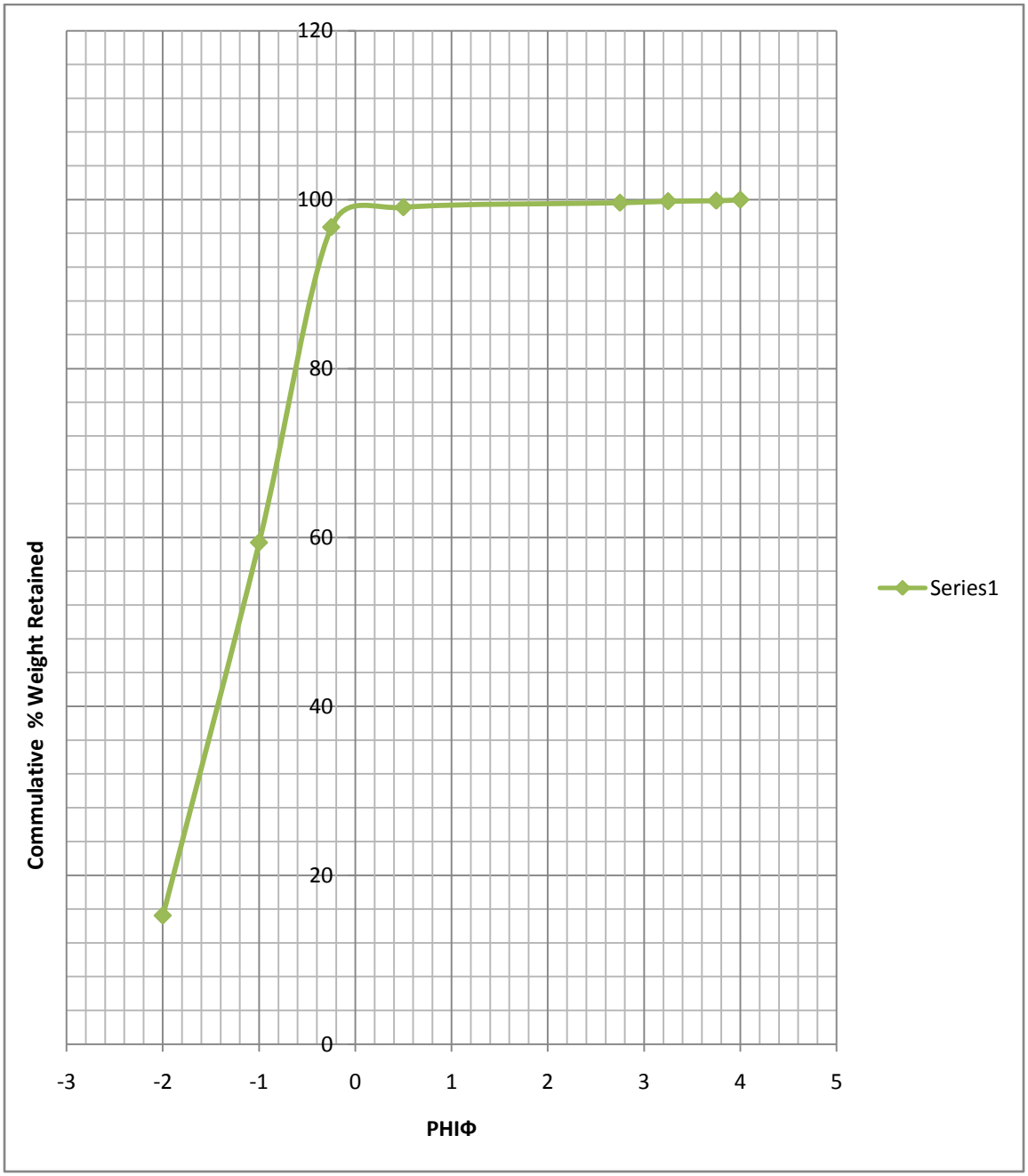
Sieve loss= 5oog- 497.3g=2.7g

Phi (Φ) Data from Graph

Φ_5= -2.25 Φ_{16} =-2.00 Φ_{25} = - 1.80 Φ_{50} = - 1.23

Φ_5 = - 0.79 Φ_{84}=0.61 Φ_{95} =-0.22

Appendix 2F: particle Size Distribution Curve Sediment Sample at Uratta



Appendix 3A: Hydraulic conductivity (K)

Hydraulic conductivity of Benin Formation aquifer in the study area using sediment sample from Orji Mechanic borehole

Therefore, $K = 1.0 \times (0.63)^2$

$= 1.0 \times 0.39369$

$K = 0.4 m/s = 4 \times 10^{-1} m/s$

Hydraulic conductivity of Benin Formation aquifer in the study area using sediment sample from Concorde borehole

A = constant whose value is 1.0 for sand

Therefore, $K = 1.0 \times (0.68)^2$

$= 1.0 \times 0.4624$

$K = 5 \times 10^{-1} m/s$

Hydraulic conductivity of Benin Formation aquifer in the study area using sediment sample from Uratta borehole

A = constant whose value is 1.0 for sand

Therefore, $K = 1.0 \times (0.62)^2$

$= 1.0 \times 0.3844$

$K = 0.34 m/s = 4 \times 10^{-1} m/s$

Appendix 3B: Transmissivity (T)

Transmissivityin Benin Formation aquifer in the study area using aquifer thickness located at Umuokirika-Ahiazu borehole

Hydraulic conductivity for Umuokirika-Ahiazuborehole is 4×10^{-1} m/s

Therefore, T = 0.4 m/s ×25m

Transmissivity (T) = 864,000m^2/day

Transmissivityin Benin Formation aquifer in the study area using aquifer thickness located at Nekede borehole

Hydraulic conductivity for Nekedeborehole is 5×10^{-1}m/s

Therefore, T = 0.5 × 20m

Transmissivity (T) = 864,000m^2/day

Transmissivityin Benin Formation aquifer in the study area using aquifer thickness located at Ogbe-Ahiazu borehole

Hydraulic conductivity for Ogbe-Ahiazu borehole is 1.24m/s

Therefore, T = 0.4 × 20m

Transmissivity (T) = 864,000m^2/day

Appendix 4: Area of Owerri(study area) using topographical map studied

The dimension of the topographical map of the area studied was traced out using a transparent graph sheet (1cm × 1cm) and the scale on the map representing the scale on the ground (2.7cm on the map representing 9000m or 9km on the ground) was determined using rule. The complete square on the graph sheet was counted and recorded while the incomplete square on the graph sheet was also counted and divided by two to give a complete square.

Therefore,

Complete square = 41

Incomplete square = 41/2 = 20.5

Total square = 41 + 20.5 = 61.5km^2

1cm = 9000m/2.7cm

= 3333.3333cm

1cm: 3333.3333cm

1cm × 1cm = 33.333333m × 33.333333m

1cm^2 = 1111.1111m^2

1cm × 1cm = 3.3333333km × 3.3333333km

1cm^2 = 11.111111km

Area = 11.111111 × 61.5km^2 = 683.33km^2

Appendix 5: Certified True Copy of Physicochemical and Microbial Analysis

UNITED NATIONS
INDUSTRIAL DEVELOPMENT
ORGANIZATION

UNIDO Laboratory, Ministry of Petroleum and Environment,
Prefab Area, Owerri, Imo State Nigeria

Sample Water Analysis Report

Client: Nwanya Anthony C (Private)
Project: Master's Degree (MSc)
Date Collected: March, 2013
Sample Identification: Boreholes/Rivers

Analysed by: Lab Technologist
Project Number: MSc/Scie/1034/10-11
Time Collected: 12:59:03 pm
Lab Number: 086

PHYSICOCHEMICAL/MICROBIAL LABORATORY REPORTS		
S/No	LOCATIONS	RESULTS AND UNITS
1	IRETE	Temperature (27°C), pH (6.4), Conductivity (0.04µS/cm), Turbidity (2.2 mg/l), Total hardness (11.2mg/l), TDS (10mg/l), Colour (10 hazen), Na^{+} (4.59 mg/l), K^{+} (1.1 mg/l), Ca^{2+} (2.8 mg/l), Mg^{2+} (1.02 mg/l), Fe^{2+} (0.38 mg/l), Cu^{2+} (0.07 mg/l), Pb^{2+} (-), Zn^{2+} (0.18 mg/l), Cd^{2+} (0.15 mg/l), Hg^{2+} (BDL),SO_4^{2-} (2.8 mg/l), NO_3^{-} (0.08 mg/l), Cl^{-} (1.4 mg/l), HCO_3^{-} (17.5 mg/l), Total microbial load (15), Total coliform (5)
2	UMUGUMA-AVU	Temperature (27°C), pH (9.9), Conductivity (0.1µS/cm), Turbidity (5 mg/l), Total hardness (12.8 mg/l), TDS (6 mg/l), Colour (10 hazen), Na^{+} (5.35 mg/l), K^{+} (0.85 mg/l), Ca^{2+} (3.5 mg/l), Mg^{2+} (1.26 mg/l), Fe^{2+} (0.49 mg/l), Cu^{2+} (0.06 mg/l), Pb^{2+} (0.001 mg/l), Zn^{2+} (0.21 mg/l), Cd^{2+} (0.16 mg/l), Hg^{2+} (BDL),SO_4^{2-} (2 mg/l), NO_3^{-} (0.07 mg/l), Cl^{-} (1.7 mg/l), HCO_3^{-} (18.4 mg/l), Total microbial load (20), Total coliform (10)
3	AVU	Temperature (28.3°C), pH (5.6), Conductivity (0.07µS/cm), Turbidity (ND), Total hardness (12.6 mg/l), TDS (38 mg/l), Colour (15 hazen), Na^{+}(3.95 mg/l), K^{+} (2 mg/l), Ca^{2+} (7.6 mg/l), Mg^{2+} (1.5 mg/l), Fe^{2+} (0.17 mg/l), Cu^{2+} (0.15 mg/l), Pb^{2+} (-), Zn^{2+} (0.08 mg/l), Cd^{2+} (0.14 mg/l), Hg^{2+} (0.001),SO_4^{2-} (0), NO_3^{-} (0.09 mg/l), Cl^{-} (2.5 mg/l), HCO_3^{-} (20.75 mg/l), Total microbial load (46), Total coliform (13)
4	UBOMIRI	Temperature (26°C), pH (6.8), Conductivity (0.05µS/cm), Turbidity (ND), Total hardness (4.6 mg/l), TDS (15 mg/l), Colour (5 hazen), Na^{+} (3.35 mg/l), K^{+} (1.74 mg/l), Ca^{2+} (7.8 mg/l), Mg^{2+} (1.24 mg/l), Fe^{2+} (0.59 mg/l), Cu^{2+} (0.44 mg/l), Pb^{2+} (0.005 mg/l), Zn^{2+} (0.13 mg/l), Cd^{2+} (ND) Hg^{2+} (BDL),SO_4^{2-} (1.0 mg/l), NO_3^{-} (3.08 mg/l) Cl^{-} (5.08 mg/l) HCO_3^{-} (9.64 mg/l), Total microbial load (ND), Total coliform (ND)
5	MBIERI	Temperature (27°C), pH (10.2), Conductivity (0.2µS/cm), Turbidity (10), Total hardness (11.8 mg/l), TDS (26 mg/l), Colour (5 hazen), Na^{+}(4.36 mg/l), K^{+}(ND), Ca^{2+}(4.1 mg/l), Mg^{2+} (1.11 mg/l), Fe^{2+}(0.001 mg/l), Cu^{2+}(0.76 mg/l), Pb^{2+} (ND), Zn^{2+} (0.17 mg/l), Cd^{2+} (BDL) Hg^{2+}(BDL),SO_4^{2-} (3.2 mg/l), NO_3^{-} (4.06 mg/l) Cl^{-} (0.04 mg/l) HCO_3^{-} (18.5 mg/l), Total microbial load (ND), Total coliform (ND)
6	AMAKOHIA-URATTA	Temperature (28°C), pH (6.4), Conductivity (NA), Turbidity (12), Total hardness (11.5mg/l), TDS(16.3mg/l), Colour (5 hazen), Na^{+}(4.27 mg/l), K^{+}(0 mg/l), Ca^{2+}(2.88 mg/l), Mg^{2+} (3.3 mg/l), Fe^{2+}(0.39 mg/l), Cu^{2+}(0.35 mg/l), Pb^{2+} (0.001 mg/l), Zn^{2+} (0.06 mg/l), Cd^{2+} (0.12 mg/l), Hg^{2+}(BDL),SO_4^{2-} (1.8 mg/l), NO_3^{-} (0 mg/l), Cl^{-} (1.6 mg/l), HCO_3^{-} (18.5 mg/l), Total microbial load (31), Total coliform (15)

7	ORJI	Temperature (26.4°C), pH (6.2), Conductivity (0.03µS/cm), Turbidity (4.8), Total hardness (12.6mg/l), TDS(11mg/l), Colour (10 hazen), Na^{+}(4.21 mg/l), K^{+}(1.9 mg/l), Ca^{2+}(2.89 mg/l), Mg^{2+} (1.23 mg/l), Fe^{2+}(0.38 mg/l), Cu^{2+}(0.14 mg/l), Pb^{2+} (0.008 mg/l), Zn^{2+} (0.02 mg/l), Cd^{2+} (0.16 mg/l) Hg^{2+}(0.001 mg/l),SO_4^{2-} (3 mg/l), NO_3^{-} (0.1 mg/l) Cl^{-} (1.4 mg/l) HCO_3^{-} (18.2 mg/l), Total microbial load (ND), Total coliform (ND)
8	EGBU	Temperature (27.4°C), pH (6.3), Conductivity (NA), Turbidity (5.2), Total hardness (11.6mg/l), TDS(36 mg/l), Colour (5 hazen), Na^{+}(7.6 mg/l), K^{+}(2 mg/l), Ca^{2+}(2.89 mg/l), Mg^{2+} (2.13), Fe^{2+}(0.19 mg/l), Cu^{2+}(0.25 mg/l), Pb^{2+} (0), Zn^{2+} (0.18 mg/l), Cd^{2+} (0.02 mg/l) Hg^{2+}(BDL),SO_4^{2-} (3.8 mg/l), NO_3^{-} (0) Cl^{-} (1.6 mg/l), HCO_3^{-} (17.6 mg/l), Total microbial load (6), Total coliform (ND)
9	UMUGUMA-IMO HOUSING	Temperature (28°C), pH (6.2), Conductivity (NA), Turbidity (3), Total hardness (4 mg/l), TDS(24.7mg/l), Colour (5 hazen), Na^{+}(4.59 mg/l), K^{+}(2.0 mg/l), Ca^{2+}(8.3 mg/l), Mg^{2+} (1.05 mg/l), Fe^{2+}(0.26 mg/l), Cu^{2+}(0.43 mg/l), Pb^{2+} (0), Zn^{2+} (0.01 mg/l), Cd^{2+} (0.01 mg/l), Hg^{2+}(BDL),SO_4^{2-} (2.1 mg/l), NO_3^{-} (0.05 mg/l) Cl^{-} (1.7 mg/l), HCO_3^{-} (20.4 mg/l), Total microbial load (15), Total coliform (5)
10	NEKEDE	Temperature (27.2°C), pH (7.3), Conductivity (NA), Turbidity (5), Total hardness (3 mg/l), TDS(64.1 mg/l), Colour (5 hazen), Na^{+}(3.92 mg/l), K^{+}(0.9 mg/l), Ca^{2+}(3.6 mg/l), Mg^{2+} (1.08 mg/l), Fe^{2+}(0.41 mg/l), Cu^{2+}(0.03 mg/l), Pb^{2+} (0), Zn^{2+} (2.51 mg/l), Cd^{2+} (0.03 mg/l), Hg^{2+}(BDL),SO_4^{2-} (4.2 mg/l), NO_3^{-} (0.04 mg/l), Cl^{-} (1.6 mg/l), HCO_3^{-} (19.0 mg/l), Total microbial load (48), Total coliform (20)
11	IHIAGWA	Temperature (29°C), pH (6.3), Conductivity (NA), Turbidity (2.3), Total hardness (1.02mg/l), TDS(21.7mg/l), Colour (10 hazen), Na^{+}(4.32 mg/l), K^{+}(0.3 mg/l), Ca^{2+}(4.5 mg/l), Mg^{2+} (1.05 mg/l), Fe^{2+}(0.13 mg/l), Cu^{2+}(0.56 mg/l), Pb^{2+} (0), Zn^{2+} (1.95 mg/l), Cd^{2+} (0.05 mg/l), Hg^{2+}(BDL),SO_4^{2-} (1.1 mg/l), NO_3^{-} (0.08 mg/l) Cl^{-} (16.5 mg/l), HCO_3^{-} (18.5 mg/l), Total microbial load (49), Total coliform (18)
12	AGBALA	Temperature (26°C), pH (8.3), Conductivity (0.21µS/cm), Turbidity (16), Total hardness (4.6mg/l), TDS (20.0 mg/l), Colour (5 hazen), Na^{+}(3.3 mg/l), K^{+}(1.15 mg/l), Ca^{2+}(7.6 mg/l), Mg^{2+} (1.28 mg/l), Fe^{2+}(0.38 mg/l), Cu^{2+}(0.83 mg/l), Pb^{2+} (0.003 mg/l), Zn^{2+} (2.10 mg/l), Cd^{2+} (0.03 mg/l), Hg^{2+}(BDL),SO_4^{2-} (1.0 mg/l), NO_3^{-} (0.04 mg/l), Cl^{-} (2.0 mg/l), HCO_3^{-} (17.5 mg/l), Total microbial load (ND), Total coliform (ND)
13	OBINZE	Temperature (27°C), pH (7.3), Conductivity (0.12µS/cm), Turbidity (4.2), Total hardness (12.8 mg/l), TDS (52.1 mg/l), Colour (10 hazen), Na^{+}(4.21 mg/l), K^{+}(0.5 mg/l), Ca^{2+}(2.7 mg/l), Mg^{2+} (1.5 mg/l), Fe^{2+}(0.49 mg/l), Cu^{2+}(0.51 mg/l), Pb^{2+} (0.004 mg/l), Zn^{2+} (2.05 mg/l), Cd^{2+} (0.16 mg/l), Hg^{2+}(BDL),SO_4^{2-} (1.02 mg/l), NO_3^{-} (0.09 mg/l), Cl^{-} (3.0 mg/l) HCO_3^{-} (19.2 mg/l), Total microbial load (17), Total coliform (6)
14	URATTA	Temperature (27°C), pH (7.2), Conductivity (0.03µS/cm), Turbidity (11), Total hardness (11.5 mg/l), TDS (32.2 mg/l), Colour (15 hazen), Na^{+}(4.28 mg/l), K^{+}(0.6 mg/l), Ca^{2+}(2.4 mg/l), Mg^{2+} (3.44 mg/l), Fe^{2+}(0.59 mg/l), Cu^{2+}(0.73 mg/l), Pb^{2+} (BDL), Zn^{2+} (2.18 mg/l), Cd^{2+} (-), Hg^{2+}(BDL),SO_4^{2-} (1.05 mg/l), NO_3^{-} (0.02 mg/l), Cl^{-} (0.06 mg/l), HCO_3^{-} (20.7 mg/l), Total microbial load (ND), Total coliform (ND)
15	NDEGWU	Temperature (28°C), pH (6.5), Conductivity (0.44µS/cm), Turbidity (40), Total hardness (2.0 mg/l), TDS (38.7 mg/l), Colour (5 hazen), Na^{+}(6.2 mg/l), K^{+}(0.4 mg/l), Ca^{2+}(4.6 mg/l), Mg^{2+} (1.22 mg/l), Fe^{2+}(0.17 mg/l), Cu^{2+}(0.25 mg/l), Pb^{2+} (BDL), Zn^{2+} (0.78 mg/l), Cd^{2+} (-) Hg^{2+}(BDL),SO_4^{2-} (1.01 mg/l), NO_3^{-} (0.01 mg/l), Cl^{-} (1.7 mg/l), HCO_3^{-} (19.5 mg/l), Total microbial load (ND), Total coliform (ND)
16	NAZE	Temperature (29°C), pH (6.5), Conductivity (0.21µS/cm), Turbidity (1.0), Total hardness (4.4 mg/l), TDS (39 mg/l), Colour (5 hazen), Na^{+}(5.5 mg/l), K^{+}(0.2 mg/l), Ca^{2+}(2.8 mg/l), Mg^{2+} (1.11 mg/l), Fe^{2+}(0.13 mg/l), Cu^{2+}(0.14 mg/l), Pb^{2+} (0.01 mg/l), Zn^{2+} (0.58 mg/l), Cd^{2+} (0.041 mg/l), Hg^{2+}(BDL),SO_4^{2-} (2.8 mg/l), NO_3^{-}(0.01 mg/l), Cl^{-} (1.8 mg/l), HCO_3^{-} (18.5 mg/l), Total microbial load (5), Total coliform (4)

17	NWORIE RIVER	Temperature (20°C), pH (10.4), Conductivity (0.2µS/cm), Turbidity (20), Total hardness (2.2 mg/l), TDS(60 mg/l), Colour (10 hazen), Na^{+}(5.4 mg/l), K^{+}(6.8 mg/l), Ca^{2+}(3.5 mg/l), Mg^{2+} (3.4 mg/l), Fe^{2+}(0.08 mg/l), Cu^{2+}(2.88 mg/l), Pb^{2+} (0.003 mg/l), Zn^{2+} (0.47 mg/l), Cd^{2+} (0.043 mg/l), Hg^{2+}(0.001 mg/l),SO_4^{2-} (4.0 mg/l), NO_3^{-} (2.0 mg/l), Cl^{-}(3.04 mg/l), HCO_3^{-} (28.5 mg/l), Total microbial load (115), Total coliform (224)
18	OKITANKWO RIVER	Temperature (20°C), pH (10.2), Conductivity (NA), Turbidity (43), Total hardness (4.7 mg/l), TDS(62.5 mg/l), Colour (15 hazen), Na^{+}(5.5 mg/l), K^{+}(4.4 mg/l), Ca^{2+}(2.4 mg/l), Mg^{2+} (1.7 mg/l), Fe^{2+}(0.09 mg/l), Cu^{2+}(2.19 mg/l), Pb^{2+} (0.006 mg/l), Zn^{2+} (0.68 mg/l), Cd^{2+} (0.052 mg/l), Hg^{2+}(BDL),SO_4^{2-} (3.0 mg/l), NO_3^{-} (2.1 mg/l), Cl^{-} (4.2 mg/l), HCO_3^{-} (26.4 mg/l), Total microbial load (120), Total coliform (262)
19	OTAMIRI RIVER	Temperature (20°C), pH (10.2), Conductivity (NA), Turbidity (28), Total hardness (6.2 mg/l), TDS(67 mg/l), Colour (10 hazen), Na^{+}(5.68 mg/l), K^{+}(1.42 mg/l), Ca^{2+}(2.7 mg/l), Mg^{2+} (2.88 mg/l), Fe^{2+}(0.15 mg/l), Cu^{2+}(2.6 mg/l), Pb^{2+} (0.009 mg/l), Zn^{2+} (0.22 mg/l), Cd^{2+} (0.061 mg/l,), Hg^{2+}(0.001 mg/l),SO_4^{2-} (4.0 mg/l), NO_3^{-} (2.2 mg/l), Cl^{-} (5.2 mg/l), HCO_3^{-} (28.8 mg/l), Total microbial load (62), Total coliform (74)
20	MBAA RIVER	Temperature (26°C), pH (7.5), Conductivity (0.12µS/cm), Turbidity (50), Total hardness (4.5 mg/l), TDS (52.5 mg/l), Colour (15 hazen), Na^{+}(6.4 mg/l), K^{+}(10.1 mg/l), Ca^{2+}(2.88 mg/l), Mg^{2+} (2.02 mg/l), Fe^{2+}(0.38 mg/l), Cu^{2+}(2.33 mg/l), Pb^{2+} (0.01 mg/l), Zn^{2+} (0.06 mg/l), Cd^{2+} (0.029 mg/l) Hg^{2+}(BDL),SO_4^{2-} (3.5 mg/l), NO_3^{-} (2.2 mg/l), Cl^{-}(21.0 mg/l), HCO_3^{-} (24.6 mg/l), Total microbial load (73), Total coliform (64)

Remarks: Principles, Procedures and Methods used for this analysis was adopted as described by APHA (1971)

Checked by.....
Laboratory Engineer

Approve d by.....
Quality Control Engineer

Appendix 6: Logging Details of Water Borehole at Umuokirika-Ahiazu

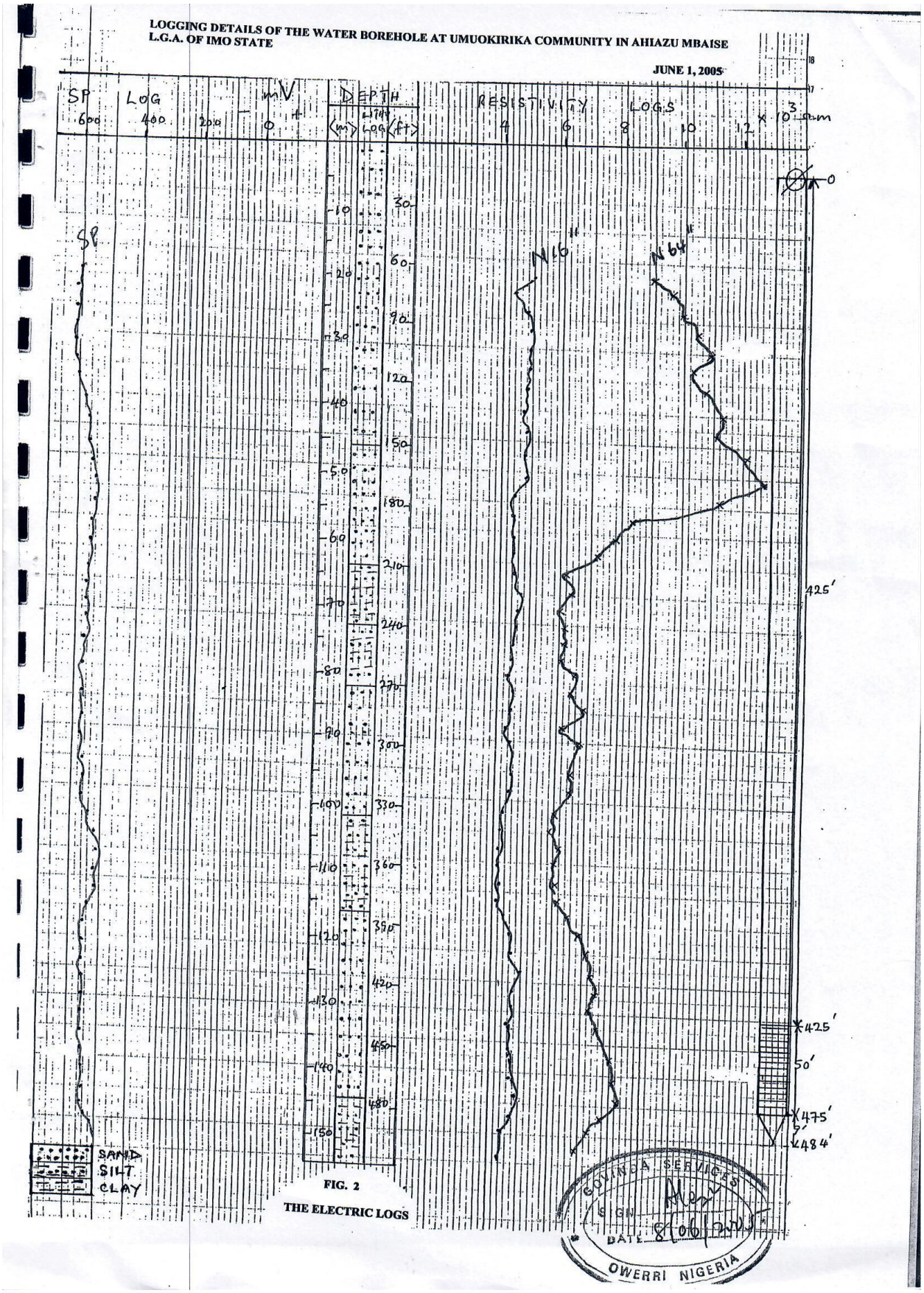
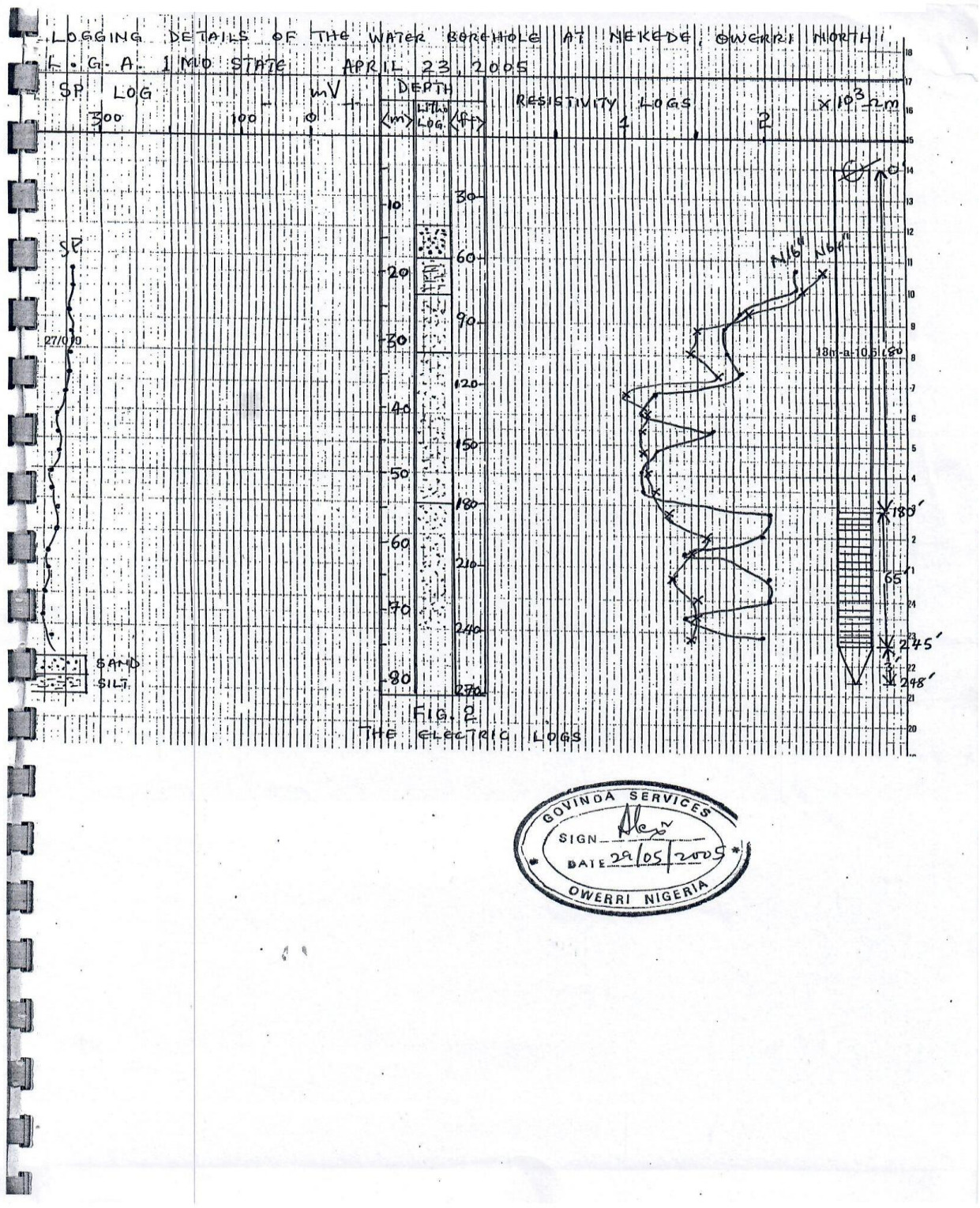
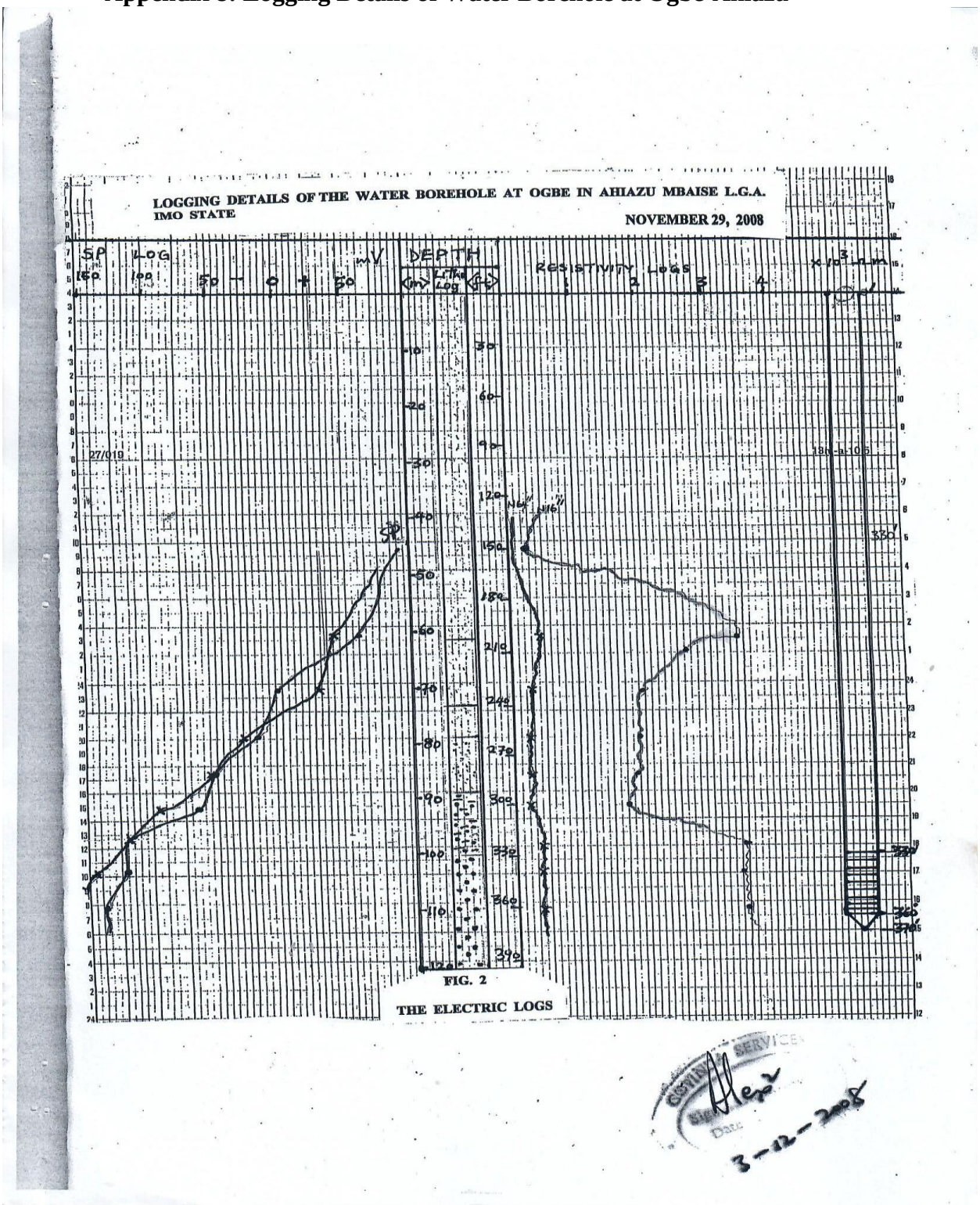


FIG. 2
THE ELECTRIC LOGS

Appendix 7: Logging Details of Water Borehole Nekede



Appendix 8: Logging Details of Water Borehole at Ogbe-Ahiazu



Appendix 9: Pumping Test Data at Mbutu-Aboh

MBUTU-ABOH MBAISE BOREHOLE PUMPING TEST
STATIC WATER LEVEL = 8M
PUMP TYPE – 7.5HP – GRUNDFOS
DEPTH OF INSTALLATION – 90M

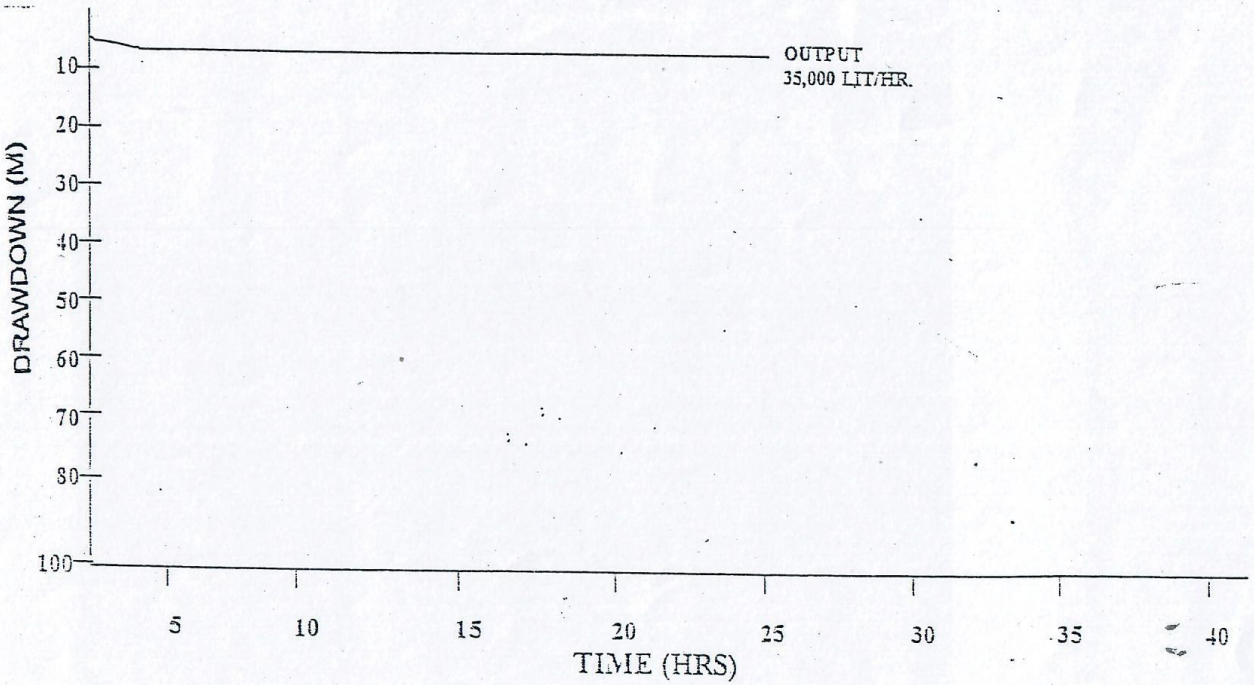
SEPTEMBER 19, 2005.

TIME	DYNAMIC WATER LEVEL (M)
9.00 am pumping	8m
9.05	8,5m
9.10	9.0m
9.20	9.5m
9.30	9.5m
10.00	9.5m
11.00	9.5m
12.00	9.5m
1.00 PM	9.5m
1.00	9.5m
2.00	9.5m
3.00	9.5m
4.00	9.5m
5.00	9.5m
6.00	9.5m
7.00	9.5m
8.00	9.5m
9.00	9.5m
10.00	9.5m
11.00	9.5m
12.00	9.5m
1.00AM	9.5m
2.00	9.5m
3.00	9.5m
4.00	9.5m
5.00	9.5m
6.00	9.5m
7.00	9.5m
8.00	9.5m
9.00	9.5m

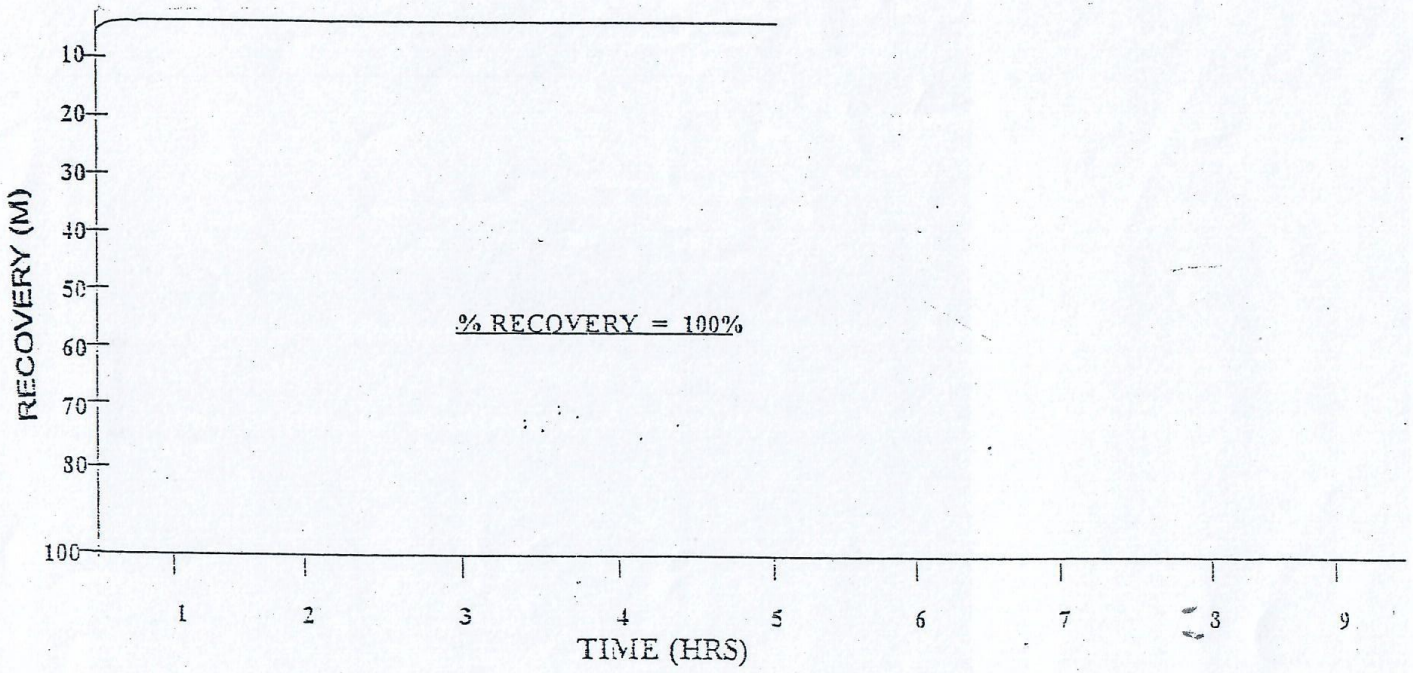
10.00		9.5m
11.00		9.5m
12.00		9.5m
1.00		9.5m
2.00		9.5m
3.00		9.5m
4.00		9.5m
5.00		9.5m
6.00		9.5m
7.00		9.5m
8.00		9.5m
9.00		9.5m
10.00		9.5m
11.00		9.5m
12.00		9.5m
1.00		9.5m
2.00		9.5m
3.00		9.5m
4.00		9.5m
5.00		9.5m
6.00		9.5m
7.00		9.5m
8.00		9.5m
9.00	STOPPED PUMPING	9.5m

9.05	8.2m↓
9.10	8.0m
9.20	8.0m
9.30	8.0m
10.00	8.0m
11.00	8.0m
12.00	8.0m
1.00	8.0m
2.00	8.0m RECOVERY
3.00	8.0m
4.00	8.0m
5.00PM	8.0m
6.00	8.0m
7.00	8.0m
8.00	8.0m
9.00	8.0m
10.00	8.0m↑

MBUTU – ABOH MBAISE BOREHOLE PUMPING TEST RESULT
DRAWDOWN TEST



MBUTU – ABOH MBAISE BOREHOLE PUMPING TEST RESULT
RECOVERY TEST



Appendix 10: Pumping Test Data at Agbaja

OBIMO BOREHOLE NO: 1

CONSTANT DISCHARGE TEST.

Page 11

Date D	M	Y	Time hr	min	Static Water Level Mb. G.L.	Pumping Rate l/s	Pumping Level Mb. G.L	Draw down b. St. W.L	Sand content ccm/ 10l	Remarks Kind of works Water Temperature
24	8	07								
			6	00	FREE		-	-		
			6	01	"	2	36.45	36.45		WARM WATER
			6	02	"	"	50.08	50.08		AND SAND FREE
			6	03	"	"	58.12	58.12		
			6	04	"	"	66.60	66.60		
			6	05	"	"	73.08	73.08		
			6	06	"	"	77.85	77.85		
			6	07	"	"	81.98	81.98		
			6	08	"	"	84.53	84.53		
			6	09	"	"	86.10	86.10		
			6	10	"	"	87.08	87.08		
			6	12	"	"	87.73	87.73		
			6	14	"	"	87.94	87.94		
			6	16	"	"	88.08	88.08		
			6	18	"	"	88.13	88.13		
			6	20	"	"	88.12	88.12		
			6	25	"	"	88.15	88.15		
			6	30	"	"	88.18	88.18		
			6	35	"	"	88.08	88.08		
			6	40	"	"	88.14	88.14		
			6	45	"	"	88.12	88.12		
			6	50	"	"	87.98	87.98		
			6	55	"	"	87.98	87.98		
			7	00	"	"	87.86	87.86		
			7	10	"	"	87.55	87.55		
			7	20	"	"	87.00	87.00		
			7	30	"	"	86.85	86.85		
			7	40	"	"	86.60	86.60		
			7	50	"	"	85.85	85.85		
			8	00	"	"	86.25	86.25		
			8	30	"	"	85.30	85.30		
			9	00	"	"	85.35	85.35		
			9	30	"	"	85.40	85.40		
			10	00	"	"	85.40	85.40		
			10	30	"	"	85.22	85.22		
			11	00	"	"	84.90	84.90		

AND
PUMPING TEST DATA

OBIMO . BOREHOLE NO: 1

CONSTANT DISCHARGE TEST.

WELL NO.

Page II

Date			Time		Static Water Level	Pumping Rate	Pumping Level	Draw down	Sand content	Remarks Kind of works Water Temperature.
	M	Y	hr	min	Mb. G.L.	l/s	Mb. G.L.	b. St. W.L	ccm/l	
25	8	07	6	30	REE	2.0	85.18	85.18		
			7	00	"	"	85.17	85.17		
			7	30	"	"	85.16	85.16		
			8	00	"	"	85.18	85.18		WARM WATER
			8	30	"	"	85.18	85.18		AND SAND FREE
			9	00	"	"	85.19	85.19		
			9	30	"	"	85.20	85.20		
			10	00	"	"	85.20	85.20		
			10	30	"	"	85.19	85.19		
			11	00	"	"	85.19	85.19		
			11	30	"	"	85.19	85.19		
			12	00	"	"	85.19	85.19		
			12	30	"	"	85.21	85.21		
			13	00	"	"	85.21	85.21		
			13	30	"	"	85.21	85.21		
			14	00	"	"	85.21	85.21		
			14	30	"	"	85.18	85.18		
			15	00	"	"	85.18	85.18		
			15	30	"	"	85.18	85.18		
			16	00	"	"	85.18	85.18		
			16	30	"	"	85.18	85.18		
			17	00	"	"	85.18	85.18		
			17	30	"	"	85.19	85.19		
			18	00	"	"	85.18	85.18		
			18	30	"	"	85.18	85.18		
			19	00	"	"	85.18	85.18		
			19	30	"	"	85.19	86.19		
			20	00	"	"	85.20	85.20		
			20	30	"	"	85.20	85.20		
			21	00	"	"	85.19	85.19		
			21	30	"	"	85.19	85,19		
			22	00	"	"	85.19	85.19		
			22	30	"	"	85.19	85.19		
			23	00	"	"	85.19	85.19		
			23	30	"	"	85.19	85.19		
16	10	95	24	00	"	"	85.19	85.19		
			24	30	"	"	85.19	85,19		

WELL DEVELOPMENT AND PUMPING TEST DATA

OBIMO BOREHOLE NO 1

RECOVERY TEST. (CONSTANT DISCHARGE TEST).

WELL NO.

Page II

Date D	M	Y	Time hr	min	Static Water Level Mb. G.L.	Pumping Rate l/s.	Pumping Level Mb. G.L	Draw down b. St. W.L	Sand content c.m/10l	Remarks Kind of works Water Temperature
26	8	07	6	$0^{1/2}$			84.27			
			6	01			81.14			
			6	$1^{1/2}$			79.52			
			6	02			77.13			
			6	$2^{1/2}$			73.85			
			6	03			70.74			
			6	$3^{1/2}$			66.95			
			6	04			62.26			
			6	$4^{1/2}$			58.62			
			6	05			55.45			
			6	06			46.70			
			6	07			40.44			
			6	08			35.56			
			6	09			32.27			
			6	10			28.54			
			6	11			25.00			
			6	12			21.91			
			6	13			19.25			
			6	14			16.85			
			6	15			14.98			
			6	16			13.10			
			6	17			11.45			
			6	18			10.08			
			6	19			8.75			
			6	20			7.39			
			6	21			6.19			
			6	22			5.25			
			6	23			4.56			
			6	24			4.00			
			6	25			3.53			
			6	26			3.00			
			6	27			3.61			
			6	28			2.24			
			6	29			1.90			
			6	30			1.56			
			6	31			1.32			
			6	32			1.10			

3.4	PUMPING TEST DIAGRAMS	WELL NO. Page

