

EVALUATION OF THE FACTORS AFFECTING THE SELF-PURIFICATION CAPACITY OF RIVER KADUNA, NIGERIA.

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By

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NIGERIA

DECEMBER, 2016.

DECLARATION

I declare that the work in this Dissertation entitled 'Evaluation of the factors affecting the Self-Purification Capacity of River Kaduna, Nigeria' was carried out by me in the Department of Chemical Engineering. The information derived from literature has been duly acknowledged in the text and a list of references provided. No part of this Dissertation work was previously presented for another degree or diploma at this or any other institution.

Kingsley PATRICK	_____	_____
Name of Student	Signature	Date

CERTIFICATION

This Dissertation entitled 'EVALUATION OF THE FACTORS AFFECTING THE SELF-PURIFICATION CAPACITY OF RIVER KADUNA, NIGERIA' by Kingsley PATRICK meets the regulations governing the award of the degree of Master of Science in Chemical Engineering of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

_____ _____

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DEDICATION

This work is dedicated to my father, late Mr. PATRICK OSIKE (for your advice and passion for education) and mother, Mrs. Theresa Osike who gave me the best education from their scarce resources. May GOD almighty bless them forever! Also to my wife Engr. Mrs. Bukola Patrick, my daughter Isabel Patrick, may GOD bless you all! Amen.

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My profound gratitude goes first and foremost to my Creator and the one who keeps me in existence-God for His grace throughout my study and this thesis work.

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ABSTRACT

The study of the evaluation of the factors affecting the Self-Purification Capacity of River Kaduna, Nigeria in addition to developing an empirical relationship for the reaeration constant was investigated during the period of February, 2014 to July, 2014. The physico-chemical properties and river flow variables were collected bi-monthly. This was achieved by sourcing data within a pre-selected segment of the river. The river flow variables include: depth, width, time of travel and velocity, while the physico-chemical variables are Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), pH and Temperature. Regression Analysis was carried out using Excel Spreadsheet and Matlab with the reaeration constant k_2 (as a function of BOD, DO & Temperature) as the dependent variable while stream velocity and depth were the regressors. The mean monthly DO was between 4.1mg/l to 6.6mg/l which is within the range suitable for aquatic life. The pH value was found to be in the range of 6.1 to 7.3 with most of the points being in the 6.1 region thus showing the water as slightly acidic. The mean water temperature ranged between 20.4^{o}C and 23.6^{o}C during the study period which is ideal for aquatic life according to WHO. The mean BOD value for most of the months was found to be greater than 10mg/l which is higher than the WHO permissible value thus making the river unfit for human consumption without treatment because of high microbial activity. The coefficient of reaeration was developed and validated statistically having an R^2 value of 0.814. The performance of this model was compared with six (6) well known reaeration coefficient models and it was found to compare favourably with the model for February having the closest fit. The average self-purification factor (f value) was found to be greater than unity in all the months studied which show that reaeration exceed deoxygenation with the months of March and April being the lowest and respectively 1.8 and 2.8. The average self-purification capacity of the month of June and July were higher because of the higher rate of transfer of oxygen from the atmosphere to the river and the values are 4.16 and 4.11 which shows the predominance of reaeration rate over deoxygenation rate.

TABLE OF CONTENTS

Title page ----------
---i

Declaration ----------
---ii

Certification ----------
--iii

Dedication ----------
--iv

Acknowledgment ----------
--v

Abstract ----------
--vi

Table of Contents ----------
xiii

List of Tables ----------
-xiii

List of Figures ----------
xiv

List of Plates ----------
-xv

List of Appendices ----------
xvi

Abbreviations ----------
xvii

CHAPTER ONE: INTRODUCTION
1

1.1 Background ----------
--1

1.2 Statement of the Research Problem ----------
-2

1.3 Aim of the Study ----------
--3

1.4 Objectives of the Study ----------
-3

1.5 Justification---------- ----------
--3

1.6 Scope of the study ----------
--3

1.7 Significance of the Study ----------
--4

CHAPTER TWO: LITERATURE REVIEW
5

2.1 Background ----------
--5

2.2 Global Urban Rivers/Lakes and Usage ----------
-6

2.3 Nigerian Urban Rivers/Lakes and usage ----------
-8

2.4 Sources of Urban Rivers Pollution ----------
-9

2.5 Waste Water Quality and indicators ----------
10

2.5.1 Biochemical Oxygen Demand (BOD) ----------
10
2.5.2 Chemical oxygen demand (COD) ----------
11
2.5.3 Temperature ----------
-12
2.5.4 Solids ----------
-12
2.5.5 pH/Acidity/Alkalinity ----------
12
2.5.6 Oxygen ----------
-13
2.6 Self Purification Assessment/Capacity of Global/Nigeria Water Bodies ----------
14
2.6.1 The Indian k_2 model ----------
17
2.6.2 The Chilean k_2 model ----------
18
2.6.3 The Nigerian k_2 model ----------
19
2.7 Statistical Data Analysis using Matlab, Excel. ----------
20
2.7.1 Some Relevant Statistical Operations ----------
20

2.7.2 Statistical Software ----------
22
2.7.3 Model Calibration and Validation in Water Quality Data ----------
22

CHAPTER THREE: MATERIALS AND METHODS

26
3.1 Materials/Equipment ----------
-26
3.2 Reagents ----------
-26
3.3 Methodology ----------
29
3.3.1 Field Activities ----------
30
3.3.2 Activities during the Field Exercises ----------
31
3.3.3 DO and BOD_5 Determination ----------
32
3.3.4 Data Analysis ----------
32
3.3.5 Hydraulic Radius ----------
-32
3.3.6 Ultimate BOD and De-oxygenation rate k_1 ----------
-33
3.3.7 Saturation DO and the Upstream and Downstream DO deficits ----------
33

3.3.8 Time of travel ----------
- 33
3.3.9 Re-aeration Coefficient Model ----------
-34

CHAPTER FOUR: RESULTS AND DISCUSSION

35

4.1 Introduction ----------
-35
4.2 Monthly Variations in DO, Temperature, BOD, pH ----------
-41
4.3 Determination of k_2 ---------- ---
-47
4.3.1 Average Stream Velocity ----------
-50
4.3.2 Average Hydraulic Radius (Water Depth) ----------
-51
4.3.3 The fair Ratio (f) ----------
-51
4.4 Model Parameters ----------
52
4.4.1 The Model ----------
-53

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

56

5.1 Conclusions ----------
-56

5.2 Recommendations ----------
56

5.3 Contributions to Knowledge ----------
-57

REFERENCES----------
-58

APPENDICES ----------
-64

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	The self-purification factor, *f*, of different water bodies at 20^{o}C.	6
2.2	Solubility of Oxygen in water.	16
3.1	Details of Sampling Stations.	29
4.1a	Hydraulic Data for February, 2014.	35
4.1b	Physico-Chemical Parameters for February, 2014.	35
4.2a	Hydraulic Data for March, 2014.	36
4.2b	Physico-Chemical Parameters for March, 2014.	36
4.3a	Hydraulic Data for April, 2014.	37
4.3b	Physico-Chemical Parameters for April, 2014.	37
4.4a	Hydraulic Data for May, 2014.	38
4.4b	Physico-Chemical Parameters for May, 2014.	38
4.5a	Hydraulic Data for June, 2014.	39
4.5b	Physico-Chemical Parameters for June, 2014.	39

4.6a Hydraulic Data for July, 2014.
40
4.6b Physico-Chemical Parameters for July, 2014.
40
4.7a Modelling Parameters for the Month of February.
46
4.7b Modelling Parameters for the Month of March.
46
4.7c Modelling Parameters for the Month of April.
47
4.7d Modelling Parameters for the Month of May.
47
4.7e Modelling Parameters for the Month of June.
48
4.7f Modelling Parameters for the Month of July.
49
4.8 R-squared values of six (6) models when tested with experimentally generated River Kaduna data.
51

LIST OF FIGURES

FIGURE **TITLE**

PAGE

2.1 Monograph of the Self-purification Factor f.
21

3.1 Sequence of activities for the work
30

4.1a BOD_5 Values at Each Sampling Point for the Months of February, March, April, May, June& July. 41

4.1b DO at each Sampling Point for the Months of February, March, April, May, June& July. 42

4.1c pH Values at each Sampling Point for the Months of February, March, April, May, June& July. 44

4.1d Temperature Profile at each Sampling Point for the Months of February, March, April, May, June& July. 45

LIST OF PLATES

PLATES **TITLE** **PAGE**

3.1a Aerial and Satellite View of Kaduna from Stadium to Kudenda

Mountain showing River Kaduna 29

3.1b Aerial and Satellite Photograph of Kaduna from Stadium to Kudenda Mountain showing the Sampling on River Kaduna 29

LIST OF APPENDICES

APPENDIX **TITLE** **PAGE**

I Matlab Code for Obtaining the Reaeration Coefficient 60

II Model Output from Matlab 68

III Computed Data Sheet for the Months Studied 75

LIST OF SYMBOLS AND ABBREVIATIONS

Symbols	Description	Unit
BOD	Biochemical Oxygen Demand	mg/L
COD	Chemical Oxygen Demand	mg/L
DO	Dissolved Oxygen	mg/L
f	Self-Purification Factor	Nil

k_1	De-oxygenation constant	per day
k_2	Re-aeration constant	per day
pH	Percentage of hydrogen ion concentration	Nil
TDS	Total Dissolved Solids	mg/L
TSS	Total Suspended Solids	mg/L

Abbreviations

ANOVA – Analysis of Variance

GPS – Global Positioning System

MATLAB – Matrix Laboratory software

USEPA – United States Environmental Protection Agency

USGS – United States Geological Society

SSE – Error Sum of Squares

SSR – Residual sum of squares

SST – Total sum of squares

RMSE – Root mean square error

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Surface water pollution is globally an environmental issue (Alam *et al*., 2007). Flowing surface water bodies have the natural capacities to purify themselves from the pollutions that come into them from external sources (Garg, 2006; Longe and Omole, 2008). The process of purification is achieved mainly through the absorption and dissolution of atmospheric oxygen

from the water body surface. This absorbed and dissolved oxygen (DO) is required for the chemical process of breaking down biological and chemical pollutants (into benign products), thereby reducing their concentration and ultimately eliminating the pollution threat over a period of time and distance, (Alam *et al*., 2007). However, there are other natural factors that affect the auto purification capacity of water bodies. These include; the water body velocity, depth, volumetric flow rate and temperature (Agunwamba *et al*., 2007). Fast flowing water bodies are able to absorb atmospheric oxygen faster than slow moving water bodies. Similarly, turbulent water bodies are generally very clean because of the natural capacity to absorb and digest pollutants at a very high rate because of mixing. Stagnant water bodies on the other hand tend to become septic when there is high pollutant content because of the low rate of oxygen absorption. Furthermore, the depth of the water body also affects the rate of diffusion and mixing of the absorbed oxygen. Deeper water bodies require more time and bulk movement for the oxygen that was absorbed at the surface to mix evenly and reach the bottom of the channel.

Similarly, volumetric discharge flow rate which is defined as the product of velocity and cross-sectional area of the water body affects the auto purification of water bodies. Furthermore, the importance of temperature on the auto purification process of water bodies cannot be overemphasized. Fundamentally, from solubility perspective, DO is an inverse function of temperature. Therefore, water bodies situated in temperate regions have higher DO concentration than water bodies situated in tropical regions. At certain temperatures, water cannot absorb oxygen beyond a certain level.

Water quality modelling describes a situation whereby mathematical models are employed to explain, describe and predict the response of aquatic ecosystems to changes imposed on them either by anthropogenic activities or by other naturally induced conditions. Scores of empirical water quality models have been developed simply because no single model can be representative of all situations (Chapman, 1992; Garg 2006, Agunwamba *et al.,* 2007; Longe *et al.*, 2008; Omole, 2010). While some models are situation or problem specific, others are time specific and yet others are more general. Thus, modelling (development, verification and validation) is a problem solving exercise that is going to be around for a long time to come (Omole *et al.,* 2008).

Re-aeration coefficient modeling is an integral part of water quality modeling, which is a scientific tool employed to predict and monitor pollutant loads and nutrient constituents in fresh water bodies for effective resource planning and management (Longe and Omole, 2008). This field of study pioneered by Streeter and Phelps (1925) through their study on the recovery dynamics of River Ohio from pollution, has since become an interesting research area in water quality among scientists world over (Streeter and Phelps, 1925; Streeter *et al*., 1936; Villeneuve *et al*., 1998). The principles of Streeter and Phelps had been widely applied to water quality studies across the globe for examples: in England (Owens *et al*., 1964), Chile (Baecheler and Lazo, 1999) and India (Jha *et al*., 2001).

The Streeter-Phelps Dissolved Oxygen (DO) model is a very popular general model put forward in 1925 by the scientists after whom the model was named (Villeneuve *et al.*, 1998). The model has since been modified and metamorphosed many times into various forms and applications (Fair *et al.*, 1971; Longe and Omole, 2011).

1.2 Statement of the Research Problem

The increase in population and pollution sources would necessitate a more recent study of the factors affecting the regenerative capacity of River Kaduna, Nigeria after pollution loads.

1.3 Aim

Therefore, the aim of this study is to evaluate the factors affecting the self-purification capacity of River Kaduna, during the dry season (from February to May) and the beginning of the raining season (June & July). Also an empirical expression of the reaeration coefficient will be developed.

1.4 Objectives of the Study

The objectives of this study include:

i To map out a particular segment of River Kaduna where there is heavy discharge of pollutants from the industries.

ii To generate data (BOD, DO, Temperature, Velocity, Hydraulic Radius etc.) of the self-purification dynamics of a particular segment of interest on the river.

iii To determine reaeration constant (k_2) and develop an expression that will fit the sets of data for monitoring the self-purification of the river.

iv To generate self-purification values (f values) for the months and its consequences for this water body.

1.5 Justification

Kaduna is one of the few highly industrialized cities in Nigeria. Most of the industries in Kaduna are located in two industrial estates in Kaduna South which are the Kakuri and Kudenda Industrial estates. The outcome of this study will provide general guidance in the development of a water quality monitoring plan for this water body. The model will also be applied in future reaeration studies on River Kaduna and environs. Some of the achievements will include: the stretch of distance at which waste can be discharged into the river by the processing industries within its self-purification capacity and the period of the year at which this will be best.

1.6 Scope of Study

The study composed of three major aspects. The first aspect is the fieldwork, for the gathering of in-situ information on DO, the acquisition of raw water samples for BOD analysis as well as information on other hydrodynamic factors such as stream velocity and bathymetry. The second aspect of this research work was the laboratory analyses of the raw water samples for physical and chemical characterisation. Data recording and handling was carried out with the aid of Microsoft Excel while the modelling was done with the use of MATLAB software. The final aspect of this study was the development of a k_2 model for generation of f values based on the data collected.

1.7 Significance of the Study

The significance of this research work are as follows:

i An expression for the re-aeration constant which reflects the existing local conditions of River Kaduna will be developed.

ii Future legislations, regulations and researches can take their cue from the research findings.

The research findings would be made available to all stakeholders. They include: The private citizens (so that they can be more alert to their responsibility of protecting their environment and guarding their health); The polluters (so that they can know that their activities have a direct impact on human lives and the environment); and the government (through their regulatory agencies, so that they can realize the impact of defaulters of pollution standards on people and the environment).

(iii) The result will suggest what can be done to improve the reaeration of River Kaduna

CHAPTER TWO

LITERATURE REVIEW

2.1 Background

The field of water quality modelling was found by the duo of Streeter and Phelps through their pioneering work published in 1925 (Villeneuve *et al.*, 1998; Streeter and Phelps, 1925). They proposed the idea of measuring and predicting the dissolved atmospheric oxygen (DO) and Biochemical Oxygen Demand (BOD) dynamics of a water body as a parameter for measuring the self-purification capacity of a water body. Their research was performed on the Ohio River and the source of pollution was municipal wastewater (Villeneuve *et al.*, 1998). Their predicted model was given as:

$$\frac{dD(t)}{dt} = k_1 L(t) - k_2 D(t) \quad (2.1)$$

Where $\frac{dD(t)}{dt}$ = the rate of change of the Dissolved Oxygen content (DO) of the river with time, k_1 = de-oxygenation rate, L(t) = BOD at the instantaneous time, t, k_2 = re-aeration rate and D(t) = dissolved oxygen at an instantaneous time, t (Kiely, 1998). The research work formed the basis of further studies which modified the initial equations in order to accommodate additional variables in nature (Villeneuve *et al.*, 1998). By integrating equation 2.1, the equation commonly used for the prediction of DO is obtained (Longe and Omole, 2008; Lin and Lee, 2007; Waite and Freeman, 1977 and Fair *et al.*, 1971).

$$D = \frac{L_a}{f-1} 10^{k_2 t} \left\{ 1 - 10^{[-(f-1)k_2 t]} \left[1 - (f-1) \frac{D_a}{L_a} \right] \right\} \quad (2.2)$$

where D = instantaneous DO, L_a = initial BOD, *f* is the self-purification factor (which varies for different types of surface water bodies), k_2 is as defined in equation (2.1), D_a = initial DO and t is the instantaneous time. The value of *f* is determined by dividing computed value of k_2 by the observed or tabulated value of k_1 (Garg, 2006). The range of *f* at 20^{o}C is given in Table 2.1. Based on the original work by Streeter and Phelps, some models and software have been developed.

Table 2.1: The self-purification factor, *f*, of different water bodies at 20 ^{o}C.

S/N	Description of water body	Range
1	Small ponds and backwaters	0.15-1.0

2	Sluggish streams, Large Lakes and impounding reservoirs.	1.0-1.5
3	Large stream of low velocity.	
4	Large streams of normal velocity.	1.5 - 2.0
5	Swift stream.	2.0 – 3.0
6	Rapids/ Water falls	3.0 – 5.0
		Over 5.0

Source: Garg, 2006.

2.2 Global Urban Rivers/Lakes and Usage

A river is a natural flowing watercourse, usually freshwater, flowing towards an ocean, sea, lake or another river. In some cases, a river flows into the ground and becomes dry at the end of its course without reaching another body of water. Small rivers can be referred to using names such as stream, creek, brook, rivulet, and rill. There are no official definitions for the generic term river as applied to geographic features, although in some countries or communities a stream is defined by its size. Many names for small rivers are specific to geographic location; examples are "run" in some parts of the United States, "burn" in Scotland and northeast England, and "beck" in northern England. Sometimes a river is defined as being larger than a creek, but not always: the language is vague.

Rivers are part of the hydrological cycle. Water generally collects in a river from precipitation through a drainage basin from surface runoff and other sources such as groundwater recharge, springs, and the release of stored water in natural ice and snow packs (e.g. from glaciers) Chu, (2012).

A river begins at a source (or more often several sources), follows a path called a course, and ends at a mouth or mouths. The water in a river is usually confined to a channel, made up of a stream bed between banks. In larger rivers there is often also a wider floodplain shaped by flood-waters over-topping the channel. Floodplains may be very wide in relation to the size of the river channel. This distinction between river channel and floodplain can be blurred, especially in urban areas where the floodplain of a river channel can become greatly developed by housing and industry.

Rivers can flow down mountains, through valleys (depressions) or along plains, and can create canyons or gorges.

The term upriver (or upstream) refers to the direction towards the source of the river, i.e. against the direction of flow. Likewise, the term downriver (or downstream) describes the direction towards the mouth of the river, in which the current flows.

The term left bank refers to the left bank in the direction of flow, right bank to the right.

The river channel typically contains a single stream of water, but some rivers flow as several interconnecting streams of water, producing a braided river. Extensive braided rivers are now found in only a few regions worldwide, such as the South Island of New Zealand. They also occur on peneplains and some of the larger river deltas. Anastamosing Rivers are similar to braided rivers and are also quite rare. They have multiple sinuous channels carrying large volumes of sediment. There are rare cases of river bifurcation in which a river divides and the resultant flows ending in different seas. An example is the bifurcation of Nerodime River in Kosovo. (Cave, 2015).

Rivers have been used as a source of water, for obtaining food, for transport, as a defensive measure, as a source of hydropower to drive machinery, for bathing, and as a means of disposing of waste.

Rivers have been used for navigation for thousands of years. The earliest evidence of navigation is found in the Indus Valley Civilization, which existed in northwestern India around 3300 BC. Riverine navigation provides a cheap means of transport, and is still used extensively on most major rivers of the world like the Amazon, the Ganges, the Nile, the Mississippi, and the Indus. Since river boats are often not regulated, they contribute a large amount to global greenhouse gas emissions, and to local cancer due to inhaling of particulates emitted by the transports. (Achim, 2003)

In some heavily forested regions such as Scandinavia and Canada, lumberjacks use the river to float felled trees downstream to lumber camps for further processing, saving much effort and cost by transporting the huge heavy logs by natural means.

Rivers have been a source of food since pre-history. They are often a rich source of fish and other edible aquatic life, and are a major source of fresh water, which can be used for drinking and irrigation. Most of the major cities of the world are situated on the banks of rivers. Rivers help to determine the urban form of cities and neighbourhoods and their corridors often present opportunities for urban renewal through the development of foreshore ways such as

river walks. Rivers also provide an easy means of disposing of waste water and, in much of the less developed world, other wastes

2.3 Nigerian Urban Rivers/Lakes and usage

The Kaduna River with coordinates 8^0 45' 00'N and 5^0 48' 00'E is a tributary of the Niger River which flows for 550 kilometers through Nigeria. It got its name from the crocodiles that lived in the river and surrounding area. Kaduna in the native dialect, Hausa, was the word for "crocodiles". (USGS, 2012)

It starts in Plateau State on the Jos Plateau 29 kilometers southwest of Jos town, flows through its namesake Kaduna State and through its capital Kaduna, and meets the Niger River in Niger State. Most of its course passes through open savanna woodland, but its lower section has cut several gorges above its entrance into the extensive Niger floodplains.

The importance of urban Rivers (Rivers Niger, Benue, Kaduna etc.) to Nigeria generally cannot be over emphasized. River Niger is the third longest river in Africa covering 2,600 miles (4, 180 km), while the River Benue is about 673 miles (1083 km) in length. These two rivers provides a major landmark in the landscape of Nigeria.

There is no economy without electricity. Nigeria uses Hydro Electric Power to generate its electricity and this requires substantial amount of water provided by the confluence of the two rivers (Niger and Benue). This confluence provided the needed volume and speed to power the turbines for the generation of electricity not only for Nigeria but other West African States.

In recent years when the government of President Obasanjo took the initiative to settle displaced white farmers from Zimbabwe, they all chose to stay and farm around the Rivers Niger and Benue. Most of them settled in Kwara State along the rivers. The farmers are erecting houses at Tsonga, some 110 kilometers north of Ilorin, the capital of Kwara State, where local villagers have welcomed and hailed them as saviors. These farmers are highly mechanized and the two rivers provide a ready source of water for their crops, livestock and for their own survival as well

2.4 Sources of Urban Rivers Pollution

Urban rivers are prone to pollution mainly due to their proximity to many pollution sources like wastewater discharge points, on-site sanitation systems for domestic institutional sources, industrial effluent discharge points, solid waste disposal sites and agricultural uses they can be grouped into natural, agricultural, industrial and urban sources. Natural pollution arises from storm wash, seepage ground water, swamp drainage and aquatic life of stream. Storm wash usually carries large quantities of organic matter from decaying flora and fauna and inorganic silt from soil erosion into streams. Seepage from ground water may contribute a variety of chemical components dissolved from the soil and geologic formations through which the seepage water passes to reach the water course. (Frank, 1996).

Water quality is often described in terms of a number of physico-chemical and biological parameters depending on the intended use of water. River water quality is described for instance by parameters such as Dissolved Oxygen (DO), pH, Temperature, Most Probable Number (MPN) of coliforms, and analyzed in field and laboratory for various physico-chemical characteristics as per the APHA standards. Kaduna River Pollution Study Project (Beecroft, 1987) has been considered for comparison of water quality of Romi River within the influence zone. Following the Koko toxic waste episode in Delta state, the Federal Government of Nigeria promulgated the Harmful Waste Decree 42 of 1988, which led to the establishment of the Federal Environmental Protection Agency (FEPA) through Decree 58 of 1988. In the wisdom of Government, FEPA and other relevant Departments in other Ministries were merged to form the Federal Ministry of Environment in 1999, but without an appropriate enabling law on enforcement issues. This situation, created a vacuum in the effective enforcement of environmental laws, standards and regulations in the country. To address this situation, the National Environmental Standards and Regulations Enforcement Agency (NESREA) were established as a parastatal of the Federal Ministry of Environment, Housing and Urban Development.

NESREA is charged with the responsibility of enforcing all environmental laws, guidelines, policies, standards and regulations in Nigeria. It also has the responsibility to enforce compliance with provisions of international agreements, protocols, conventions and treaties on the environment. The vision of the Agency is to ensure a cleaner and healthier environment for all Nigerians, while the mission is to inspire personal and collective responsibility in building an environmentally conscious society for the achievement of sustainable development in Nigeria.

The natural elements which causes water pollution are gases, soil, minerals, humus materials, waste created by animals and other living organisms present in water from sewage. During

raining season, surface water with soil, mud and humus enter into the river, tanks and other water bodies. The inorganic minerals like sodium, potassium, calcium, magnesium and heavy metals like iron, manganese, lead, mercury, chromium, cadmium, nickel, cobalt, beryllium copper, when present above the permissible limit are harmful.

2.5 **Wastewater Quality and indicators**

2.5.1 Biochemical Oxygen Demand

The BOD test measures the amount of oxygen consumed in breaking down organic matter using both aerobic biological and chemical degradation processes, giving an indication of the organic strength of a wastewater. The test has its widest application in measuring waste loadings of treatment plants and in evaluating the BOD-removal efficiency of such treatment systems. BOD is determined by incubating a water sample in a sealed container for a specified time and measuring the loss of oxygen that occurs between the beginning and end of the test. Samples must often be diluted prior to incubation (Jay L. *et al.,* 2005).

Biodegradable organic matter is a composite substrate and is difficult to quantify directly. The BOD test estimates the amount of dissolved oxygen used during the degradation of organic waste as a surrogate for measuring the waste itself. The amount of molecular oxygen measured during the incubation period can accrue from three sources:

i The oxygen used for the biochemical degradation of organic material
ii The oxygen used to oxidize inorganic materials such as sulfides and ferrous iron.
iii The oxygen used to oxidize reduced forms of nitrogen (nitrogenous demand), although a nitrifying inhibitor is often used to suppress the nitrogenous demand.

In a report prepared by the Royal Commission on Sewage Disposal in the United Kingdom at the beginning of the last century, it was recommended that a five-day,18.3°C, BOD_5 value be used as a reference in Great Britain. These values were selected because British rivers do not have a flow time to the open sea greater than five days and the average long-term summer temperatures do not exceed 18.3°C. The temperature has been rounded upward to 20°C, but the five-day time period has become the universal scientific and legal reference.

The BOD_5 test is still the most important and most widely used environmental index for monitoring organic pollutants in waters, mainly as proof of compliance with relevant legislation. Most developed countries strictly regulate the permissible BOD loadings of water as it is discharged from a treatment plant into receiving waters (e.g. sea or river), which is typically

required to be less than 20 mg/L. The BOD_5 value for potable water is close to zero; domestic wastewater effluent entering a treatment plant typically has a BOD_5 of around 300mg/L; and industrial effluents can have BOD_5 values greater than 20,000 mg/L.

2.5.2 Chemical oxygen demand (COD)

The COD test measures the chemical oxidation of wastewater by using a strong oxidizing agent under acid conditions. As for BOD, it measures the amount of oxygen required as a surrogate for measuring the organic waste component directly. The COD test does not differentiate between biologically active and inert organic matter and measures the total quantity of oxygen required to oxidize all organic matter into carbon-dioxide and water.

COD values are always greater than BOD values, but the results can be obtained within two hours and the presence of toxic compounds in the sample does not affect COD measurements. In many cases, the BOD/COD ratio is used to provide an indication of the biodegradability of the wastewater. However, the chemicals used, such as acid, chromium, silver, and mercury, produce liquid hazardous waste that requires careful handling and disposal.

2.5.2.1 *Oxygen generation and consumption*

Dissolved oxygen is the amount of oxygen dissolved in water, measured in milligrams per litre (mg/L). This component in water is critical to the survival of various aquatic lives in streams, such as fish. The ability of water to hold oxygen in solution is inversely proportional to the temperature of the water. Generally, the solubility of gas in water, falls with temperature (Chehalis River Council, 2008).

Biodegradable means that a substance can be converted into simpler compounds by bio-mediated reactions. The second law of thermodynamics predicts that oxidation of high energy level organics (relative to low energy level CO_2) is favoured. Oxygen is one of the strongest oxidizing agents found in natural aquatic systems. Oxidation reactions are thermodynamically favoured, but kinetically slow unless microbially mediated. The end products of complete aerobic biodegradation are CO_2 and H_2O (Ellis *et al.,* 1996).

2.5.3 Temperature

Aquatic organisms cannot survive outside of specific temperature ranges. Irrigation runoff and water cooling of power stations may elevate temperatures above the acceptable range for some species. Temperature may be measured with a calibrated thermometer.

2.5.4 Solids

Solid material in wastewater may be dissolved, suspended, or settleable. Total dissolved solids or TDS (sometimes called filterable residue) is measured as the mass of residue remaining when a measured volume of filtered water is evaporated. The mass of dried solids remaining on the filter after filtering the whole wastewater is called total suspended solids (TSS) or non-filterable residue. Settleable solids are measured as the visible volume accumulated at the bottom of an Inhofe cone after water has settled for one hour. Turbidity is a measure of the light scattering ability of suspended matter in the water. Salinity measures water density or conductivity changes caused by dissolved materials.

2.5.5 pH/Acidity/Alkalinity

pH is a measure of the amount of free hydrogen ions in water. Specifically, pH is the negative logarithm of the molar concentration of hydrogen ions. pH = -log[H+]

for example, at pH 2, $[H+] = 10^{-2}$ or .01 at pH 10 $[H+] = 10^{-10}$ or .0000000001 at pH 4 $[H+] = 10^{-4}$ or .0001

Because pH is measured on a logarithmic scale, an increase of one unit indicates an increase of ten times the amount of hydrogen ions. A pH of 7 is considered to be neutral. Acidity increases as pH values decrease below 7, and alkalinity increases as pH values increase above 7. Most natural waters are buffered by a carbon-dioxide-bicarbonate system, since the carbon dioxide in the atmosphere serves as a source of carbonic acid.

$H_2CO_3 \rightarrow HCO_3 + H^+$ pK ~ 7.5 (2.3a)

This reaction tends to keep pH of most waters around 7 - 7.5, unless large amounts of acid or base are added to the water. Most streams draining coniferous woodlands tend to be slightly acidic (6.8 to 6.5) due to organic acids produced by the decaying of organic matter. Natural waters in the Piedmont of Georgia also receive acidity from the soils. In waters with high algal concentrations, pH varies diurnally, reaching values as high as 10 during the day when algae are using carbon dioxide in photosynthesis. pH drops during the night when the algae respire and produce carbon dioxide.

The pH of water affects the solubility of many toxic and nutritive chemicals; therefore, the availability of these substances to aquatic organisms is affected. As acidity increases, most metals become more water soluble and more toxic. Toxicity of cyanides and sulfides also increases with a decrease in pH (increase in acidity). Ammonia, however, becomes more toxic with only a slight increase in pH.

Alkalinity is the capacity to neutralize acids, and the alkalinity of natural water is derived principally from the salts of weak acids. Hydroxide, carbonates, and bicarbonates are the dominant source of natural alkalinity. Reactions of carbon dioxide with calcium or magnesium carbonate in the soil creates considerable amounts of bicarbonates in the soil. Organic acids also form salts that increase alkalinity. Alkalinity itself has little public health significance, although highly alkaline waters are unpalatable and can cause gastrointestinal discomfort.

2.5.6 Oxygen

Most aquatic habitats are occupied by fish or other animals requiring certain minimum dissolved oxygen concentrations to survive. Dissolved oxygen concentrations may be measured directly in wastewater, but the amount of oxygen potentially required by other chemicals in the wastewater is termed an oxygen demand. Dissolved or suspended oxidizable organic material in wastewater will be used as a food source. Finely divided material is readily available to microorganisms whose populations will increase to digest the amount of food available. Digestion of this food requires oxygen, so the oxygen content of the water will ultimately be decreased by the amount required to digest the dissolved or suspended food. Oxygen concentrations may fall below the minimum required by aquatic animals if the rate of oxygen utilization exceeds replacement by atmospheric oxygen.

The reaction for biochemical oxidation may be written as:

Oxidizable material + bacteria + nutrient + $O_2 \rightarrow CO_2 + H_2O$ + oxidized inorganics such as NO_3 or SO_4 (2.3b)

Oxygen consumption by reducing chemicals such as sulfides and nitrites is typified as follows:

$$S^- + 2O_2 \rightarrow SO_4^- \quad (2.3c)$$

$$NO_2^- + {}^1/_2\, O_2 \rightarrow NO_3^- \quad (2.3d)$$

Since all natural waterways contain bacteria and nutrient, almost any waste compound introduced into such waterways will initiate biochemical reactions (such as shown above). Those biochemical reactions create what is measured in the laboratory as the biochemical oxygen demand (BOD).

Oxidizable chemicals (such as reducing chemicals) introduced into a natural water will similarly initiate chemical reactions (such as shown above). Those chemical reactions create what is measured in the laboratory as the chemical oxygen demand (COD).

Both the BOD and COD tests are a measure of the relative oxygen-depletion effect of a waste contaminant. Both have been widely adopted as a measure of pollution effect. The so-called 5-day BOD measures the amount of oxygen consumed by biochemical oxidation of waste contaminants in a 5-day period. The total amount of oxygen consumed when the biochemical reaction is allowed to proceed to completion is called the Ultimate BOD. The Ultimate BOD is too time consuming, so the 5-day BOD has almost universally been adopted as a measure of relative pollution effect.

There are also many different COD tests. Perhaps, the most common is the 4-hour COD. There is no generalized correlation between the 5-day BOD and the Ultimate BOD. Likewise, there is no generalized correlation between BOD and COD. It is possible to develop such correlations for a specific waste contaminant in a specific wastewater stream, but such correlations cannot be generalized for use with any other waste contaminants or wastewater streams.

2.6 Self Purification Assessment/Capacity of Global/Nigeria water bodies

It can be seen from the foregoing that the core issues of water quality model building are the coefficient of de-oxygenation and re-aeration. The coefficient of deoxygenation is a function of the concentration of waste discharged into the surface water body (the BOD loading). This is because the natural process of breakdown or digestion of wastes by surface water bodies requires oxygen and the inherent dissolved oxygen within the surface water body therefore naturally becomes the only source for this metabolic activity (Omole and Longe, 2008; Kilpatrick *et al.*, 1989). The coefficient of re-aeration (k_2), on the other hand, is a function of the rate at which the surface water traps and dissolves atmospheric oxygen. The DO in clean natural waters usually ranges between 7.6 mg/L - 14.6 mg/L for temperatures varying between 30^{o}C - 0^{o}C as shown in Table 2.2.

Table 2.2: Solubility data of Oxygen in water.

Temperature ℃	**Average Dissolved Oxygen (mg/l)**	**Temperature** ℃	**Average Dissolved Oxygen (mg/L)**
0	14.6	16	9.9
1	14.2	17	9.7
2	13.9	18	9.5
3	13.5	19	9.3
4	13.1	20	9.1
5	12.8	21	8.9

6	12.5	22	8.7
7	12.1	23	8.6
8	11.8	24	8.4
9	11.6	25	8.3
10	11.3	26	8.1
11	11.0	27	8.0
12	10.8	28	7.8
13	10.5	29	7.7
14	10.3	30	7.6
15	10.1		

Source; **(**Weiner and Matthews, 2003)

When the existing DO in the surface water body is utilized by the BOD loading, the result is that the DO level drops sharply and in extreme cases, the water becomes septic and begins to stink. The recovery of the surface water from this polluted state depends on the rate at which the surface water can trap and dissolve atmospheric oxygen (which is a mass transfer problem) (Omole and Longe, 2008; Kiely, 1998; Chapman, 1992).

Although, the pioneering research in this field of study was carried out in the United States, customized research that would meet the peculiarities of other countries has been undertaken by different scientists (Churchill *et al.,* 1962; Baecheler, 1999; Jha *et al.,* 2001; Park and Lee, 2002; Mehrdadi *et al.,* 2006; Agunwamba *et al.,* 2007; Lin and Lee, 2007; Al-Zboon and Al-Suhaili, 2009). The reason for such customized studies is predicated on climatic differences in different parts of the world. Temperature is one of the most important climatic factors that determine the rate at which atmospheric oxygen gets dissolved in water (Agunwamba *et al.*, 2007). The higher the temperature, the lower the DO concentration and rate of re-aeration (Agunwamba *et al.*, 2007). Other variables that affect re-aeration rate are stream velocity, river depth, width and friction of the river bed (Jha *et al,* 2005*;* Garg, 2006; Alam *et al.,* 2007). These other variables are usually similar all over the world but temperature varies widely in different parts of the world.

Equation 2.3a suggests a general expression for k_2 models

$$k_2 = c\frac{V^n}{H^m} \qquad (2.4a)$$

where

V = velocity of flow (m/s)

H = Hydraulic Radius (m)

where c, n and m are constants with specific values based on the characteristics of the river under study. For temperature conversions, Agunwamba (2007) introduced a temperature coefficient as in Equation (2.3b).

$$k_2 = \frac{a_1 U^{b_1} C}{R^{d_1}} \quad (2.4b)$$

Where a_1 = constant of flow, U = the velocity, C = Arrhenius constant (which is a conversion factor inserted in the American k_2 model to accommodate the variations in rate of re-aeration at varying temperatures) and R = hydraulic radius. A typical example is given in Equation (2.4).

$$k_2 = \frac{5.026u^{0.969}(1.024)^{T-20}}{R^{1.673}} \quad (2.5)$$

where T is different from 20 ℃.

Other k_2 models that have been used for computations are shown in Equations (2.6), (2.7), (2.8) and (2.9) (Garg, 2006).

$$k_R(20) = \frac{3.9\sqrt{V}}{y^{1.5}} \quad (2.6)$$

where k_R = coefficient of re-aeration at 20℃ = k_2, v = average stream velocity in m/s, y = average stream depth in m. The Arrhenius constant for converting to other temperatures was taken as:

$$k_R(T) = K_R(20)[1.016]^{T-20} \quad (2.7)$$

Other models of interest are the O'Connor and Dobbins (1958) and Wilcock (1988) model. O'Connor and Dobbins (1958) model is of the form:

$$k_2 = \frac{(D_o U)^{1/2}}{H^{3/2}} \quad (2.8)$$

where D_o = molecular diffusion coefficient for oxygen in water = 1.76 x 10^{-4} m^2/d at 20℃ to be multiplied by $1.037^{(T-20)}$ for other temperatures, U = water current velocity. H= river depth. O'Connor and Dobbins (1958) model is based on surface renewal of re-aeration. Wilcock (1988) model, is of the form:

$$k_2 = C_e \frac{\Delta L}{t_f} \quad (2.9)$$

Where:ΔL = change in surface elevation, L; t_f = travel time, T; and C_e = escape coefficient = 0.177 m^{-1} at 20 ℃. Wilcock (1988) model is based on energy dissipation.

These variations therefore indicate that much research is being done to update all that have been put forward by earlier researchers. It is also important to look at studies related to other nations.

2.6.1 The Indian k_2 model

The coefficient of re-aeration model developed in some water bodies in India is as follows (Jha *et al.,* 2001):

$$k_2 = \frac{5.792V^{0.5}}{H^{0.25}} \quad (2.10)$$

where *V* = stream flow velocity and *H* = hydraulic radius in meters. This model is devoid of the Arrhenius constant as in equation 2.4 and this is the essence of this work. The temperature changes, which would already have been taken into consideration at the point of sampling is already in-built into the models. Sampling therefore is necessary all year round in order to appreciate the effect of the temperature variation on the atmospheric DO dynamics and to have a model that is not prone to errors of conversion through the use of Arrhenius constant. The Indian model was not only derived from first principles but is already in use such that other recent works have been built on it (Jha *et al*., 2005; Jha *et al.,* 2007). The Indian team went about their research by acquiring 270 field data sets over a period of 12 months from River Kali. Eleven well known re-aeration prediction equations were tested. Mean stream velocity, bed slope, flow depth, friction factor and Froude number were factors also considered using data generated during field survey. The k_2 values computed from these predictive equations were compared with the k_2 values observed from field measurements (Jha *et al.,* 2001). The performance of the predictive equations were evaluated using error estimation, namely standard error (SE), normal mean error (NME), mean multiplicative error (MME) and correlation statistics. The authors observed that the equations developed by Smoot *et al.,* (1995) and by Cadwallader and McDonnell, (1969) showed comparatively better results among all the predictive models considered. Jha *et al.,* (2001) thereafter refined these better models and developed their own customized predictive equation using a least-square algorithm for the River Kali that minimizes error estimates and improves correlation between observed and computed re-aeration coefficients. This is the process that produced Equation (2.9) (Jha *et al.,* 2001).

A closer look at the Smoot *et al.* (1995) and Cadwallader and McDonnell (1969) models showed that their adopted process of predicting k_2 was based on the use of three regressors namely slope, velocity and hydraulic radius whereas the Jha *et al.*, (2001) model was based on two regressors namely velocity and hydraulic radius.

2.6.2 The Chilean k_2 model

Baecheler and Lazo (1999) also reported the results of modelling experiments carried out by them in Chile. They were of the opinion that no universal and clear criterion exists to decide

which formulation should be used to model water quality of any particular river, and that this has accounted for the variations in k_2 models the world over. They reported that most of the rivers in Chile are Mountain Rivers with great quantities of granular sediments, rocky beds filled with potholes that contain most of the pollutant loads as a result of the discharge of urban and industrial wastes into the rivers. These peculiarities therefore prompted them to carry out some experiments and they came up with two k_2 model equations. Equation (2.10) is used for slight slope rivers, Equation (2.11) is used on medium slope rivers.

$$k_2 = \frac{10.046U^{2.696}}{H^{3.902}} \quad (2.11)$$

and

$$k_2 = \frac{1.923U^{1.325}}{H^{2.006}} \quad (2.12)$$

where U is mean stream velocity and H = mean stream depth..

2.6.3 The Nigerian k_2 model

In Nigeria, scanty research has been done in this regard (Omole *et al*., 2012). For example, Agunwamba *et al.,* 2007 calculated k_2 for Amadi creek in Port Harcourt, Rivers State, Nigeria. In this very study, k_2 was estimated in Equation (2.13).

$$K_2 = \frac{11.6325U^{1.6954}}{R^{0.0016}} \quad (2.13)$$

Where: U = stream flow velocity (m/s) and R = hydraulic radius (m) of the stream.

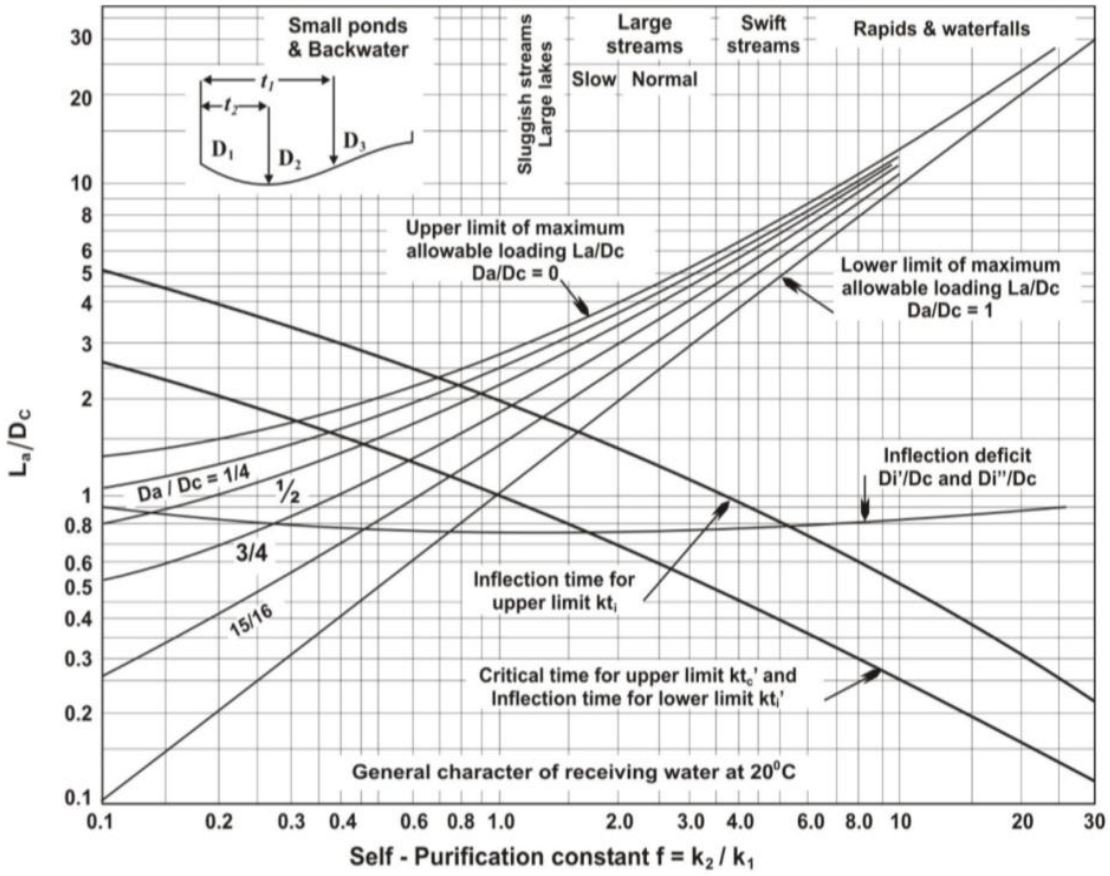


Figure 4: Monograph of the Self-purification Factor f (Fair et al, 1968).

The Figure above is the monograph of the self-purification factor f. The Equations on the monograph were sourced from Fair *et al.*, where $\boldsymbol{C_c}$, is the critical dissolved oxygen concentration (minimum acceptable). The initial dissolved oxygen deficit: Da (mg/L) is derived from subtracting C_a from C_s; where C_a is the initial dissolved oxygen concentration (prior to discharge point) and Cs is the DO saturation value. L_a is the maximum allowable concentration of BOD.

2.7 Statistical Data Analysis using Matlab, Excel, etc. as Tools towards generating useful Parameters.

When raw data is obtained from the field, it makes no meaning until some mathematical analyses are performed on them in order to obtain some information and interpretation. Data itself is varied in form. There are four different types of data namely: Nominal, Ordinal, Interval and Ratio data (Vowler, 2007 and Brower *et al.,* 1997). While Nominal and Ordinal data are categorical, interval and Ratio data are continuous.

2.7.1 Some Relevant Statistical Operations.

Five relevant statistical operations are discussed;

2.7.1.1Correlation

If the association between two continuous variables is of interest, then correlation should be used. For normally distributed data, Pearson's correlation coefficient, r, can be used. The coefficient of determination, R^2, is the proportion of variance explained by the association. When the data is not normally distributed, Spearman's rank correlation can be used. Kendall's tau can also be used if there are many ties (identical values) in the data (Vowler, 2007).

2.7.1.2 Regression analysis: - Regression analysis is used to predict a continuous dependent variable from a number of independent variables. Usually, it is used with naturally-occurring variables and sometimes with experimentally manipulated variables (Tabacknick and Fidell, 1989; U.S. Navy, 1999). The process of regression analysis include: Checking for the number of cases, checking the accuracy of data entry, looking for missing data, checking for outliers and checking for normality. Regression analysis also has an assumption of linearity (Kruskal and Tanur, 1978). Linearity means that there is a straight line relationship between the Independent Variables (IV) and the dependent variables (DV). This assumption is important because regression analysis only tests for a linear relationship between the IV and DV. Any nonlinear relationship between the IV and DV is ignored (Kruskal and Tanur, 1978). One can test for linearity between an IV and the DV by looking at a bivariate scatterplot (i.e., a graph with the IV on one axis and the DV on the other). If the two variables are linearly related, the scatter plot will be oval. The general form of a simple linear regression is given by (Draper and Smith, 1998):

$$y_i = \alpha + \beta x_i + \varepsilon_i \tag{2.14}$$

Where; α is the intercept, β is the slope and ε is the error term which picks up the unpredictable part of the response variable, y_i. The *x*'s and the *y*'s are the data quantities from the sample or population in question, and α and β are the unknown parameters to be estimated from the data.

2.7.1.3 Multiple Regression Analysis

Standard multiple regression has the same idea as simple linear regression, except now one has several independent variables predicting the dependent variables. In addition to telling one the predictive value of the overall model, standard multiple regression shows how well each independent variable predicts the dependent variable, controlling for each of the other independent variables (Kotsiantis and Pintelas, 2005).

The significance levels given for each independent variable indicates whether the particular independent variable is a significant predictor of the dependent variable, over and above the other independent variables. Because of this, an independent variable that is a significant predictor of a dependent variable in simple linear regression may not be significant in multiple regression (i.e., when other independent variables are added into the equation). This could happen because the variance that the first independent variable shares with the dependent variable could overlap with the variance that is shared between the second independent variable and the dependent variable. Consequently, the first independent variable is no longer uniquely predictive and thus would not show up as being significant in the multiple regression. Because of this, it is possible to get a highly significant R^2, but have none of the independent variables being significant (Lindley, 1987).

2.7.1.4 *Least Square Method* (Schilling and Sandra, 2000)

When the number of samples is large or if the dependent variable contains measurement noise (variations in data value taken under similar conditions), it is often better to find a function f that approximates the data by minimizing an error criterion such as

$$E = \sum_{k=1}^{n} [f(x_k) - y_k]^2 \qquad (2.15)$$

A method that minimizes E is called least squares method. This approach is best when the representation of the underlying trend of data is the objective.

2.7.1.5. *Non-linear Regression*

In scientific applications there is usually relevant theory for constructing a mechanistic model. Often such models are nonlinear in the unknown parameters. Nonlinear models are more difficult to fit, requiring iterative methods that start with an initial guess of the unknown parameters. Each iteration alters the current guess until the algorithm converges (Dos Santos and Porta Nova, 2007; Berthouex and Brown, 2002).

2.7.2 Statistical Software

Some of the most commonly used statistical software is the Microsoft Excel, Stata, SAS, SPSS and MATLAB statistical toolbox (U.S. Navy, 1999; Nelson, 2002; SUAC, 2005). In addition to the basic spreadsheet functions, the Analysis ToolPak in Excel contains procedures such as ANOVA, correlations, descriptive statistics, histograms, percentiles, regression, and t-tests. The primary reason for using Excel for statistical data analysis is because it is so widely available. Statistical data analysis in Excel is however not recommended for analyzing datasets with a large sample size or a large number of variables, performing advanced

statistical analyses, or for projects in which a number of procedures need to be performed (Nelson, 2002; SUAC, 2005).

While Excel can do the regression procedure, it does not report standardized coefficients, important regression diagnostics or information about co-linearity. For this reason, it is recommended that users who are doing anything more than exploratory research use a statistical software package such as SPSS, SAS or MATLAB statistical toolbox for regression analysis (SUAC, 2005).

2.7.3 Model Calibration and Validation in Water Quality Data

Mathematical models can be classified as theoretical or empirical. Theoretical models are ideal for situations where all the underlying processes are well understood and are not time varied (Chatterjee and Hadi, 2006; Montgomerry and Runger, 2003; Chapman, 1992). An example of this are the equations of motion put forward by Sir Isaac Newton. The underlying processes are well understood and the models developed are as useful today as 200 years ago. However, theoretical models are generally more complex, require significant time periods of observation for calibration, require too many parameters and variables for measurement and extended time frames for model validation. These requirements therefore limit the usefulness of theoretical models in water quality modelling processes. Empirical models (statistically based models) on the other hand are helpful in establishing the relationship between time variable parameters (Chapman, 1992). They require comparatively lesser time frames and variables for calibration. They are very powerful tools in the explanation of cause-effect relationships between parameters and are still useful even when there is insufficient information.

Empirical models however are not directly transferable to other geographic locations or to different time scales (Chapman, 1992). This is because empirical models are based on data generated from surveys of specific sites. Water quality parameters are place and time variable and therefore not subject to universal laws (Berthouex and Brown, 2002). The knowledge of aquatic systems is yet to be fully understood; therefore empirical methods are more realistic in the effort to understand it (Chapman, 1992). The validation of a model describes the numeric means of measuring the accuracy of the model and/or comparing its performance. If, for instance, two models are being compared, the model with the least error estimate could be deemed as the better model in the circumstances. Error estimation methods include standard error (SE), normal mean error (NME), mean multiplicative error (MME) and correlation statistics (Jha *et al.,* 2005).

2.7.3.1 *Sum of Squares Due to Error.*

This statistic measures the total deviation of the response values from the fit to the response values. It is also called the summed square of residuals and is usually labelled as SSE. A value closer to 0 indicates a better fit (MATLAB, 2004).

$$SSE = \sum_1^n w_i(y_i - \hat{y}_i)^2 \quad (2.16)$$

2.7.3.2 *The R-Square*.

This statistic measures how successful the fit is in explaining the variation of the data. Put another way, R-square is the square of the correlation between the response values and the predicted response values (MATLAB, 2004). It is also called the square of the multiple correlation coefficient and the coefficient of multiple determination. R-square is defined as the ratio of the sum of squares of the regression (SSR) and the total sum of squares (SST). SSR is defined as

$$R^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{SST} \quad (2.17)$$

Where

$$SST = SSR + SSE \quad (2.18)$$

and

SSE is as defined in Equation 2.16.

$$SSR = \sum_1^n w_i(\hat{y}_i - \bar{y})^2 \quad (2.19)$$

And

$$SST = \sum_1^n w_i(y_i - \bar{y})^2 \quad (2.20)$$

R-square can take on any value between 0 and 1, with a value closer to 1 indicating a better fit. For example, an R^2 value of 0.8234 means that the fit explains 82.34% of the total variation in the data about the average. If the number of fitted coefficients in the model is increased, R-square might increase although the fit may not improve. To avoid this situation, the degrees of freedom adjusted R-square statistic described below should be used. Note that it is possible to get a negative R-square for equations that do not contain a constant term. If R-square is defined as the proportion of variance explained by the fit, and if the fit is actually worse than just fitting a horizontal line, then R-square is negative. In this case, R-square cannot be interpreted as the square of a correlation.

2.7.3.3 *Degrees of Freedom Adjusted R-Square.*

This statistic uses the R-square statistic defined above, and adjusts it based on the residual degrees of freedom (MATLAB, 2004). The residual degrees of freedom is defined as the

number of response values, n minus the number of fitted coefficients, m estimated from the response values.

$$v = n - m \tag{2.21}$$

where v indicates the number of independent pieces of information involving the n data points that are required to calculate the sum of squares. Note that if parameters are bounded and one or more of the estimates are at their bounds, then those estimates are regarded as fixed. The degrees of freedom are increased by the number of such parameters. The adjusted R-square statistic is generally the best indicator of the fit quality when you add additional coefficients to your model.

$$AdjustedR^2 = 1 - \frac{SSE(n-1)}{SST(v)} \tag{2.22}$$

The adjusted R-square statistic can take on any value less than or equal to 1, with a value closer to 1 indicating a better fit.

2.7.3.4 *Root Mean Squared Error (RMSE).*

The Root Mean Squared Error statistic is also known as the fit standard error and the standard error of the regression (MATLAB, 2004).

$$RMSE = s = \sqrt{MSE} \tag{2.23}$$

where MSE is the mean square error or the residual mean square

$$MSE = \frac{SSE}{v} \tag{2.24}$$

An RMSE value closer to 0 indicates a better fit.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials/Equipment

The river was navigated with the aid of a paddled boat. Three Assistants were employed. While, two Assistants concentrated on steering the boat, another Assistant helped in holding the other end of the measuring tape, one person carried the water samples from the river. Other materials that were used and the mode of use are presented below.

The following equipment were used for this research work:

i Hand held Garmin GPS Map 78s was used to determine the sampling point's distances.

ii An orange which was used to measure the flow velocity in a relatively uniform stretch of the River.

iii All glass wares were manufactured by Pyrex.

iv A stop watch: used to time the orange traveling from one measured point of the river to another

v BOD bottles

vi Conical flask

vii Dissolved Oxygen Meter by The Yellow Spring Instrument Model 57 was used to measure dissolved oxygen

viii pH meter (Jenway 3505, UK) with a pH range of 0 to 14 ± 0.001.

ix Tape rule: used to measure the length, surface width and depth of the river

x Sterile transfer pipettes (dropper pipettes)

xi Sterile test-tubes for serial dilution.

3.2 Reagents

All reagents used were of analytical grade and they are;

i. Ammonia-free water.

ii. Nessler's reagent.

iii. Rochell's salt solution.

iv. Mercury tetraoxosulphate (vi).

v. Sulphuric acid.

vi. Potassium chromate.

vii. Distilled water.

viii. Ferroin indicator.

ix. Hydrochloric acid.

x. Standard iodine solution.

xi. Potassium Iodide.

xii. Iodine.

xiii. Standard sodium thiosulphate solution.

xiv. Starch solution.

xv. Zinc sulphide.

xvi. Silver nitrate solution.

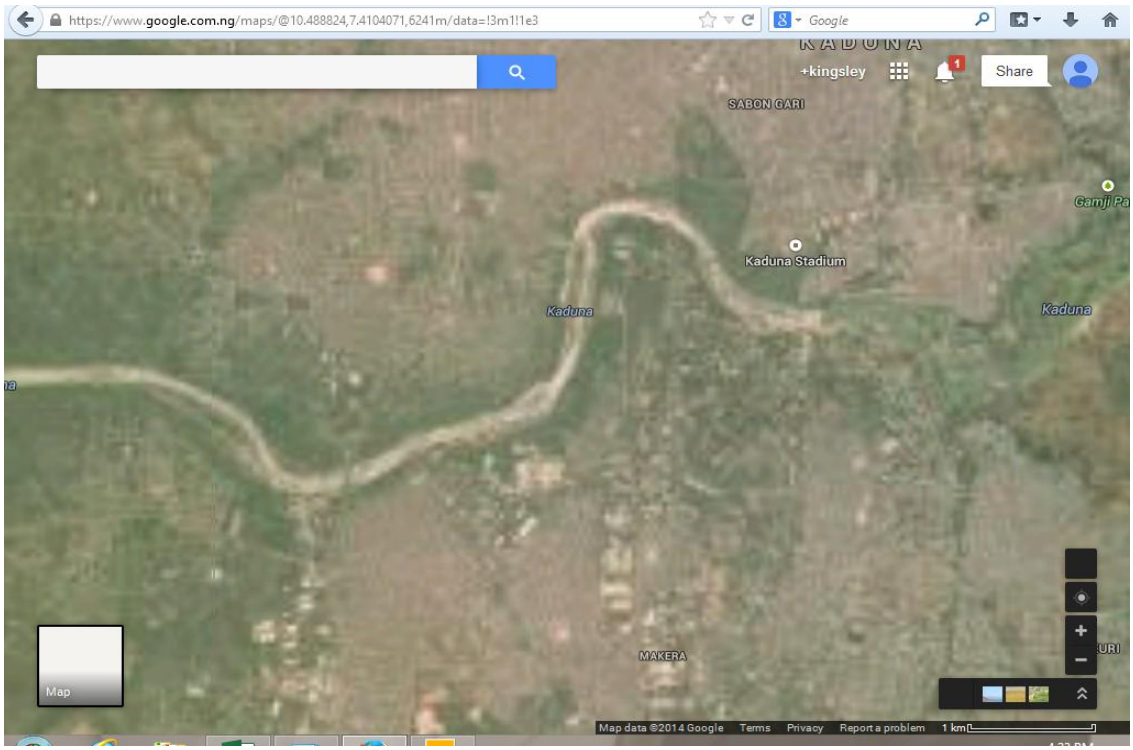


Plate 1a: Aerial and Satellite view of Kaduna from stadium to Kudenda Mountain showing River Kaduna.

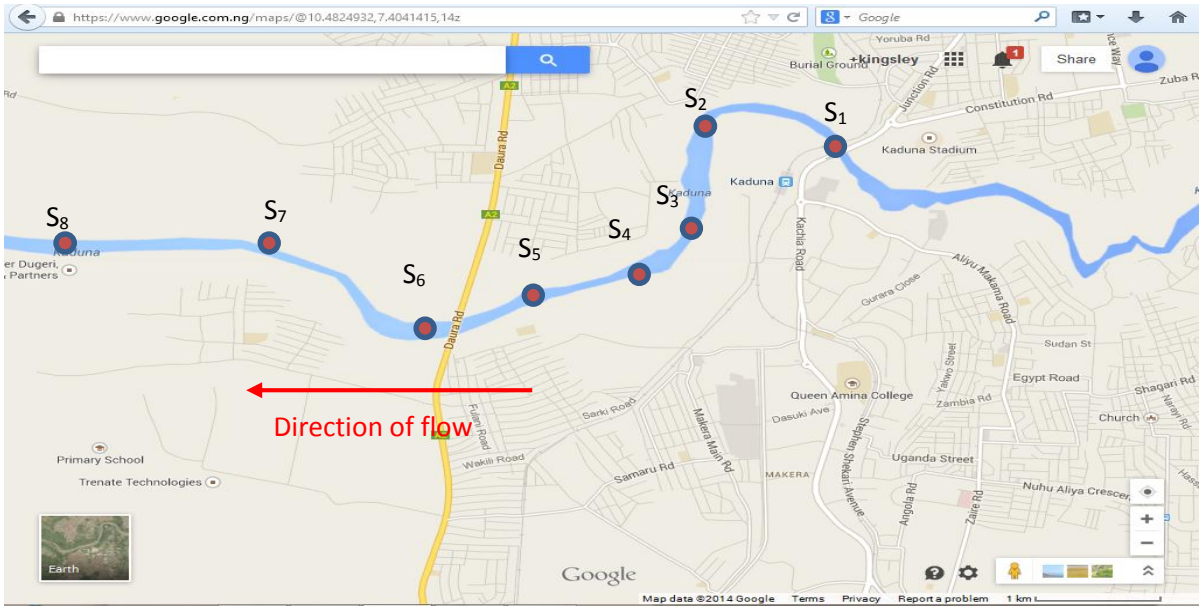


Plate 1b: Aerial and Satellite Photograph of Kaduna from Kachia Bridge to Kudenda Mountain showing the Sampling Points on River Kaduna

Table 3.1: Details of Sampling Stations

Sampling Stations	Station Description	Inter-station Distance (km)
S1	0.3km after Kachia road bridge	0.3
S2	Kaduna south water intake, station market Effluent discharge	2.6
S3	Just before Nigerian Breweries and Coca-Cola Water intake of which there are few domestic effluent Discharge points	3.4
S4	Nigerian breweries discharge point along which it carries several domestic discharge effluents	3.4
S5	Major Domestic effluent discharge point along which it carries waste from the Kakuri abattoir.	4.6
S6	Just after the Nnamdi Azikiwe Express bridge with few domestic discharge points	4.8
S7	Just after the IBBI major effluent discharge point	5.3
S8	Just after a sand quarrying point.	8.0

3.3 Methods

This section details the procedure carried out during the course of the study. Figure 3.1 presents the flow of the procedure

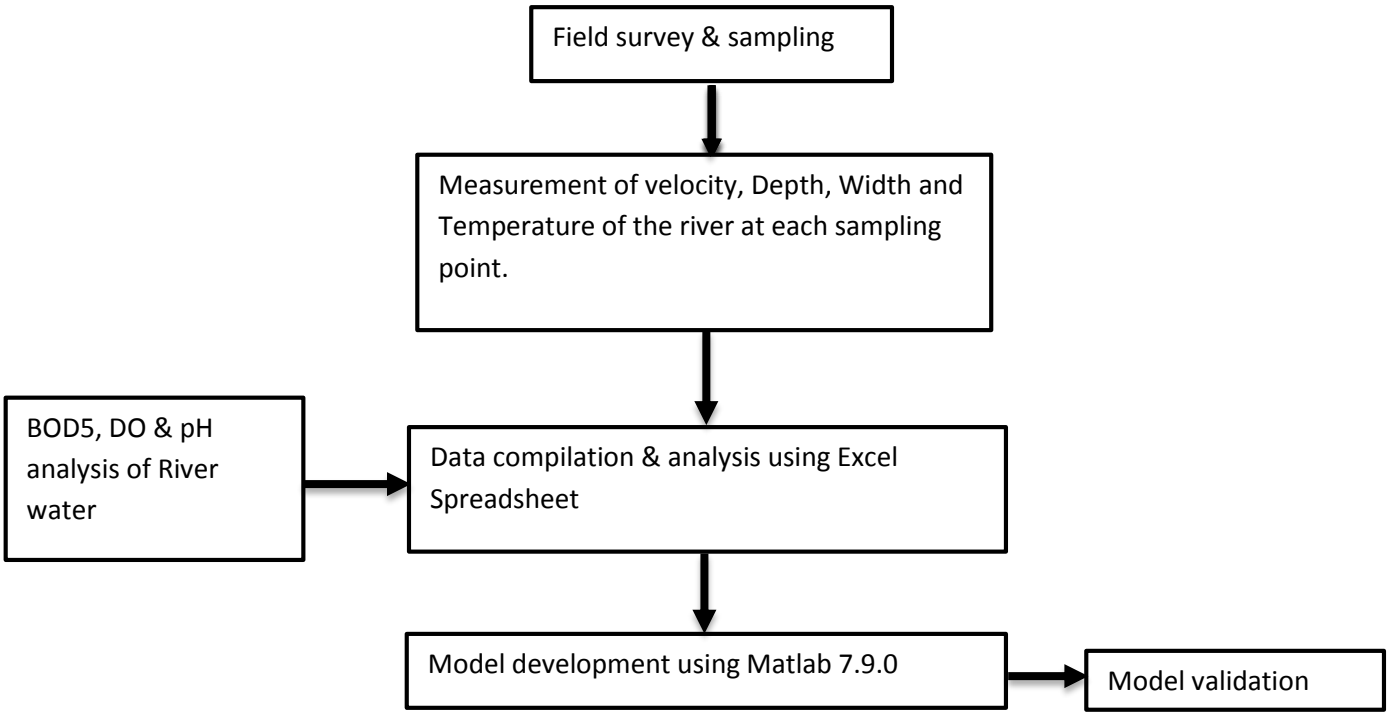


Figure 3.1: Sequence of activities for the work

3.3.1 Field Activities & Sampling Collection.

The field activities consisted of two distinct activities namely observation visits and the field sampling visits.

This exercise led to the familiarity with the people, determination of the sources of waste discharge into the river and the identification of the sampling points that was to be marked out for the research.

At this stage, repeated visits were made to collect data. Some of the parameters were determined in-situ while others were determined in the laboratory. The parameters determined in-situ were further sub-divided into two, namely: physical water quality parameters and hydraulic parameters. The physical parameter that was determined in-situ is temperature. The hydraulic parameters that were determined in-situ were stream velocity, river depth and width using the instruments mentioned in Table 3.1. Only three parameters, pH, DO and BOD, were determined in the laboratory. These were classified as chemical water quality parameters. In order to capture the climatic conditions of both the dry and rainy seasons, samplings were carried out in the following months:

i. Rainy season: June & July (2014).

ii. Dry Season: February, March, April and May (2014)

It is going to be extremely cumbersome or practically impossible to collect data from every part of the river along the selected segment. Although, taking samples every day of the selected months under study would capture the prevailing conditions better, but it will also mean that the cost of carrying out this research will be way off beyond my reach. Considering some related works (Agunwamba *et al*., 2007, Omole *et al*., 2010, Chiejine *et al*., 2014), samples were taken once a month in other to capture the prevailing conditions of their studied river. As an improvement on the related works, the samples were taken bi-monthly when carrying out this study.

On the sampling dates, the team assembled at the river side by 7:15am when the exercises was scheduled to start. At each sampling point on the selected segment, two assistants stretched the tape across the width of the river to determine the width and remained in position. The depth was measured using a rope with a metal tied at the tip of the rope at three different but equal intervals measured along the stretched out tape, e.g. ¼ distance ½ distance and ¾ distance. Also, velocity was obtained at the interval where depth measurements were obtained. The float method was used to determine the velocity across the selected segment and this was done with the aid of a 2-5 meter rope, an orange and a stop watch. Time taken by the float (orange) to go to a fixed distance was measured. (www.geography-site.co.uk/../vel.html, 2007). This is because it floats is round and so less likely to get caught up on things, not easily influenced by the ambient air and it is also cheap if one loses it. 2-5 meter of the river was measured using a rope, the orange was then dropped at the point of interest i.e. at ¼, ½ and ¾ across the sampling points and a stopwatch was then used to determine how long it took to go to the specified distance. This was repeated at least 3 times and average speed = Distance/time gave the unit in meters per second. The water bottles that were used were thoroughly washed and rinsed with the river water before taking the samples for pH, DO and BOD. These samples were collected carefully from the point where the mid-stream velocity is taken, tightly sealed and stored in a cooler containing iced blocks which was transported to the laboratory within 12 hours from the collection time. Finally, the ambient (air) and water temperature at that location was recorded using a mercury-in-glass thermometer. All recordings were done on paper and were later transferred to the excel spreadsheet on the laptop computer the next day.

3.3.3 DO and BOD_5 Determination

All laboratory analyses were carried out at the Public Health Engineering laboratory, Department of Water Resources & Environmental Engineering, A.B.U. Zaria. The DO of all

water samples were determined using titrimetric method (Azide modification) (APHA, 1992). The water samples meant for BOD_5 determination were stored in the Gallenkamp series cooled incubator for 5 days which was set at 20 degree Celsius constant temperature. On the 5th day, the samples were brought out of the incubator and the remaining DO measured again using titrimetric method. The difference between the initial DO and final DO was taken as the BOD value. All values that were obtained were transferred to excel spreadsheet for computation.

3.3.4 Data Analysis

An average of six months data were used to determine the model equation. Thus, the re-aeration coefficient model was obtained which represent the final output of this work.

Hydraulic data include depth, stream velocity and width. The river is assumed to have a semi-circular section, the hydraulic Radius was calculated using the formula:

$$\frac{\frac{1}{2}Area}{\frac{1}{2}Perimeter} = \frac{\frac{\pi d^2}{8}}{\frac{\pi d}{2}} = \frac{d}{4} = \frac{r}{2} \qquad (3.1)$$

Source: Omole *et al.,* (2007)

Where d = diameter of a circle (mean depth).

The mean velocity, v, refers to the average of the three different velocity measurements taken at each cross-section. This was also applied in determining the mean depth.

3.3.5 Hydraulic Radius

The hydraulic radius, whose relationship is defined by equation (3.1), was determined using the principles and assumptions described by Agunwamba *et al.,* (2001) below:

i. The stream channel is semi-circular in shape.

ii. There were no oxygen sinks in the system.

iii. The stream is uniformly mixed.

3.3.6 Ultimate BOD and De-oxygenation rate k_1

The ultimate BOD, Lo, was computed for each reach of the six model months. Its values were then inserted in the programmed excel sheet for the determination of k_1.

3.3.7 Saturation DO and the Upstream and Downstream DO deficits

At each sampling point, the temperature was used to read off the saturation DO (Table 2.2). These values were inserted in the programmed excel sheet. They were further used in the determination of the upstream and downstream DO deficits.

3.3.8 Time of travel

Phase one was the extraction of the time of travel, t, the coefficient of de-oxygenation, k_1 and the coefficient of re-aeration, k_2 values from the experimental data. This was computed with the Excel spreadsheet. The time of travel, *t*, was computed from velocity and distance travelled as follows:

$$Time\ (days) = \frac{Distance\ (km)}{velocity\ (km/hr)} \times \frac{1\ day}{24hrs} \quad (3.2)$$

The primary aim of the study was to evaluate the factors affecting the self-purification capacity of the said river and also developing an empirical expression for the reaeration constant that can be used together with a de-oxygenation coefficient. The de-oxygenation coefficient, k_1 (day^{-1}), was computed from the equation 3.2 (Appendix 3) (Weiner *et al*., 2003).

$$L = L_o 10^{-k_1 t} \quad (3.3)$$

Where L = instantaneous BOD, L_o = ultimate BOD and t = time in days. Therefore,

$$k_1 = \frac{1}{t}\log\frac{L_o}{L} \quad (3.4)$$

Experimental k_2 (day^{-1}) was determined using Equation (3.4) (Agunwamba *et al.,* 2007)

$$k_2 = \frac{(\log D_0 - \log D)}{t} \quad (3.5)$$

Which is also the same as

$$k_2 = \frac{\left(\log\frac{D_o}{D}\right)}{t} \quad (3.6)$$

where D_o is the initial DO deficit at point of pollution at the upstream and D is DO deficit at any point downstream of the point of pollution. When these two coefficients are known, then the self-purification capacity, *f*, of any stream can be derived by the equation $f = k_2/k_1$ which in turn be used in Equation 2.2 (the equation for predicting DO content along the river).

3.3.9 Re-aeration Coefficient Model

The modelling was undertaken with the aid of MATLAB statistics toolbox using a nonlinear regression and the model was statistically validated. Full residual analysis was carried out in both the MATLAB and Excel Spreadsheet. The equation with the best result was chosen based on the statistic indicator; coefficient of determination, R^2.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Tables 4.1a – 4.6b are the results of the hydraulic and physico-chemical data obtained in the process of carrying out this research.

Table 4.1a: Hydraulic Data for February, 2014.

Sampling points	Mean velocity (m/s)	Hydraulic radius (m)	Mean depth (m)	Volumetric flow rate (m^3/s)
S1	0.18	0.8133	1.6266	60.6
S2	0.1413	0.9150	1.8300	64.1
S3	0.1533	0.9583	1.9166	82.87
S4	0.2566	0.6500	1.300	0.71
S5	0.1386	0.3700	0.7400	9.63
S6	0.2333	0.5533	1.1066	3.6
S7	0.2033	0.4283	0.8566	45.6
S8	0.2733	0.6150	1.2300	97.5

Average mean velocity, depth and discharge for the month of February, 2014 were found to be respectively 0.1975m/s, 1.33m and 61.1m^3/s.

Table 4.1b: Physico-Chemical Parameters for February, 2014.

Sampling Points	Ambient Temperature (^OC)	Water Temperature (^OC)	BOD (mg/L)	DO (mg/L)	pH
S1	20	24	8	2.8	6.7
S2	20	24	11	6.8	6.8
S3	22	23	21	5.8	6.4
S4	21	23	23	6.8	6.8
S5	20	23	21	6.0	6.7
S6	18	22	19	5.3	6.7
S7	19	23	26	6.0	7.3
S8	24	22	20	5.5	6.5

Table 4.2a: Hydraulic Data for March, 2014.

Sampling Points	Mean Velocity (m/s)	Hydraulic Radius (m)	Mean Depth (m)	Volumetric flow rate (m^3/s)
S1	0.3900	0.7583	1.5166	91.8294
S2	0.3466	0.8600	1.7200	110.9056
S3	0.4766	0.9133	1.8266	245.5405
S4	0.3466	0.6333	1.2666	69.8152
S5	0.1100	0.3250	0.6500	10.3523
S6	0.2366	0.5266	1.0533	24.3056

S7	0.2733	0.4166	0.8333	44.7583
S8	0.3966	0.6700	1.3400	115.6217

Average mean velocity, depth and discharge for the month of March, 2014 are respectively 0.32m/s, 1.28m and 77.5m^3/s.

Table 4.2b: Physico-Chemical Parameters for March, 2014.

Sampling Points	**Ambient Temperature (^oC)**	**Water Temperature (^oC)**	**BOD_5 (mg/L)**	**DO (mg/L)**	**pH**
S_1	25	25	10	3.6	6.2
S_2	23	22	13	4.5	6.1
S_3	23	20	28	8.0	6.3
S_4	24	23	29	8.0	6.1
S_5	25	24	26	6.8	6.2
S_6	23	23	25	7.3	6.2
S_7	24	24	27	7.4	6.8
S_8	29	23	24	7.3	6.7

Table 4.3a: Hydraulic Data for April, 2014.

Sampling Points	**Mean Velocity (m/s)**	**Hydraulic Radius (m)**	**Mean Depth (m)**	**Volumetric flow rate (m^3/s)**
S1	0.0686	0.7433	1.4866	15.5423
S2	0.1193	0.8100	1.6200	34.2176
S3	0.1180	0.5916	1.1833	28.6946
S4	0.2466	0.6150	1.2300	45.7375
S5	0.1266	0.3133	0.6266	10.7160
S6	0.1733	0.500	1.000	15.0800

S7	0.2466	0.3933	0.7866	35.2191
S8	0.1566	0.6633	1.3266	42.7120

Average mean velocity, depth and discharge for the month of April, 2014 are respectively 0.157m/s, 1.16m and 40m^3/s.

Table 4.3b: Physico-Chemical Parameters for April, 2014.

Sampling Points	**Ambient Temperature (^OC)**	**Water Temperature (^OC)**	**BOD_5 (mg/L)**	**DO (mg/L)**	**pH**
S1	24	23	9.0	3.3	6.1
S2	22	22	12	3.5	6.0
S3	22	23	26	7.2	6.2
S4	22	24	24	8.0	6.1
S5	23	23	22	7.0	6.1
S6	23	24	23	5.8	6.2
S7	24	24	20	5.2	6.5
S8	26	25	22	6.5	6.6

Table 4.4a: Hydraulic Data for May, 2014.

Sampling Points	**Mean Velocity (m/s)**	**Hydraulic Radius (m)**	**Mean Depth (m)**	**Volumetric flow rate (m^3/s)**
S1	0.2366	0.8633	1.7266	62.5226
S2	0.2433	0.9100	1.8200	80.3803
S3	0.1420	0.6366	1.2733	37.1571
S4	0.3266	0.6400	1.2800	63.6608
S5	0.2200	0.5900	1.1800	35.4354
S6	0.1153	0.5716	1.1433	11.9666
S7	0.1196	0.4566	0.9133	19.0993
S8	0.1380	0.8133	1.6266	46.1306

Average mean velocity, depth and discharge for the month of May, 2014 are respectively 0.193m/s, 1.37m and 44.5m^3/s.

Table 4.4b: Physico-Chemical Parameters for May, 2014.

Sampling Points	Ambient Temperature (^OC)	Water Temperature (^OC)	BOD (mg/L)	DO (mg/L)	pH
S1	23	23	8.0	3.8	6.4
S2	23	22	7.0	4.0	6.3
S3	25	23	7.0	3.5	6.5
S4	26	25	6.0	3.8	6.3
S5	26	25	8.0	3.0	6.2
S6	25	24	9.0	3.5	6.4
S7	27	24	21	5.5	6.6
S8	26	23	13	5.0	6.6

Table 4.5a: Hydraulic Data for June, 2014.

Sampling Points	Mean Velocity (m/s)	Hydraulic Radius (m)	Mean Depth (m)	Volumetric flow rate (m^3/s)
S1	0.1866	1.8866	3.7733	111.4642
S2	0.3166	1.9783	3.9566	235.8667
S3	0.2566	1.6400	3.2800	178.0548
S4	0.2466	1.8066	3.6133	142.3834
S5	0.2800	1.6033	3.2066	126.5992
S6	0.2333	1.6050	3.2100	72.4657
S7	0.3333	1.1733	2.3466	140.8000
S8	0.3766	1.8733	3.7466	297.4197

Average mean velocity, depth and discharge for the month of June, 2014 are respectively 0.28m/s, 3.4m and 213.1m^3/s.

Table 4.5b: Physico-Chemical Parameters for June, 2014.

Sampling Points	Ambient Temperature (^oC)	Water Temperature (^oC)	BOD_5 (mg/L)	DO (mg/L)	pH
S1	24	19	7	3.5	6.6
S2	24	19	7	4	6.6
S3	25	19	6	3.5	6.5
S4	26	22	6	3.3	6.4
S5	26	23	8	4	6.8
S6	26	22	14	5	6.6
S7	26	24	21	5.7	6.7
S8	27	24	12	5.5	6.8

Table 4.6a: Hydraulic Data for July, 2014.

Sampling points	Mean Velocity (m/s)	Hydraulic Radius (m)	Mean Depth (m)	Volumetric flow rate (m^3/s)
S1	0.3300	2.1233	4.2466	227.0268
S2	0.2900	2.2733	4.5466	252.1695
S3	0.3566	1.8466	3.6933	283.5464
S4	0.3433	1.9100	3.8200	212.4684
S5	0.3400	1.8900	3.7800	184.1049
S6	0.3933	1.9083	3.8166	148.6210
S7	0.3933	1.4450	2.8900	208.02220
S8	0.3166	2.1400	4.2800	288.6860

Average mean velocity, depth and discharge for the month of July, 2014 are respectively 0.35m/s, 3.88m and 306.9m^3/s.

Table 4.6b: Physico-Chemical Parameters for July, 2014.

Sampling Point	Ambient Temperature (^{O}C)	Water Temperature (^{O}C)	BOD_5 (mg/L)	DO (mg/L)	pH
S1	23	20	40	3.2	6.5
S2	23	19	6.0	3.0	6.7
S3	24	19	8.0	3.8	6.7
S4	23	20	8.0	3.8	6.4
S5	22	20	9.0	4.0	6.3
S6	23	21	5.0	2.6	6.5
S7	24	22	17	5.7	6.2
S8	24	22	19	6.5	6.4

4.2 Monthly Variations in DO, Temperature, BOD, pH

For a dynamic system, the physical parameters of the river such as DO, temperature, BOD and pH changes with time.

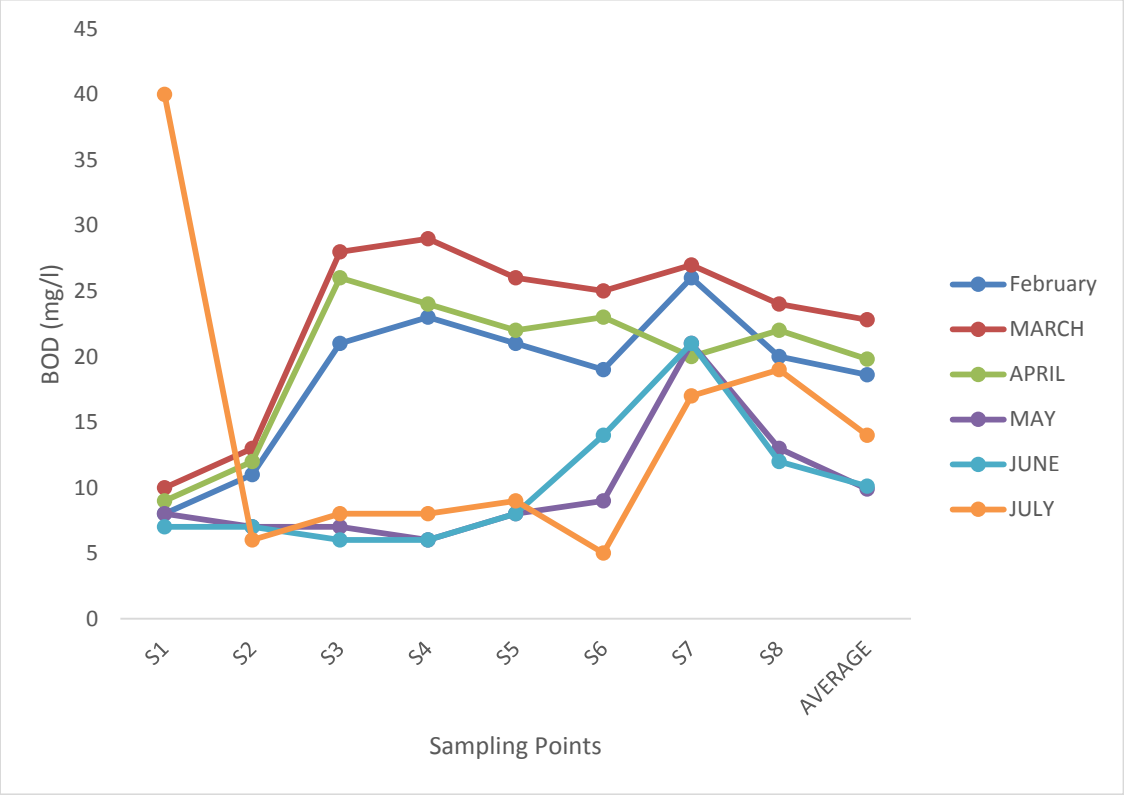


Figure 4.1a: BOD_5 Values at Each Sampling Point For The Months Of February, March, April, May, June & July.

Fig4.1a presents the variation of BOD between the sampling points for the consecutive months of interest. BOD directly affects the amount of dissolved oxygen in rivers. The greater the BOD, the more rapidly oxygen is depleted. This means less oxygen is available to aquatic organisms (microbes). This is because of aerobic microbial and biochemical degradation of organic matter present in the water. The consequences of high BOD are the same as those for low DO: many aquatic organisms become stressed, suffocate, and die. The overall mean BOD values is between 9.9mg/L and 22.8mg/L. It can be seen from the results in figure 4.1a that the assimilative capacity and the maximum allowable BOD are higher during the rainy season for the period and the segments studied. This conforms to reality consequent upon dilution factor. The rainy season supplies the river with fresh water thus increasing the river volume. The fresh water passed through the atmosphere dissolving atmospheric oxygen in the course of its descent. This makes the DO level to be farther away from the critical point due to the relatively sufficient DO in the river before the introduction of the wastewater. Chiejine *et al*., (2014) reported similar observations. This high dilution factor could also be the reason why at S1 in the month of July, there is a sharp drop in the BOD from 40mg/L down to about 5mg/L. The volume of the effluent discharged close to S1 is very low when compared with the width to depth ratio of the river body.

Furthermore, an earlier study by Igboanugo *et al*., (2013) analysed the relationship between the heavy metals and the other pollution determining parameters. It was discovered that heavy metals, namely Cadmium (Cd), Copper (Cu), Iron (Fe) and Lead (Pb) correlate negatively with pH and DO on the one hand but positively with BOD and COD. One possible interpretation of this correlation is that the presence of heavy metals tends to cause oxidation reaction that depletes dissolved oxygen (DO) in the river. Therefore the more the heavy-metal-bearing effluents are injected into the river, the more the oxygen consumed. As the loading abates, so do the oxygen consumed proportionately decrease.

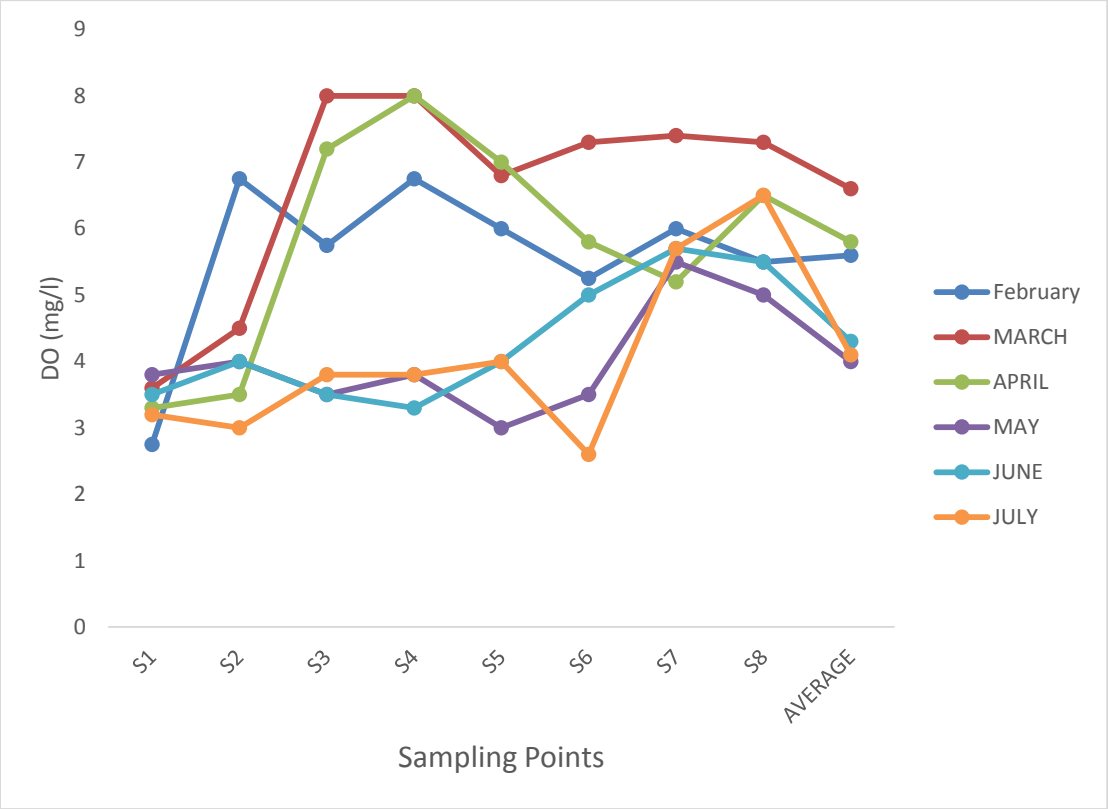


Figure 4.1b: DO at Each Sampling Point For The Months Of February, March, April, May, June & July.

Fig 4.1b presents the variation of DO between the sampling points for the consecutive months of interest. The lowest values of dissolved oxygen were found to be 2.5mg/L at S1 and 2.6mg/L at S6 in the month February and July respectively. From S1 in the month February, there is recovery in the DO oxygen content of the river. It rises until it reaches a value of about 6.8mg/L. The reason could be attributed to lower temperature at that period of the year which enhances or increases the capacity of the water to hold more oxygen thus increasing the amount of oxygen per liter of the river water. Also it was found that the volume of the effluent discharge from the point source around station market was very low and almost insignificant when compared to the volume of the river. What this translates to is that there is less nutrient for the organic microbes which means less oxygen will be consumed in that process. Since the oxygen consumed is less than the oxygen added via reaeration, there is thus an increase in the DO content of the water at that region. There is a decline in DO from point S2 to S3. This is attributed to very low velocity observed in that region which reduces the mixing capacity of the river thus lowering the rate at which oxygen is replenished or added to the river. Furthermore, the average DO oxygen in that studied month was found to be less than 5mg/L

which according to Rao et al., (2005), DFID, (1999) and WHO, indicates that the DO is lower than the available standard of 8-10 mg/L. This means that the aquatic animals are been stressed and that the river is slightly polluted at this month. Taking a closer look at the month of July, while rainfall may dilute and weaken the effects of point source pollution, it also increases the contribution of non-point sources or diffuse pollution through land runoff from and leaches from refuse dumps, which may account for the low dissolved oxygen observed at point S1-S6. There is sharp increase in DO value of the river from point S6-S7 which is as a result of reduction in the number non-point sources around this region and the subsequent increase in velocity which increases the distribution across the river. This is similar to what Chiejine *et al.,* (2014) observed.

Judging from the results in comparison with these standards, River Kaduna can be said to be not fit for direct human consumption without treatment. However, when considering the average mean dissolved oxygen across the eight sampling points and within the six months under study, it was found to be in the range 4.1mg/L to 6.6mg/L, thus ensuring that the river may pose a threat to the survival of the aquatic biota but at certain points, the aquatic biota may not be very stressed. (Omole *et al.,* 2010).

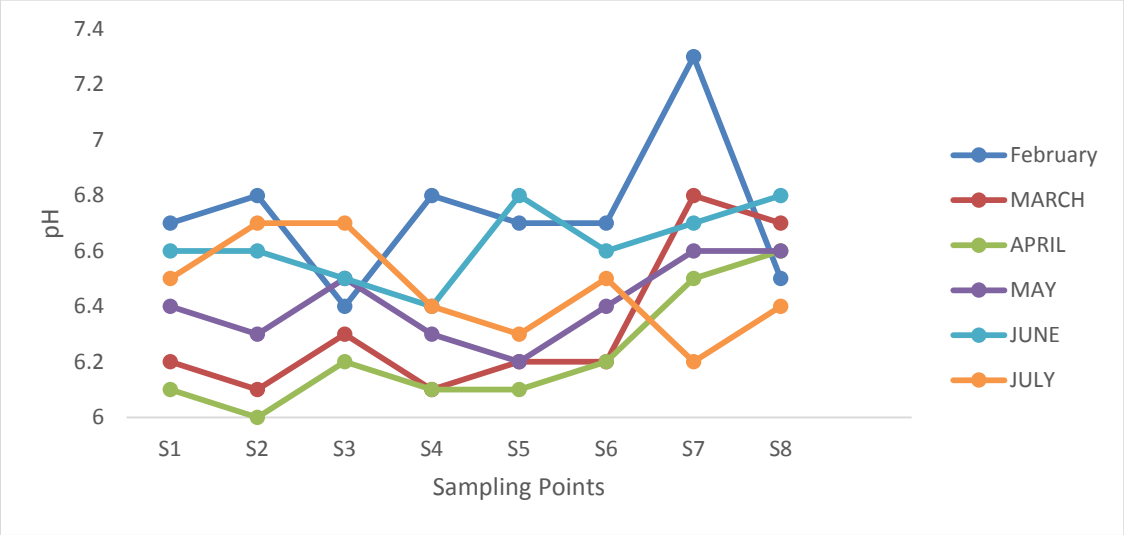


Figure 4.1c: pH Values at Each Sampling Point for the Months of February, March, April, May, June & July.

The pH values from this research are not significantly different and are within the accepted limits although, some values were found to be very slightly acidic (6.0). According to WHO (2011), there is no health-based guideline value for pH, although 6.5 – 8.5 is proposed for drinking water. The pH of River Kaduna might not pose any negative effects on the inhabitant biota because most aquatic animals prefer a pH range of 6.5 - 8.0 which is slightly acidic and slightly alkaline. For instance, Lawson (2011) reported that aquatic shrimps and crabs require optimum pH range of 6.8 - 8.7 for maximum growth and reproduction. The lowest mean value of pH was found to be in the month of July and this may be attributed to the amount of acid precipitation that falls in the watershed. Acid rain is caused by nitrogen oxides (NOx) and sulfur oxides (SOx) in the air combining with water vapor. These pollutants are primarily from automobile and coal-fired power plant emissions. Acid rain is responsible for many of our first order streams becoming acidic. A similar situation was noticed by Oguejiofor (1995) and Emeaso (2008).

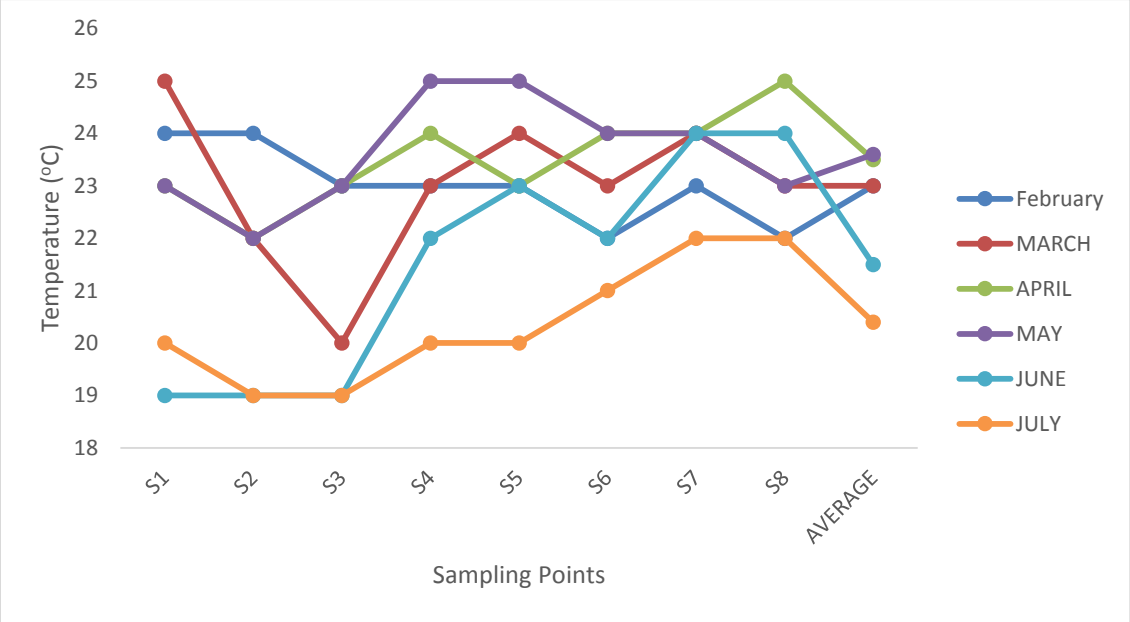


Figure 4.1d: Temperature Profile at Each Sampling Point For The Months Of February, March, April, May, June & July.

The mean water temperature obtained within the sampling period were found to be ranged 23.6°C to 20.4°C. This may not pose any danger to the aquatic organisms. Temperature of the water is probably the most important environmental variable since it affects metabolic activities, growth, feeding, reproduction, distribution and migratory behaviours of aquatic organisms Ikenna *et al.* (2008) made similar observation for River Romi in Kaduna.

Warmer temperatures decrease oxygen solubility in water while at the same time increasing metabolic rates that affect BOD decay, sediment oxygen demand, nitrification, photosynthesis, and respiration (Minnesota Pollution Control Agency 2005). This is because temperature influences enzymatic reactions through hormonal and nervous control to digestion, from respiration and osmoregulation to all aspects of an organism's performance and behaviours. High and low temperature that are lethal to individual organism of a specie determines the distribution and abundance of its population. The colder the water, the more oxygen it can hold. Therefore, DO concentrations at one location can vary as a result temperature variations. For instance, at the same sampling point in the month of June, the DO was found to be 5.5mg/L when the temperature was 24 ^{o}C and 6.5mg/L when the temperature dropped to 22 ^{o}C. This can be seen from the solubility data in Weiner et al., (2003), when the temperature is 24^{o}C, the DO is 8.4mg/L, but at a lower temperature of 22^{o}C, the DO increases to 8.7mg/L.

4.3 Determination of k_2

The computation of the independent variables as stated in equation (3.5) for the consecutive months starting from February through to July was carried out using the Excel Spread sheet and this can be seen in Appendix II. (Derick G. 1995).

The k_2 values were determined using equation (3.5) and are as presented in Tables 4.7a– 4.7f.

Table 4.7a: Modelling Parameters for the Month of February

Sampling Points	Hydraulic Radius (m)	Mean Velocity (m/s)	k_1 (per day)	k_2 (per day)	Self- purification factor $f=k_2/k_1$
S1	0.8133	0.1800	6.2956	37.7722	6.0
S2	0.9150	0.1413	0.5820	1.0097	1.7
S3	0.9583	0.1533	0.5175	1.7466	3.4
S4	0.6500	0.2566	0.8630	1.7108	2.0
S5	0.3700	0.1386	0.3480	1.0714	3.1
S6	0.5533	0.2333	0.6020	2.2401	3.7
S7	0.4283	0.2033	0.4417	1.3601	3.1
S8	0.6150	0.2733	0.4235	1.4801	3.5

Table 4.7b: Modelling Parameters for the Month of March

Sampling Points	Hydraulic Radius (m)	Mean Velocity (m/s)	k_1 (per day)	k_2 (per day)	Self- purification factor $f=k_2/k_1$
S1	0.7583	0.3900	12.6408	73.0549	5.8
S2	0.8600	0.3466	1.6459	7.0979	4.3
S3	0.9133	0.4766	1.9707	0.9452	0.5
S4	0.6333	0.3466	1.1655	0.3580	0.3
S5	0.3250	0.1100	0.2567	0.4180	1.6
S6	0.5266	0.2366	0.5693	0.4813	0.8
S7	0.4166	0.2733	0.5522	0.1823	0.3
S8	0.6700	0.3966	0.5730	0.4845	0.8

Table 4.7c: Modelling Parameters for the Month of April

Sampling Points	Hydraulic Radius (m)	Mean Velocity (m/s)	k_1 (per day)	k_2 (per day)	Self- purification factor $f=k_2/k_1$
S1	0.7433	0.0686	2.5790	13.8612	5.4
S2	0.8100	0.1193	0.5666	2.8069	5.0
S3	0.5916	0.1180	0.3982	0.4318	1.1
S4	0.6150	0.2466	0.7714	0.2547	0.3
S5	0.3133	0.1266	0.3178	0.4814	1.5
S6	0.500	0.1733	0.3879	1.2840	3.3
S7	0.3933	0.2466	0.4984	2.0085	4.0
S8	0.6633	0.1566	0.1953	0.4287	2.2

Table 4.7d: Modelling Parameters for the Month of May

Sampling Points	Hydraulic Radius (m)	Mean Velocity (m/s)	k_1 (per day)	k_2 (per day)	Self- purification factor $f=k_2/k_1$
S1	0.8633	0.2366	8.8888	44.9356	5.1
S2	0.9100	0.2433	1.1553	5.3726	4.7
S3	0.6366	0.1420	0.4792	2.5162	5.3
S4	0.6400	0.3266	0.9478	5.3237	5.6
S5	0.5900	0.2200	0.4764	2.9670	6.2
S6	0.5716	0.1153	0.2581	1.4210	5.5
S7	0.4566	0.1196	0.2418	0.8919	3.7
S8	0.8133	0.1380	0.1993	0.8229	4.1

Table 4.7e: Modelling Parameters for the Month of June

Sampling Points	Hydraulic Radius (m)	Mean Velocity (m/s)	k_1 (per day)	k_2 (per day)	Self- purification factor $f=k_2/k_1$
S1	1.8866	0.1866	9.0670	39.7180	4.4
S2	1.9783	0.3166	1.8302	7.5346	4.2
S3	1.6400	0.2566	1.1202	4.9071	4.4
S4	1.8066	0.2466	0.9074	4.5073	5.0
S5	1.6033	0.2800	0.7247	3.4554	4.8
S6	1.6050	0.2333	0.6141	2.3667	3.9
S7	1.1733	0.3333	0.7028	2.3177	3.3
S8	1.8733	0.3766	0.5281	1.8670	3.5

Table 4.7f: Modelling Parameters for the Month July

Sampling Points	Hydraulic Radius (m)	Mean Velocity (m/s)	k_1 (per day)	k_2 (per day)	Self- purification factor $f=k_2/k_1$
S1	2.1233	0.3300	15.1838	70.8985	4.7

S2	2.2733	0.2900	1.6756	7.6153	4.5
S3	1.8466	0.3566	1.5709	6.6130	4.2
S4	1.9100	0.3433	1.4141	6.2041	4.4
S5	1.8900	0.3400	1.0452	4.4796	4.3
S6	1.9083	0.3933	1.0858	5.6125	5.2
S7	1.4450	0.3933	0.9163	3.0250	3.3
S8	2.1400	0.3166	0.4905	1.1623	2.4

4.3.1 Average Stream Velocity

The average stream velocity is an important factor in both the reaeration constant and the time of travel along the stream. Examining Table 4.7a - 4.7f, we observed that as the velocity increases, the reaeration coefficient also increases, implying an increased rate of oxygen transfer from the atmosphere to the water. The velocity also affects the temporal distribution of the DO because an increase in velocity implies less time taken for the DO to spread. This transfer occurs at the air/water interface. The transfer of DO from the atmosphere to the surface of the water body is controlled by the transfer rate and the DO deficit. The transfer rate depends on the turbulence of water near the water surface, which is generally estimated from the water velocity, depth and other hydraulic parameters such as density and kinematic viscosity. The presence of rocks along the water course in this studied region enhances mixing. The velocity also affects the spatial distribution of the dissolved oxygen, because an increased velocity means it will take less time for the oxygen to spread. Thus, the combined effect of these two relationships results in a lower overall oxygen deficit due to the increased reaeration coefficient, with a more widespread effect of the dissolved oxygen deficit. Longe (2008) and Omole *et al*., (2011) reported similar observation in River Illo, Ota and River Atuwara Ogun State respectively.

4.3.2 Average Hydraulic Radius (Water Depth)

The reaeration term is inversely proportional to water depth. As the depth increases, the reaeration coefficient becomes smaller, and the volumetric amount of oxygen produced by the phytoplankton becomes smaller. This is because solar radiation is affected by the depth, in other words, as the depth increases, the amount of solar radiation that gets to the phytoplankton is reduced. Due to the effects of depth on the reaeration coefficient and

phytoplankton oxygen production, and the constant BOD concentration at each depth, we would expect that that the DO sag curve should drop lower with increasing depth due to the time it will take for oxygen at the top to diffuse to the bottom of the river. (Derick, (1995), Agunwamba et al., (2007)).

4.3.3 The fair Ratio (f)

The fair ratio f, which is the ratio of the re-aeration coefficient to the de-oxygenation coefficient is the indices used in determining the self-purification capacity for this study. Table 4.4a-4.4f shows the model parameters and the self- purification factors (fair ratio) for the months of February to July, 2014.

The average values of the fair ratio (f) in all the studied months was greater than unity which means that reaeration predominates de-aeration across the stretch of the river studied. Chiejine *et al*., (2014). The average fair ratio for the month of February was found to be 3.3 which was higher than the months of March and April with average f values of 1.8 and 2.8 respectively. The reason for these values could be as a result of less pollution activities in the month of February which is suggested by the lower BOD values generated in that month and also slight decrease in temperature occasioned by the harmattan weather when compared with the months of March and April, since the lower the temperature, the higher the river capacity to hold oxygen, leading to a corresponding increase in DO. The month of March seems to be the most polluted month since most of the f values in the sampling point calculated were less than unity which implies that the de-oxygenation rate was greater than the re-oxygenation rate as reported by Omole *et al*., (2013) and Chiejine *et al*., (2014)

The raining season provides the river with sufficient water for dilution Agunwamba *et al*. (2006). This makes the dissolved oxygen to be farther away from the critical point due to the availability of relatively sufficient DO in the river before the introduction of wastewater, thus making the fair ratio to be higher. Although, the fair ratio of June (4.16) was slightly higher than that of July (4.11). This could be as a result of increase in waste discharge by Nigerian Breweries Trikania, in the month of July at sampling point 6 and 7 which increased the deoxygenation rate and thereby subsequently affecting the fair ratio.

Generally, the average fair ratio (f) of the studied section of river Kaduna was found to be greater than unity which implies that, reaeration is greater than deoxygenation. The values, although considered to be still within limits of self-purification allowable for Nigeria, needs to be put in constant check to avoid deterioration especially in view of what was discharged at the sampling point 6 and 7 in the month of June and July.

4.4 Model Parameters

The experimental parameters that are needed for the model are re-aeration coefficient, k_2, velocity, u, in meters per second and Hydraulic Radius, H in meters. These values were sorted out for each month and taken to the MATLAB environment for simulations that produced the model of the form written in equation 4.3 (equation 3.5).

$$k_2 = a\frac{U^b}{H^c} \tag{4.3}$$

The model parameters a, b and c are the unknown values of the function that must be determined. Since b and c are in a non-linear position with respect to the defined relationships, a non-linear regression was done to determine the parameters. This gave rise to the simulated values presented in Tables 4.8

Table 4.8: Model Output for the various Months

S/N	MONTH	a	B	C	FIT TYPE
1	February	0.20	-0.62	0.16	5^{TH} Polynomial
2	March	0.55	-0.60	-0.17	6^{TH} Polynomial
3	April	0.40	2.52	0.27	4^{TH} Polynomial
4	May	0.10	-2.03	0.46	6^{TH} Polynomial
5	June	67.99	2.41	2.34	6^{TH} Polynomial
6	July	1.54	-1.54	-1.48	6^{TH} Polynomial

4.4.1 The Model

Following the model output, in Table 4.8, model validation was done based on the use of R^2 statistic parameter discussed in section 2.6.4. The model selected (equation 4.4) was based on the output with the best R^2 value. (Table 4.8).

$$K_2 = 67.99\frac{U^{2.41}}{H^{2.34}} \tag{4.4}$$

This model passed with a 6^{TH} polynomial fit to the response values with an R^2 value of 0.814 (Table 4.8).

Table 4.9: R-squared values of six (6) models when tested with experimentally generated River Kaduna data.

Months	k_2 River Kaduna	k_2 Agunwamba *et al.,*	k_2 Omole *et al.,*	k_2 Streeter & Phelps	k_2 Garg *et al.,*	k_2 Jha *et al.,*	k_2 Bach & Lee
February	0.8481	0.5482	0.5569	0.7444	0.6627	0.6978	0.8036
March	0.5142	0.5636	0.5402	0.9507	0.7834	0.2698	0.3319
April	0.8748	0.9118	0.912	0.6777	0.5301	0.9303	0.9299
May	0.515	0.8626	0.8709	0.3406	0.1798	0.8045	0.491
June	0.3956	0.7291	0.7286	0.4161	0.4085	0.6632	0.4430
July	0.6552	0.6202	0.6247	0.6759	0.6854	0.6772	0.6468

The order of performance of these models was based on their R-squared value. It was observed that no single model performed best throughout the months studied but there was rather variation in the order of their performances Omole *et al.* (2012). For instance, in the month of February, the k_2 (Kaduna) model performed best when compared with other models since it had the highest R-squared value of 0.8481. Similarly, the Streeter and Phelps model had the highest R-squared of 0.9507 which shows that the model was the best in predicting the March data. Also, Jha *et al.,* had the best R-square value (0.9303) in the month of April. Omole's model performed better in the month of May and June with their respective R-squared value being 0.8709 and 0.7286. The best performing model in the month of July was found to be Jha *et al*., which had an R-squared value 0.6854. Generally, Jha *et al*., and Omole *et al*., performed reasonably better for the months under study when considering their average performances. The generated Kaduna reaeration model relatively performed better in the month of January and also performed above 50% in all the studied months. Though some of this models were theoretical, others were empirically generated. The reason behind the

performance of other models being better than the Kaduna model could come from the fact that some of this models were developed by using re-analyses of multiple existing data.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the present study, the following conclusions are made:

i. The dissolve oxygen profile clearly indicates that there is self-purification going on in the segment studied.

ii. The minimum DO values for this segment were found to 2.5mg/L and 2.6mg/L which indicates that the aquatic life present are adversely affected when compared with the available standards of (4-5)mg/L..

iii. The pH values indicate slight acidity most especially during the raining season thus favouring the oxidation of heavy metals, thus reducing DO.

iv. An empirical expression has been developed for the re-aeration coefficient model based on the field data obtained from River Kaduna, Nigeria. The model was statistically validated and producing the expression $k_2 = 67.99 \frac{U^{2.41}}{H^{2.34}}$

v. The average fair ratio (f value) of the studied locations were found to be greater than unity which shows that reaeration predominates de-aeration.

vi. Based on its physical and chemical characteristics, River Kaduna is unsafe as portable water without treatment, for human consumption.

5.2 Recommendations

This section presents recommendation emanating from this research.

5.3.1: Recommendation for maintaining/improving water quality of River Kaduna.

i. The observed frequent fluctuations in DO deficit make the predictive capacity of k_2 model very difficult since the modified Streeter-Phelps equation was designed for exponential DO recovery shapes and not for sinusoidal curves.

ii. Boats fitted with a mobile laboratory should be acquired which will help to reduce fatigue and errors introduced through the time lapse between sampling and laboratory work.

iii. The cost of comprehensive water quality survey is enormous, thus, individuals, non-governmental and governmental agencies should be sensitized on the need for sponsorship.

iv. A more serious approach should be demonstrated by the Nigerian authorities (who are the primary custodians) to scientific monitoring, preservation and protection of our aquatic environment like some other countries have been doing. Considering the large dependency for domestic, economic, recreational, industrial and infrastructural purposes.

v. The citizenry should be sensitized on the dangers of using raw water from River Kaduna and other polluted rivers.

vi. The k_2 model as a function of pH should be studied to reduce the error generated in the study model

5.3.2: Recommendation for Future Research

i. A more systematic study to develop f values based on fundamental ideas in Chemical Engineering with a view to developing a dimensionless correlation.

ii. Comparative study of reaeration of stream bordered by vegetation.

iii A more comprehensive study where confirmatory data are obtained to strengthen assertions made in this study/other studies.

iv A comprehensive study of the effect of pH on the dissolved oxygen profile of a stream.

5.3 Contributions to Knowledge

1. The study has been able to gather data from a section of River Kaduna (Doka-Kudenda)

2. The study has developed a model that can be of use in the area of reaeration water quality modelling of River Kaduna in Nigeria.

3. The study has been able to evaluate the self-purification factors of the studied Segment in River Kaduna.

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APPENDIX 1

MATLAB CODE FOR OBTAINING THE REAERATION COEFFICIENT

FUNCTION FILE FOR THE RESEARCH MODEL

```
function NonLinearRegression

clear all
clc
% Model for Computing Reaeration coeficient
%kmod gives the predicted value of reaeration constant
%Hydraulic Radius (H) is (Stream depth/2)(m)
%U is the average stream velocity in m/s
% All negative values removed
%K2 value is per day i.e actual computation

% Data for the month February,2014.

data = [1.577172738 0.744727495 0.089731428
0.004229796 0.849755398 0.038578906
0.242194516 0.814363423 0.018483406
0.233221221 0.59063053  0.187086643
0.029988042 0.858027924 0.431798276
0.350281384 0.632023215 0.257013167
0.133577738 0.69179142  0.368218127
0.170291637 0.563307402 0.211124884
];

K2 = data(:,1);
U = data(:,2);
H = data(:,3);

% initial guess for XO is written below
X0 = [1.6255 0.3769 0.363]';
% X0 = [1 1 1]';
% Setting iteration limits
options = optimset('Display', 'iter', 'MaxIter',1e6, 'TolFun', 1e-16, 'TolX', 1e-16, 'MaxFunEval',1e6)
% Solving using Regression Analysis
X = lsqcurvefit(@ReaerationModel,X0,[U H],K2,[],[],options)

a = X(1); b = X(2); c = X(3);

K2mod = ReaerationModel(X,[U H])
% Plotting a graph of the experimental values against the predicted values
%Checking for the R-Square value

 plot(K2,K2mod,'o')

% Display Result
```

```
function K2 = ReaerationModel(par,xdata)

    a = par(1);
    b = par(2);
    c = par(3);

    U = xdata(:,1);
    H = xdata(:,2);

    K2 = a.*U.^b./H.^c;
end
end
```

APPENDIX I

MODEL OUTPUT FROM MATLAB

Model Output for February

Iteration	Func-count	f(x)	step	optimality	CG-iterations
0	4	87.2716		284	

1	8	1.95376	1.45577	1.2	0
2	12	1.82912	1.346	0.649	0
3	16	1.80205	0.718748	0.0847	0
4	20	1.80025	0.282205	0.0212	0
5	24	1.7999	0.155042	0.00753	0
6	28	1.79982	0.0875002	0.00436	0
7	32	1.7998	0.0515409	0.000961	0
8	36	1.79979	0.0311071	0.000593	0
9	40	1.79979	0.0193128	0.000207	0
10	44	1.79979	0.0122667	9.68e-005	0
11	48	1.79979	0.00793464	0.000163	0
12	52	1.79979	0.00520922	0.000116	0

X =

0.2000
-0.6178
0.1598

K2mod =

0.3528
0.3721
0.4297
0.3620
0.2515
0.3300
0.2947
0.3656

Model Output for March

Iteration	Func-count	f(x)	Norm of step	First-order optimality	CG-iterations
0	4	31.8574		85.5	
1	8	2.61442	1.07974	3.06	0
2	12	2.21442	0.644437	0.268	0
3	16	2.20556	0.210999	0.000464	0
4	20	2.20556	0.00485796	2.99e-005	0
5	24	2.20556	0.000392744	3.61e-006	0
6	28	2.20556	3.46442e-005	2.16e-006	0

7	32	2.20556	4.6769e-006	8.9e-007	0
8	36	2.20556	1.26624e-006	3.46e-007	0
9	40	2.20556	3.58708e-007	1.19e-007	0
10	44	2.20556	1.50324e-007	2.94e-008	0
11	48	2.20556	1.87958e-007	2.94e-008	0

X =

0.5454
-0.5986
-0.1661

K2mod =

0.6551
0.5520
0.6283
0.6635
0.4965
0.5839
0.6549
0.7042

Model Output for April

Iteration	Func-count	f(x)	Norm of step	First-order optimality	CG-iterations
0	4	41.5942		86.6	
1	8	0.456678	1.29911	0.903	0
2	12	0.332005	0.84858	0.0634	0
3	16	0.303239	0.579318	0.0197	0
4	20	0.29675	0.291955	0.00712	0
5	24	0.295441	0.135686	0.00307	0
6	28	0.29519	0.0603116	0.00132	0
7	32	0.295143	0.0262581	0.000563	0
8	36	0.295134	0.0113059	0.000241	0
9	40	0.295133	0.00484686	0.000103	0
10	44	0.295133	0.00207337	4.39e-005	0
11	48	0.295133	0.000886268	1.88e-005	0
12	52	0.295133	0.000378642	8.02e-006	0

X =

0.3991

2.5201
0.2667

K2mod =

1.0093
0.6176
0.4906
0.1724
0.3647
0.2763
0.1449
0.3660

Model Output for May

Iteration	Func-count	f(x)	Norm of step	First-order optimality	CG-iterations
0	4	52.9144		140	
1	8	3.47798	1.68694	9.28	0
2	12	3.47798	10	9.28	0
3	16	3.47798	2.5	9.28	0
4	20	1.28732	0.625	3.61	0
5	24	1.28732	1.17908	3.61	0
6	28	1.03558	0.294771	0.624	0
7	32	0.939582	0.589541	1.63	0
8	36	0.917196	0.494893	1.87	0
9	40	0.908197	0.15352	0.325	0
10	44	0.907707	0.056259	0.0119	0
11	48	0.907691	0.0169611	0.00225	0
12	52	0.90769	0.00509473	0.000185	0

X =

0.0957
-2.0261
0.4600

K2mod =

0.8771
1.1189
0.2830
0.8787
0.4407
0.2089
0.1852
0.3937

Model Output for June

Iteration	Func-count	f(x)	Norm of step	First-order optimality	CG-iterations
0	4	24.9624		58.3	
1	8	2.75591	0.648069	7.62	0
2	12	0.652358	1.10008	0.298	0
3	16	0.652358	2.07962	0.298	0
4	20	0.580748	0.519904	0.157	0
5	24	0.514721	1.03981	0.367	0
6	28	0.456991	1.03981	0.206	0
7	32	0.425899	2.07962	0.43	0
8	36	0.377923	2.07962	0.222	0
9	40	0.368354	4.15923	0.464	0
10	44	0.332533	1.03981	0.00454	0
11	48	0.323499	2.07962	0.0629	0

X =

67.9979
2.4074
-2.3422

K2mod =

1.5535
0.7400
0.5220
0.8502
0.3990
0.5535
0.0222
0.4107

MODEL OUTPUT FOR JULY

Iteration	Func-count	f(x)	Norm of step	First-order optimality	CG-iterations
0	4	12.7724		24.4	
1	8	1.94072	1.12375	1.77	0
2	12	1.60956	1.20438	0.0593	0
3	16	1.59854	0.540488	0.145	0
4	20	1.59492	0.144128	0.0127	0
5	24	1.59489	0.0175849	0.000117	0
6	28	1.59489	0.00221247	1.4e-005	0
7	32	1.59489	0.000296963	2.01e-006	0
8	36	1.59489	4.32552e-005	3.24e-007	0
9	40	1.59489	5.87612e-006	3e-008	0
10	44	1.59489	1.55184e-006	1.72e-008	0
11	48	1.59489	2.07397e-007	1.43e-008	0

X =

1.5369
-1.5392
-1.4751

K2mod =

0.9102
0.8731
0.7523
0.7698
0.7410
0.9472
0.4130
0.8737

APPENDIX II

A: Data Sheet for the Month of February

SAMPLING POINTS	V1 (m/s)	V2 (m/s)	V3 (m/s)	MEAN VELOCITY (m/s)	Average time (days)	D1 (m)	D2 (m)	D3 (m)	MEAN DEPTH (m)
S1	0.17	0.21	0.16	0.18	0.019910083	1.75	2.18	0.95	1.62666666
S2	0.112	0.19	0.122	0.141333333	0.215376048	0.59	1.45	3.45	1.83
S3	0.16	0.15	0.15	0.153333333	0.260416667	0.72	1.58	3.45	1.91666666
S4	0.26	0.3	0.21	0.256666667	0.156159812	0.86	1.62	1.42	1.3
S5	0.18	0.22	0.016	0.138666667	0.387286325	0.48	1.21	0.53	0.74
S6	0.21	0.28	0.21	0.233333333	0.240079365	0.88	1.52	0.92	1.10666666
S7	0.19	0.25	0.17	0.203333333	0.305100182	0.46	1.15	0.96	0.85666666
S8	0.24	0.32	0.26	0.273333333	0.341294038	1.22	1.55	0.92	1.23

B: Data Sheet for the Month of February

Hydraulic Radius (m)	RELATIVE DISTANCE	BOD (mg/l)	DO(mg/l)	DO (saturated) (mg/l)	Dissolved Oxygen Deficit (mg/l)	pH
0.813333333	0.31	8	2.75	8.4	5.65	6.7
0.915	2.63	11	6.75	8.4	1.65	6.8
0.958333333	3.45	21	5.75	8.6	2.85	6.4
0.65	3.463	23	6.75	8.6	1.85	6.8
0.37	4.64	21	6	8.6	2.6	6.7

0.553333333	4.84	19	5.25	8.7	3.45	6.7
0.428333333	5.36	26	6	8.6	2.6	7.3
0.615	8.06	20	5.5	8.7	3.2	6.5

C: Data Sheet for the Month of February

TEMP W	ki= (0.1*(1.047)^(T-20)	Lo= L/(1-10^(-ki*t)	Lo/L	log(Lo/L)	k1= 1/t*Log(Lo/L)	Log of DOD	k2= 1/t*((DoD) (per day)
24	0.120167417	10.6767021	1.334587762	0.125347138	6.295661102	0.752048448	37.7722397
24	0.120167417	14.68046538	1.334587762	0.125347138	0.581992005	0.217483944	1.00978704
23	0.114773082	28.64034174	1.363825797	0.134758901	0.51747418	0.45484486	1.74660426
23	0.114773082	31.36799333	1.363825797	0.134758901	0.862955064	0.267171728	1.71088658
23	0.114773082	28.64034174	1.363825797	0.134758901	0.347956776	0.414973348	1.07148980
22	0.1096209	26.50192988	1.394838415	0.1445239	0.601983846	0.537819095	2.24017209
23	0.114773082	35.45947072	1.363825797	0.134758901	0.441687383	0.414973348	1.3601216
22	0.1096209	27.8967683	1.394838415	0.1445239	0.423458612	0.505149978	1.48010197

D: Data Sheet for the Month of March

SAMPLING POINTS	V1 (m/s)	V2 (m/s)	V3 (m/s)	MEAN VELOCITY (m/s)	Average time (days)	D1 (m)	D2 (m)	D3 (m)	MEAN DEPTH (m)
S1	0.35	0.44	0.38	0.39	0.009199905	1.69	2.02	0.84	1.51666666
S2	0.3	0.38	0.36	0.346666667	0.087807158	0.52	1.41	3.23	1.72
S3	0.42	0.55	0.46	0.476666667	0.083770396	0.71	1.55	3.22	1.82666666
S4	0.33	0.4	0.31	0.346666667	0.115618323	0.84	1.58	1.38	1.26666666
S5	0.1	0.12	0.11	0.11	0.488215488	0.4	1.12	0.43	0.65
S6	0.21	0.28	0.22	0.236666667	0.236697966	0.82	1.48	0.86	1.05333333
S7	0.24	0.3	0.28	0.273333333	0.22696477	0.46	1.14	0.9	0.83333333
S8	0.37	0.44	0.38	0.396666667	0.235177404	1.24	1.58	1.2	1.34

E: Data Sheet for the Month of February

Hydraulic Radius (m)	RELATIVE DISTANCE	BOD (mg/l)	DO(mg/l)	DO (saturated) (mg/l)	Dissolved Oxygen Deficit (mg/l)	pH
0.758333333	0.31	10	3.6	8.3	4.7	6.2
0.86	2.63	13	4.5	8.7	4.2	6.1
0.913333333	3.45	28	8	9.1	1.2	6.3
0.633333333	3.463	29	8	8.6	1.1	6.1
0.325	4.64	26	6.8	8.4	1.6	6.2
0.526666667	4.84	25	7.3	8.6	1.3	6.2
0.416666667	5.36	27	7.4	8.4	1.1	6.8
0.67	8.06	24	7.3	8.6	1.3	6.7

F: Data Sheet for the Month of February

TEMP W	ki= (0.1*(1.047)^(T-20)	Lo= L/(1-10^(-ki*t)	Lo/L	log(Lo/L)	k1= 1/t*Log(Lo/L)	Log of DOD	k2= 1/t*((DoD) (per day)
25	0.125815286	13.07056165	1.307056165	0.11629425	12.6408098	0.672097858	73.0548691
22	0.1096209	18.13289939	1.394838415	0.1445239	1.645923894	0.62324929	7.09793260
20	0.1	40.94930828	1.462475296	0.165088539	1.970726485	0.079181246	0.94521751
23	0.114773082	39.55094811	1.363825797	0.134758901	1.165549697	0.041392685	0.35801146
24	0.120167417	34.69928182	1.334587762	0.125347138	0.256745518	0.204119983	0.41809403
23	0.114773082	34.09564493	1.363825797	0.134758901	0.569328514	0.113943352	0.48138712
24	0.120167417	36.03386958	1.334587762	0.125347138	0.552275749	0.041392685	0.18237493
23	0.114773082	32.73181913	1.363825797	0.134758901	0.57300956	0.113943352	0.48449957

G: Data Sheet for the Month of April

SAMPLING POINTS	V1 (m/s)	V2 (m/s)	V3 (m/s)	MEAN VELOCITY (m/s)	Average time (days)	D1 (m)	D2 (m)	D3 (m)	MEAN DEPTH (m)
S1	0.063	0.076	0.067	0.068666667	0.052251888	1.62	2	0.84	1.486666667
S2	0.111	0.128	0.119	0.119333333	0.255082247	0.5	1.36	3	1.62
S3	0.12	0.15	0.084	0.118	0.338394539	0.7	1.55	1.3	1.183333333
S4	0.24	0.26	0.24	0.246666667	0.162490616	0.8	1.54	1.35	1.23
S5	0.1	0.16	0.12	0.126666667	0.423976608	0.4	1.1	0.38	0.626666667
S6	0.18	0.18	0.16	0.173333333	0.323183761	0.78	1.4	0.82	1
S7	0.24	0.26	0.24	0.246666667	0.251501502	0.42	1.14	0.8	0.786666667

S8	0.15	0.18	0.14	0.156666667	0.595449173	1.22	1.56	1.2	1.326666667

H: Data Sheet for the Month of April

Hydraulic Radius (m)	RELATIVE DISTANCE	BOD (mg/l)	DO(mg/l)	DO (saturated) (mg/l)	Dissolved Oxygen Deficit (mg/l)	pH
0.743333333	0.31	9	3.3	8.6	5.3	6.1
0.81	2.63	12	3.5	8.7	5.2	6
0.591666667	3.45	26	7.2	8.6	1.4	6.2
0.615	3.463	24	8	8.4	1.1	6.1
0.313333333	4.64	22	7	8.6	1.6	6.1
0.5	4.84	23	5.8	8.4	2.6	6.2
0.393333333	5.36	20	5.2	8.4	3.2	6.5
0.663333333	8.06	22	6.5	8.3	1.8	6.6

I: Data Sheet for the Month of April

TEMP W	ki= (0.1*(1.047)^(T-20)	Lo= L/(1-10^(-ki*t)	Lo/L	log(Lo/L)	k1= 1/t*Log(Lo/L)	Log of DOD	k2= 1/t*((DoD (per day)
23	0.114773082	12.27443217	1.363825797	0.134758901	2.579024541	0.72427587	13.861238
22	0.1096209	16.73806098	1.394838415	0.1445239	0.566577648	0.716003344	2.8069509
23	0.114773082	35.45947072	1.363825797	0.134758901	0.39823013	0.146128036	0.4318274
24	0.120167417	32.03010629	1.334587762	0.125347138	0.771411553	0.041392685	0.2547389
23	0.114773082	30.00416754	1.363825797	0.134758901	0.317845132	0.204119983	0.4814416
24	0.120167417	30.69551853	1.334587762	0.125347138	0.38785098	0.414973348	1.2840167
24	0.120167417	26.69175525	1.334587762	0.125347138	0.498395188	0.505149978	2.0085366
25	0.125815286	28.75523562	1.307056165	0.11629425	0.195305082	0.255272505	0.4287057

J: Data Sheet for the Month of May

SAMPLING POINTS	V1 (m/s)	V2 (m/s)	V3 (m/s)	MEAN VELOCITY (m/s)	Average time (days)	D1 (m)	D2 (m)	D3 (m)	MEAN DEPTH (m)
S1	0.22	0.27	0.22	0.236666667	0.015160407	1.68	2.5	1	1.726666667
S2	0.2	0.28	0.25	0.243333333	0.125095129	0.54	1.42	3.5	1.82
S3	0.143	0.171	0.112	0.142	0.281201095	0.76	1.64	1.42	1.273333333
S4	0.33	0.35	0.3	0.326666667	0.122696995	0.88	1.58	1.38	1.28
S5	0.21	0.24	0.21	0.22	0.244107744	0.48	1.62	1.44	1.18
S6	0.102	0.131	0.113	0.115333333	0.485709698	0.83	1.6	1	1.143333333
S7	0.114	0.138	0.107	0.119666667	0.518415351	0.47	1.34	0.93	0.913333333
S8	0.134	0.142	0.138	0.138	0.675993022	1.53	1.77	1.58	1.626666667

K: Data Sheet for the Month of May

Hydraulic Radius (m)	RELATIVE DISTANCE	BOD (mg/l)	DO(mg/l)	DO (saturated) (mg/l)	Dissolved Oxygen Deficit (mg/l)	pH
0.863333333	0.31	8	3.8	8.6	4.8	6.4
0.91	2.63	7	4	8.7	4.7	6.3
0.636666667	3.45	7	3.5	8.6	5.1	6.5
0.64	3.463	6	3.8	8.3	4.5	6.3
0.59	4.64	8	3	8.3	5.3	6.2
0.571666667	4.84	9	3.5	8.4	4.9	6.4
0.456666667	5.36	21	5.5	8.4	2.9	6.6
0.813333333	8.06	13	5	8.6	3.6	6.6

L: Data Sheet for the Month of May

TEMP W	ki= (0.1*(1.047)^(T-20)	Lo= L/(1-10^(-ki*t)	Lo/L	log(Lo/L)	k1= 1/t*Log(Lo/L)	Log of DOD	k2= 1/t*((DoD (per day)
23	0.114773082	10.91060638	1.363825797	0.134758901	8.88887099	0.681241237	44.935551
22	0.1096209	9.763868904	1.394838415	0.1445239	1.155311964	0.672097858	5.372694
23	0.114773082	9.546780579	1.363825797	0.134758901	0.479226088	0.707570176	2.516242
25	0.125815286	7.842336987	1.307056165	0.11629425	0.947816605	0.653212514	5.323785
25	0.125815286	10.45644932	1.307056165	0.11629425	0.476405409	0.72427587	2.967033
24	0.120167417	12.01128986	1.334587762	0.125347138	0.258070075	0.69019608	1.421053
24	0.120167417	28.02634301	1.334587762	0.125347138	0.241789017	0.462397998	0.891945
23	0.114773082	17.72973536	1.363825797	0.134758901	0.199349544	0.556302501	0.822941

M: Data Sheet for the Month of June

SAMPLING POINTS	V1 (m/s)	V2 (m/s)	V3 (m/s)	MEAN VELOCITY (m/s)	Average time (days)	D1 (m)	D2 (m)	D3 (m)	MEAN DEPTH (m)
S1	0.19	0.21	0.16	0.186666667	0.01922123	3.46	4.6	3.26	3.773333333
S2	0.3	0.4	0.25	0.316666667	0.096125731	2.84	3.63	5.4	3.956666667
S3	0.24	0.29	0.24	0.256666667	0.155573593	2.84	3.52	3.48	3.28
S4	0.2	0.3	0.24	0.246666667	0.162490616	3.88	3.58	3.38	3.613333333
S5	0.25	0.3	0.29	0.28	0.191798942	2.46	3.68	3.48	3.206666667
S6	0.16	0.3	0.24	0.233333333	0.240079365	2.83	3.6	3.2	3.21
S7	0.3	0.4	0.3	0.333333333	0.186111111	2.48	2.36	2.2	2.346666667
S8	0.35	0.4	0.38	0.376666667	0.2476647	3.62	3.79	3.83	3.746666667

N: Data Sheet for the Month of June

Hydraulic Radius (m)	RELATIVE DISTANCE	BOD (mg/l)	DO(mg/l)	DO (saturated) (mg/l)	Dissolved Oxygen Deficit (mg/l)	pH
1.886666667	0.31	7	3.5	9.3	5.8	6.6
1.978333333	2.63	7	4	9.3	5.3	6.6
1.64	3.45	6	3.5	9.3	5.8	6.5
1.806666667	3.463	6	3.3	8.7	5.4	6.4
1.603333333	4.64	8	4	8.6	4.6	6.8
1.605	4.84	14	5	8.7	3.7	6.6
1.173333333	5.36	21	5.7	8.4	2.7	6.7
1.873333333	8.06	12	5.5	8.4	2.9	6.8

O: Data Sheet for the Month of June

TEMP W	ki= (0.1*(1.047)^(T-20)	Lo= L/(1-10^(-ki*t)	Lo/L	log(Lo/L)	k1= 1/t*Log(Lo/L)	Log of DOD	k2= 1/t*((DoD (per day)
19	0.096153846	10.45626877	1.493752681	0.174278698	9.066989804	0.763427994	39.717957
19	0.096153846	10.45626877	1.493752681	0.174278698	1.813028583	0.72427587	7.5346721
19	0.096153846	8.962516088	1.493752681	0.174278698	1.120233161	0.763427994	4.9071823
22	0.10816	8.425456113	1.404242685	0.14744217	0.907388835	0.73239376	4.5072988
23	0.1124864	11.01753617	1.377192022	0.138994498	0.724688556	0.662757832	3.4554822
22	0.10816	19.6593976	1.404242685	0.14744217	0.614139288	0.568201724	2.3667245
24	0.116985856	28.38061433	1.351457825	0.130802497	0.702819388	0.431363764	2.3177754
24	0.116985856	16.2174939	1.351457825	0.130802497	0.528143483	0.462397998	1.8670323

P: Data Sheet for the Month of July

SAMPLING POINTS	V1 (m/s)	V2 (m/s)	V3 (m/s)	MEAN VELOCITY (m/s)	Average time (days)	D1 (m)	D2 (m)	D3 (m)	MEAN DEPTH (m)
S1	0.33	0.4	0.26	0.33	0.010872615	3.88	5.2	3.66	4.246666667
S2	0.28	0.3	0.29	0.29	0.104964879	3.42	4.22	6	4.546666667
S3	0.33	0.4	0.34	0.356666667	0.111954829	3.43	4.21	3.44	3.693333333
S4	0.28	0.4	0.35	0.343333333	0.116740831	3.46	4.13	3.87	3.82
S5	0.34	0.4	0.28	0.34	0.15795207	3.05	4.21	4.08	3.78
S6	0.45	0.4	0.33	0.393333333	0.142419962	3.42	4.21	3.82	3.816666667
S7	0.45	0.4	0.33	0.393333333	0.157721281	3.01	2.96	2.7	2.89
S8	0.3	0.33	0.32	0.316666667	0.294590643	4.12	4.29	4.43	4.28

Q: Data Sheet for the Month of July

Hydraulic Radius (m)	RELATIVE DISTANCE	BOD (mg/l)	DO(mg/l)	DO (saturated) (mg/l)	Dissolved Oxygen Deficit (mg/l)	WIDTH(m)	pH
2.123333333	0.31	40	3.2	9.1	5.9	216	6.5
2.273333333	2.63	6	3	9.3	6.3	255	6.7
1.846666667	3.45	8	3.8	9.3	5.5	287	6.7
1.91	3.463	8	3.8	9.1	5.3	216	6.4
1.89	4.64	9	4	9.1	5.1	191	6.3
1.908333333	4.84	5	2.6	8.9	6.3	132	6.5
1.445	5.36	17	5.7	8.7	3	244	6.2
2.14	8.06	19	6.5	8.7	2.2	284	6.4

Q: Data Sheet for the Month of July

TEMP W	ki= (0.1*(1.047)^(T-20)	Lo= L/(1-10^(-ki*t)	Lo/L	log(Lo/L)	k1= 1/t*Log(Lo/L)	Log of DOD	k2= 1/t*((DoD (per day)
20	0.1	58.49901182	1.462475296	0.165088539	15.1838852	0.770852012	70.898492
19	0.095510984	8.995511015	1.499251836	0.175874589	1.675556543	0.799340549	7.615314
19	0.095510984	11.99401469	1.499251836	0.175874589	1.570942418	0.740362689	6.613048
20	0.1	11.69980236	1.462475296	0.165088539	1.414145657	0.72427587	6.204134
20	0.1	13.16227766	1.462475296	0.165088539	1.045181231	0.707570176	4.479651
21	0.1047	7.138483896	1.427696779	0.15463598	1.085774615	0.799340549	5.612559
22	0.1096209	23.71225305	1.394838415	0.1445239	0.916324665	0.477121255	3.025091
22	0.1096209	26.50192988	1.394838415	0.1445239	0.490592295	0.342422681	1.162367

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Surface water pollution is globally an environmental issue (Alam *et al*., 2007). Flowing surface water bodies have the natural capacities to purify themselves from the pollutions that come into them from external sources (Garg, 2006; Longe and Omole, 2008). The process of purification is achieved mainly through the absorption and dissolution of atmospheric oxygen from the water body surface. This absorbed and dissolved oxygen (DO) is required for the chemical process of breaking down biological and chemical pollutants (into benign products), thereby reducing their concentration and ultimately eliminating the pollution threat over a period of time and distance, (Alam *et al*., 2007). However, there are other natural factors that affect the auto purification capacity of water bodies. These include; the water body velocity, depth, volumetric flow rate and temperature (Agunwamba *et al*., 2007). Fast flowing water bodies are able to absorb atmospheric oxygen faster than slow moving water bodies. Similarly, turbulent water bodies are generally very clean because of the natural capacity to absorb and digest pollutants at a very high rate because of mixing. Stagnant water bodies on the other hand tend to become septic when there is high pollutant content because of the low rate of oxygen absorption. Furthermore, the depth of the water body also affects the rate of diffusion and mixing of the absorbed oxygen. Deeper water bodies require more time and bulk movement for the oxygen that was absorbed at the surface to mix evenly and reach the bottom of the channel.

Similarly, volumetric discharge flow rate which is defined as the product of velocity and cross-sectional area of the water body affects the auto purification of water bodies. Furthermore, the importance of temperature on the auto purification process of water bodies cannot be overemphasized. Fundamentally, from solubility perspective, DO is an inverse function of temperature. Therefore, water bodies situated in temperate regions have higher DO concentration than water bodies situated in tropical regions. At certain temperatures, water cannot absorb oxygen beyond a certain level.

Water quality modelling describes a situation whereby mathematical models are employed to explain, describe and predict the response of aquatic ecosystems to changes imposed on them either by anthropogenic activities or by other naturally induced conditions. Scores of empirical water quality models have been developed simply because no single model can be representative of all situations (Chapman, 1992; Garg 2006, Agunwamba *et al.,* 2007; Longe *et al.*, 2008; Omole, 2010). While some models are situation or problem specific, others are time specific and yet others are more general. Thus, modelling (development, verification and validation) is a problem solving exercise that is going to be around for a long time to come (Omole *et al.,* 2008).

Re-aeration coefficient modeling is an integral part of water quality modeling, which is a scientific tool employed to predict and monitor pollutant loads and nutrient constituents in fresh water bodies for effective resource planning and management (Longe and Omole, 2008). This field of study pioneered by Streeter and Phelps (1925) through their study on the recovery dynamics of River Ohio from pollution, has since become an interesting research area in water quality among scientists world over (Streeter and Phelps, 1925; Streeter *et al*., 1936; Villeneuve *et al*., 1998). The principles of Streeter and Phelps had been widely applied to water quality studies across the globe for examples: in England (Owens *et al*., 1964), Chile (Baecheler and Lazo, 1999) and India (Jha *et al*., 2001).
The Streeter-Phelps Dissolved Oxygen (DO) model is a very popular general model put forward in 1925 by the scientists after whom the model was named (Villeneuve *et al.*, 1998). The model has since been modified and metamorphosed many times into various forms and applications (Fair *et al.*, 1971; Longe and Omole, 2011).

1.3 Statement of the Research Problem

The increase in population and pollution sources would necessitate a more recent study of the factors affecting the regenerative capacity of River Kaduna, Nigeria after pollution loads.

1.3 Aim

Therefore, the aim of this study is to evaluate the factors affecting the self-purification capacity of River Kaduna, during the dry season (from February to May) and the beginning of the raining season (June & July). Also an empirical expression of the reaeration coefficient will be developed.

1.4 Objectives of the Study

The objectives of this study include:

v To map out a particular segment of River Kaduna where there is heavy discharge of pollutants from the industries.

vi To generate data (BOD, DO, Temperature, Velocity, Hydraulic Radius etc.) of the self-purification dynamics of a particular segment of interest on the river.

vii To determine reaeration constant (k_2) and develop an expression that will fit the sets of data for monitoring the self-purification of the river.

viii To generate self-purification values (f values) for the months and its consequences for this water body.

1.5 Justification

Kaduna is one of the few highly industrialized cities in Nigeria. Most of the industries in Kaduna are located in two industrial estates in Kaduna South which are the Kakuri and Kudenda Industrial estates. The outcome of this study will provide general guidance in the development of a water quality monitoring plan for this water body. The model will also be applied in future reaeration studies on River Kaduna and environs. Some of the achievements will include: the stretch of distance at which waste can be discharged into the river by the processing industries within its self-purification capacity and the period of the year at which this will be best.

1.6 Scope of Study

The study composed of three major aspects. The first aspect is the fieldwork, for the gathering of in-situ information on DO, the acquisition of raw water samples for BOD analysis as well as information on other hydrodynamic factors such as stream velocity and bathymetry. The second aspect of this research work was the laboratory analyses of the raw water samples for physical and chemical characterisation. Data recording and handling was carried out with the aid of Microsoft Excel while the modelling was done with the use of MATLAB software. The final aspect of this study was the development of a k_2 model for generation of f values based on the data collected.

1.7 Significance of the Study

The significance of this research work are as follows:

iii An expression for the re-aeration constant which reflects the existing local conditions of River Kaduna will be developed.

iv Future legislations, regulations and researches can take their cue from the research findings.

The research findings would be made available to all stakeholders. They include: The private citizens (so that they can be more alert to their responsibility of protecting their environment and guarding their health); The polluters (so that they can know that their activities have a direct impact on human lives and the environment); and the government (through their regulatory agencies, so that they can realize the impact of defaulters of pollution standards on people and the environment).

(iii) The result will suggest what can be done to improve the reaeration of River Kaduna

CHAPTER TWO

LITERATURE REVIEW

2.1 Background

The field of water quality modelling was found by the duo of Streeter and Phelps through their pioneering work published in 1925 (Villeneuve *et al.*, 1998; Streeter and Phelps, 1925). They proposed the idea of measuring and predicting the dissolved atmospheric oxygen (DO) and Biochemical Oxygen Demand (BOD) dynamics of a water body as a parameter for measuring the self-purification capacity of a water body. Their research was performed on the Ohio River and the source of pollution was municipal wastewater (Villeneuve *et al.*, 1998). Their predicted model was given as:

$$\frac{dD(t)}{dt} = k_1 L(t) - k_2 D(t) \quad (2.1)$$

Where $\frac{dD(t)}{dt}$ = the rate of change of the Dissolved Oxygen content (DO) of the river with time, k_1 = de-oxygenation rate, L(t) = BOD at the instantaneous time, t, k_2 = re-aeration rate and D(t) = dissolved oxygen at an instantaneous time, t (Kiely, 1998). The research work formed the basis of further studies which modified the initial equations in order to accommodate additional variables in nature (Villeneuve *et al.*, 1998). By integrating equation 2.1, the equation commonly used for the prediction of DO is obtained (Longe and Omole, 2008; Lin and Lee, 2007; Waite and Freeman, 1977 and Fair *et al.*, 1971).

$$D = \frac{L_a}{f-1} 10^{k_2 t} \left\{ 1 - 10^{[-(f-1)k_2 t]} \left[1 - (f-1) \frac{D_a}{L_a} \right] \right\} \quad (2.2)$$

where D = instantaneous DO, L_a = initial BOD, *f* is the self-purification factor (which varies for different types of surface water bodies), k_2 is as defined in equation (2.1), D_a = initial DO and t is the instantaneous time. The value of *f* is determined by dividing computed value of k_2 by the observed or tabulated value of k_1 (Garg, 2006). The range of *f* at 20^{o}C is given in Table 2.1. Based on the original work by Streeter and Phelps, some models and software have been developed.

Table 2.1: The self-purification factor, *f*, of different water bodies at 20 ^{o}C.

S/N	Description of water body	Range
1	Small ponds and backwaters	0.15-1.0

2	Sluggish streams, Large Lakes and impounding reservoirs.	1.0-1.5
3	Large stream of low velocity.	
4	Large streams of normal velocity.	1.5 - 2.0
5	Swift stream.	2.0 – 3.0
6	Rapids/ Water falls	3.0 – 5.0
		Over 5.0

Source: Garg, 2006.

2.2 Global Urban Rivers/Lakes and Usage

A river is a natural flowing watercourse, usually freshwater, flowing towards an ocean, sea, lake or another river. In some cases, a river flows into the ground and becomes dry at the end of its course without reaching another body of water. Small rivers can be referred to using names such as stream, creek, brook, rivulet, and rill. There are no official definitions for the generic term river as applied to geographic features, although in some countries or communities a stream is defined by its size. Many names for small rivers are specific to geographic location; examples are "run" in some parts of the United States, "burn" in Scotland and northeast England, and "beck" in northern England. Sometimes a river is defined as being larger than a creek, but not always: the language is vague.

Rivers are part of the hydrological cycle. Water generally collects in a river from precipitation through a drainage basin from surface runoff and other sources such as groundwater recharge, springs, and the release of stored water in natural ice and snow packs (e.g. from glaciers) Chu, (2012).

A river begins at a source (or more often several sources), follows a path called a course, and ends at a mouth or mouths. The water in a river is usually confined to a channel, made up of a stream bed between banks. In larger rivers there is often also a wider floodplain shaped by flood-waters over-topping the channel. Floodplains may be very wide in relation to the size of the river channel. This distinction between river channel and floodplain can be blurred, especially in urban areas where the floodplain of a river channel can become greatly developed by housing and industry.

Rivers can flow down mountains, through valleys (depressions) or along plains, and can create canyons or gorges.

The term upriver (or upstream) refers to the direction towards the source of the river, i.e. against the direction of flow. Likewise, the term downriver (or downstream) describes the direction towards the mouth of the river, in which the current flows.

The term left bank refers to the left bank in the direction of flow, right bank to the right.

The river channel typically contains a single stream of water, but some rivers flow as several interconnecting streams of water, producing a braided river. Extensive braided rivers are now found in only a few regions worldwide, such as the South Island of New Zealand. They also occur on peneplains and some of the larger river deltas. Anastamosing Rivers are similar to braided rivers and are also quite rare. They have multiple sinuous channels carrying large volumes of sediment. There are rare cases of river bifurcation in which a river divides and the resultant flows ending in different seas. An example is the bifurcation of Nerodime River in Kosovo. (Cave, 2015).

Rivers have been used as a source of water, for obtaining food, for transport, as a defensive measure, as a source of hydropower to drive machinery, for bathing, and as a means of disposing of waste.

Rivers have been used for navigation for thousands of years. The earliest evidence of navigation is found in the Indus Valley Civilization, which existed in northwestern India around 3300 BC. Riverine navigation provides a cheap means of transport, and is still used extensively on most major rivers of the world like the Amazon, the Ganges, the Nile, the Mississippi, and the Indus. Since river boats are often not regulated, they contribute a large amount to global greenhouse gas emissions, and to local cancer due to inhaling of particulates emitted by the transports. (Achim, 2003)

In some heavily forested regions such as Scandinavia and Canada, lumberjacks use the river to float felled trees downstream to lumber camps for further processing, saving much effort and cost by transporting the huge heavy logs by natural means.

Rivers have been a source of food since pre-history. They are often a rich source of fish and other edible aquatic life, and are a major source of fresh water, which can be used for drinking and irrigation. Most of the major cities of the world are situated on the banks of rivers. Rivers help to determine the urban form of cities and neighbourhoods and their corridors often present opportunities for urban renewal through the development of foreshore ways such as

river walks. Rivers also provide an easy means of disposing of waste water and, in much of the less developed world, other wastes

2.3 Nigerian Urban Rivers/Lakes and usage

The Kaduna River with coordinates 8^0 45' 00'N and 5^0 48' 00'E is a tributary of the Niger River which flows for 550 kilometers through Nigeria. It got its name from the crocodiles that lived in the river and surrounding area. Kaduna in the native dialect, Hausa, was the word for "crocodiles". (USGS, 2012)

It starts in Plateau State on the Jos Plateau 29 kilometers southwest of Jos town, flows through its namesake Kaduna State and through its capital Kaduna, and meets the Niger River in Niger State. Most of its course passes through open savanna woodland, but its lower section has cut several gorges above its entrance into the extensive Niger floodplains.

The importance of urban Rivers (Rivers Niger, Benue, Kaduna etc.) to Nigeria generally cannot be over emphasized. River Niger is the third longest river in Africa covering 2,600 miles (4, 180 km), while the River Benue is about 673 miles (1083 km) in length. These two rivers provides a major landmark in the landscape of Nigeria.

There is no economy without electricity. Nigeria uses Hydro Electric Power to generate its electricity and this requires substantial amount of water provided by the confluence of the two rivers (Niger and Benue). This confluence provided the needed volume and speed to power the turbines for the generation of electricity not only for Nigeria but other West African States.

In recent years when the government of President Obasanjo took the initiative to settle displaced white farmers from Zimbabwe, they all chose to stay and farm around the Rivers Niger and Benue. Most of them settled in Kwara State along the rivers. The farmers are erecting houses at Tsonga, some 110 kilometers north of Ilorin, the capital of Kwara State, where local villagers have welcomed and hailed them as saviors. These farmers are highly mechanized and the two rivers provide a ready source of water for their crops, livestock and for their own survival as well

2.4 Sources of Urban Rivers Pollution

Urban rivers are prone to pollution mainly due to their proximity to many pollution sources like wastewater discharge points, on-site sanitation systems for domestic institutional sources, industrial effluent discharge points, solid waste disposal sites and agricultural uses they can be grouped into natural, agricultural, industrial and urban sources. Natural pollution arises from storm wash, seepage ground water, swamp drainage and aquatic life of stream. Storm wash usually carries large quantities of organic matter from decaying flora and fauna and inorganic silt from soil erosion into streams. Seepage from ground water may contribute a variety of chemical components dissolved from the soil and geologic formations through which the seepage water passes to reach the water course. (Frank, 1996).

Water quality is often described in terms of a number of physico-chemical and biological parameters depending on the intended use of water. River water quality is described for instance by parameters such as Dissolved Oxygen (DO), pH, Temperature, Most Probable Number (MPN) of coliforms, and analyzed in field and laboratory for various physico-chemical characteristics as per the APHA standards. Kaduna River Pollution Study Project (Beecroft, 1987) has been considered for comparison of water quality of Romi River within the influence zone. Following the Koko toxic waste episode in Delta state, the Federal Government of Nigeria promulgated the Harmful Waste Decree 42 of 1988, which led to the establishment of the Federal Environmental Protection Agency (FEPA) through Decree 58 of 1988. In the wisdom of Government, FEPA and other relevant Departments in other Ministries were merged to form the Federal Ministry of Environment in 1999, but without an appropriate enabling law on enforcement issues. This situation, created a vacuum in the effective enforcement of environmental laws, standards and regulations in the country. To address this situation, the National Environmental Standards and Regulations Enforcement Agency (NESREA) were established as a parastatal of the Federal Ministry of Environment, Housing and Urban Development.

NESREA is charged with the responsibility of enforcing all environmental laws, guidelines, policies, standards and regulations in Nigeria. It also has the responsibility to enforce compliance with provisions of international agreements, protocols, conventions and treaties on the environment. The vision of the Agency is to ensure a cleaner and healthier environment for all Nigerians, while the mission is to inspire personal and collective responsibility in building an environmentally conscious society for the achievement of sustainable development in Nigeria.

The natural elements which causes water pollution are gases, soil, minerals, humus materials, waste created by animals and other living organisms present in water from sewage. During

raining season, surface water with soil, mud and humus enter into the river, tanks and other water bodies. The inorganic minerals like sodium, potassium, calcium, magnesium and heavy metals like iron, manganese, lead, mercury, chromium, cadmium, nickel, cobalt, beryllium copper, when present above the permissible limit are harmful.

2.6 **Wastewater Quality and indicators**

2.5.1 Biochemical Oxygen Demand

The BOD test measures the amount of oxygen consumed in breaking down organic matter using both aerobic biological and chemical degradation processes, giving an indication of the organic strength of a wastewater. The test has its widest application in measuring waste loadings of treatment plants and in evaluating the BOD-removal efficiency of such treatment systems. BOD is determined by incubating a water sample in a sealed container for a specified time and measuring the loss of oxygen that occurs between the beginning and end of the test. Samples must often be diluted prior to incubation (Jay L. *et al.,* 2005).

Biodegradable organic matter is a composite substrate and is difficult to quantify directly. The BOD test estimates the amount of dissolved oxygen used during the degradation of organic waste as a surrogate for measuring the waste itself. The amount of molecular oxygen measured during the incubation period can accrue from three sources:

iv The oxygen used for the biochemical degradation of organic material

v The oxygen used to oxidize inorganic materials such as sulfides and ferrous iron.

vi The oxygen used to oxidize reduced forms of nitrogen (nitrogenous demand), although a nitrifying inhibitor is often used to suppress the nitrogenous demand.

In a report prepared by the Royal Commission on Sewage Disposal in the United Kingdom at the beginning of the last century, it was recommended that a five-day,18.3°C, BOD_5 value be used as a reference in Great Britain. These values were selected because British rivers do not have a flow time to the open sea greater than five days and the average long-term summer temperatures do not exceed 18.3°C. The temperature has been rounded upward to 20°C, but the five-day time period has become the universal scientific and legal reference.

The BOD_5 test is still the most important and most widely used environmental index for monitoring organic pollutants in waters, mainly as proof of compliance with relevant legislation. Most developed countries strictly regulate the permissible BOD loadings of water as it is discharged from a treatment plant into receiving waters (e.g. sea or river), which is typically

required to be less than 20 mg/L. The BOD_5 value for potable water is close to zero; domestic wastewater effluent entering a treatment plant typically has a BOD_5 of around 300mg/L; and industrial effluents can have BOD_5 values greater than 20,000 mg/L.

2.5.2 Chemical oxygen demand (COD)

The COD test measures the chemical oxidation of wastewater by using a strong oxidizing agent under acid conditions. As for BOD, it measures the amount of oxygen required as a surrogate for measuring the organic waste component directly. The COD test does not differentiate between biologically active and inert organic matter and measures the total quantity of oxygen required to oxidize all organic matter into carbon-dioxide and water.

COD values are always greater than BOD values, but the results can be obtained within two hours and the presence of toxic compounds in the sample does not affect COD measurements. In many cases, the BOD/COD ratio is used to provide an indication of the biodegradability of the wastewater. However, the chemicals used, such as acid, chromium, silver, and mercury, produce liquid hazardous waste that requires careful handling and disposal.

2.5.2.1 *Oxygen generation and consumption*

Dissolved oxygen is the amount of oxygen dissolved in water, measured in milligrams per litre (mg/L). This component in water is critical to the survival of various aquatic lives in streams, such as fish. The ability of water to hold oxygen in solution is inversely proportional to the temperature of the water. Generally, the solubility of gas in water, falls with temperature (Chehalis River Council, 2008).

Biodegradable means that a substance can be converted into simpler compounds by bio-mediated reactions. The second law of thermodynamics predicts that oxidation of high energy level organics (relative to low energy level CO_2) is favoured. Oxygen is one of the strongest oxidizing agents found in natural aquatic systems. Oxidation reactions are thermodynamically favoured, but kinetically slow unless microbially mediated. The end products of complete aerobic biodegradation are CO_2 and H_2O (Ellis *et al.,* 1996).

2.5.3 Temperature

Aquatic organisms cannot survive outside of specific temperature ranges. Irrigation runoff and water cooling of power stations may elevate temperatures above the acceptable range for some species. Temperature may be measured with a calibrated thermometer.

2.5.4 Solids

Solid material in wastewater may be dissolved, suspended, or settleable. Total dissolved solids or TDS (sometimes called filterable residue) is measured as the mass of residue remaining when a measured volume of filtered water is evaporated. The mass of dried solids remaining on the filter after filtering the whole wastewater is called total suspended solids (TSS) or non-filterable residue. Settleable solids are measured as the visible volume accumulated at the bottom of an Inhofe cone after water has settled for one hour. Turbidity is a measure of the light scattering ability of suspended matter in the water. Salinity measures water density or conductivity changes caused by dissolved materials.

2.5.5 pH/Acidity/Alkalinity

pH is a measure of the amount of free hydrogen ions in water. Specifically, pH is the negative logarithm of the molar concentration of hydrogen ions. pH = -log[H+]

for example, at pH 2, $[H+] = 10^{-2}$ or .01 at pH 10 $[H+] = 10^{-10}$ or .0000000001 at pH 4 $[H+] = 10^{-4}$ or .0001

Because pH is measured on a logarithmic scale, an increase of one unit indicates an increase of ten times the amount of hydrogen ions. A pH of 7 is considered to be neutral. Acidity increases as pH values decrease below 7, and alkalinity increases as pH values increase above 7. Most natural waters are buffered by a carbon-dioxide-bicarbonate system, since the carbon dioxide in the atmosphere serves as a source of carbonic acid.

$H_2CO_3 \rightarrow HCO_3 + H^+$ pK ~ 7.5 (2.3a)

This reaction tends to keep pH of most waters around 7 - 7.5, unless large amounts of acid or base are added to the water. Most streams draining coniferous woodlands tend to be slightly acidic (6.8 to 6.5) due to organic acids produced by the decaying of organic matter. Natural waters in the Piedmont of Georgia also receive acidity from the soils. In waters with high algal concentrations, pH varies diurnally, reaching values as high as 10 during the day when algae are using carbon dioxide in photosynthesis. pH drops during the night when the algae respire and produce carbon dioxide.

The pH of water affects the solubility of many toxic and nutritive chemicals; therefore, the availability of these substances to aquatic organisms is affected. As acidity increases, most metals become more water soluble and more toxic. Toxicity of cyanides and sulfides also increases with a decrease in pH (increase in acidity). Ammonia, however, becomes more toxic with only a slight increase in pH.

Alkalinity is the capacity to neutralize acids, and the alkalinity of natural water is derived principally from the salts of weak acids. Hydroxide, carbonates, and bicarbonates are the dominant source of natural alkalinity. Reactions of carbon dioxide with calcium or magnesium carbonate in the soil creates considerable amounts of bicarbonates in the soil. Organic acids also form salts that increase alkalinity. Alkalinity itself has little public health significance, although highly alkaline waters are unpalatable and can cause gastrointestinal discomfort.

2.5.6 Oxygen

Most aquatic habitats are occupied by fish or other animals requiring certain minimum dissolved oxygen concentrations to survive. Dissolved oxygen concentrations may be measured directly in wastewater, but the amount of oxygen potentially required by other chemicals in the wastewater is termed an oxygen demand. Dissolved or suspended oxidizable organic material in wastewater will be used as a food source. Finely divided material is readily available to microorganisms whose populations will increase to digest the amount of food available. Digestion of this food requires oxygen, so the oxygen content of the water will ultimately be decreased by the amount required to digest the dissolved or suspended food. Oxygen concentrations may fall below the minimum required by aquatic animals if the rate of oxygen utilization exceeds replacement by atmospheric oxygen.

The reaction for biochemical oxidation may be written as:

Oxidizable material + bacteria + nutrient + $O_2 \rightarrow CO_2 + H_2O$ + oxidized inorganics such as NO_3 or SO_4 (2.3b)

Oxygen consumption by reducing chemicals such as sulfides and nitrites is typified as follows:

$$S^- + 2O_2 \rightarrow SO_4^- \quad (2.3c)$$

$$NO_2^- + {}^1/_2\, O_2 \rightarrow NO_3^- \quad (2.3d)$$

Since all natural waterways contain bacteria and nutrient, almost any waste compound introduced into such waterways will initiate biochemical reactions (such as shown above). Those biochemical reactions create what is measured in the laboratory as the biochemical oxygen demand (BOD).

Oxidizable chemicals (such as reducing chemicals) introduced into a natural water will similarly initiate chemical reactions (such as shown above). Those chemical reactions create what is measured in the laboratory as the chemical oxygen demand (COD).

Both the BOD and COD tests are a measure of the relative oxygen-depletion effect of a waste contaminant. Both have been widely adopted as a measure of pollution effect. The so-called 5-day BOD measures the amount of oxygen consumed by biochemical oxidation of waste contaminants in a 5-day period. The total amount of oxygen consumed when the biochemical reaction is allowed to proceed to completion is called the Ultimate BOD. The Ultimate BOD is too time consuming, so the 5-day BOD has almost universally been adopted as a measure of relative pollution effect.

There are also many different COD tests. Perhaps, the most common is the 4-hour COD. There is no generalized correlation between the 5-day BOD and the Ultimate BOD. Likewise, there is no generalized correlation between BOD and COD. It is possible to develop such correlations for a specific waste contaminant in a specific wastewater stream, but such correlations cannot be generalized for use with any other waste contaminants or wastewater streams.

2.6 Self Purification Assessment/Capacity of Global/Nigeria water bodies

It can be seen from the foregoing that the core issues of water quality model building are the coefficient of de-oxygenation and re-aeration. The coefficient of deoxygenation is a function of the concentration of waste discharged into the surface water body (the BOD loading). This is because the natural process of breakdown or digestion of wastes by surface water bodies requires oxygen and the inherent dissolved oxygen within the surface water body therefore naturally becomes the only source for this metabolic activity (Omole and Longe, 2008; Kilpatrick *et al.*, 1989). The coefficient of re-aeration (k_2), on the other hand, is a function of the rate at which the surface water traps and dissolves atmospheric oxygen. The DO in clean natural waters usually ranges between 7.6 mg/L - 14.6 mg/L for temperatures varying between 30^{o}C - 0^{o}C as shown in Table 2.2.

Table 2.2: Solubility data of Oxygen in water.

Temperature ℃	**Average Dissolved Oxygen (mg/l)**	**Temperature** ℃	**Average Dissolved Oxygen (mg/L)**
0	14.6	16	9.9
1	14.2	17	9.7
2	13.9	18	9.5
3	13.5	19	9.3
4	13.1	20	9.1
5	12.8	21	8.9

6	12.5	22	8.7
7	12.1	23	8.6
8	11.8	24	8.4
9	11.6	25	8.3
10	11.3	26	8.1
11	11.0	27	8.0
12	10.8	28	7.8
13	10.5	29	7.7
14	10.3	30	7.6
15	10.1		

Source; **(**Weiner and Matthews, 2003)

When the existing DO in the surface water body is utilized by the BOD loading, the result is that the DO level drops sharply and in extreme cases, the water becomes septic and begins to stink. The recovery of the surface water from this polluted state depends on the rate at which the surface water can trap and dissolve atmospheric oxygen (which is a mass transfer problem) (Omole and Longe, 2008; Kiely, 1998; Chapman, 1992).

Although, the pioneering research in this field of study was carried out in the United States, customized research that would meet the peculiarities of other countries has been undertaken by different scientists (Churchill *et al.,* 1962; Baecheler, 1999; Jha *et al.,* 2001; Park and Lee, 2002; Mehrdadi *et al.,* 2006; Agunwamba *et al.,* 2007; Lin and Lee, 2007; Al-Zboon and Al-Suhaili, 2009). The reason for such customized studies is predicated on climatic differences in different parts of the world. Temperature is one of the most important climatic factors that determine the rate at which atmospheric oxygen gets dissolved in water (Agunwamba *et al.*, 2007). The higher the temperature, the lower the DO concentration and rate of re-aeration (Agunwamba *et al.*, 2007). Other variables that affect re-aeration rate are stream velocity, river depth, width and friction of the river bed (Jha *et al,* 2005*;* Garg, 2006; Alam *et al.,* 2007). These other variables are usually similar all over the world but temperature varies widely in different parts of the world.

Equation 2.3a suggests a general expression for k_2 models

$$k_2 = c\frac{V^n}{H^m} \qquad (2.4a)$$

where

V = velocity of flow (m/s)

H = Hydraulic Radius (m)

where c, n and m are constants with specific values based on the characteristics of the river under study. For temperature conversions, Agunwamba (2007) introduced a temperature coefficient as in Equation (2.3b).

$$k_2 = \frac{a_1 U^{b_1} C}{R^{d_1}} \quad (2.4b)$$

Where a_1 = constant of flow, U = the velocity, C = Arrhenius constant (which is a conversion factor inserted in the American k_2 model to accommodate the variations in rate of re-aeration at varying temperatures) and R = hydraulic radius. A typical example is given in Equation (2.4).

$$k_2 = \frac{5.026u^{0.969}(1.024)^{T-20}}{R^{1.673}} \quad (2.5)$$

where T is different from 20 ℃.

Other k_2 models that have been used for computations are shown in Equations (2.6), (2.7), (2.8) and (2.9) (Garg, 2006).

$$k_R(20) = \frac{3.9\sqrt{V}}{y^{1.5}} \quad (2.6)$$

where k_R = coefficient of re-aeration at 20℃ = k_2, v = average stream velocity in m/s, y = average stream depth in m. The Arrhenius constant for converting to other temperatures was taken as:

$$k_R(T) = K_R(20)[1.016]^{T-20} \quad (2.7)$$

Other models of interest are the O'Connor and Dobbins (1958) and Wilcock (1988) model. O'Connor and Dobbins (1958) model is of the form:

$$k_2 = \frac{(D_o U)^{1/2}}{H^{3/2}} \quad (2.8)$$

where D_o = molecular diffusion coefficient for oxygen in water = 1.76 x 10^{-4} m^2/d at 20℃ to be multiplied by $1.037^{(T-20)}$ for other temperatures, U = water current velocity. H= river depth. O'Connor and Dobbins (1958) model is based on surface renewal of re-aeration. Wilcock (1988) model, is of the form:

$$k_2 = C_e \frac{\Delta L}{t_f} \quad (2.9)$$

Where:ΔL = change in surface elevation, L; t_f = travel time, T; and C_e = escape coefficient = 0.177 m^{-1} at 20 ℃. Wilcock (1988) model is based on energy dissipation.

These variations therefore indicate that much research is being done to update all that have been put forward by earlier researchers. It is also important to look at studies related to other nations.

2.6.1 The Indian k_2 model

The coefficient of re-aeration model developed in some water bodies in India is as follows (Jha *et al.,* 2001):

$$k_2 = \frac{5.792V^{0.5}}{H^{0.25}} \quad (2.10)$$

where *V* = stream flow velocity and *H* = hydraulic radius in meters. This model is devoid of the Arrhenius constant as in equation 2.4 and this is the essence of this work. The temperature changes, which would already have been taken into consideration at the point of sampling is already in-built into the models. Sampling therefore is necessary all year round in order to appreciate the effect of the temperature variation on the atmospheric DO dynamics and to have a model that is not prone to errors of conversion through the use of Arrhenius constant. The Indian model was not only derived from first principles but is already in use such that other recent works have been built on it (Jha *et al*., 2005; Jha *et al.,* 2007). The Indian team went about their research by acquiring 270 field data sets over a period of 12 months from River Kali. Eleven well known re-aeration prediction equations were tested. Mean stream velocity, bed slope, flow depth, friction factor and Froude number were factors also considered using data generated during field survey. The k_2 values computed from these predictive equations were compared with the k_2 values observed from field measurements (Jha *et al.,* 2001). The performance of the predictive equations were evaluated using error estimation, namely standard error (SE), normal mean error (NME), mean multiplicative error (MME) and correlation statistics. The authors observed that the equations developed by Smoot *et al.,* (1995) and by Cadwallader and McDonnell, (1969) showed comparatively better results among all the predictive models considered. Jha *et al.,* (2001) thereafter refined these better models and developed their own customized predictive equation using a least-square algorithm for the River Kali that minimizes error estimates and improves correlation between observed and computed re-aeration coefficients. This is the process that produced Equation (2.9) (Jha *et al.,* 2001).

A closer look at the Smoot *et al.* (1995) and Cadwallader and McDonnell (1969) models showed that their adopted process of predicting k_2 was based on the use of three regressors namely slope, velocity and hydraulic radius whereas the Jha *et al.*, (2001) model was based on two regressors namely velocity and hydraulic radius.

2.6.2 The Chilean k_2 model

Baecheler and Lazo (1999) also reported the results of modelling experiments carried out by them in Chile. They were of the opinion that no universal and clear criterion exists to decide

which formulation should be used to model water quality of any particular river, and that this has accounted for the variations in k_2 models the world over. They reported that most of the rivers in Chile are Mountain Rivers with great quantities of granular sediments, rocky beds filled with potholes that contain most of the pollutant loads as a result of the discharge of urban and industrial wastes into the rivers. These peculiarities therefore prompted them to carry out some experiments and they came up with two k_2 model equations. Equation (2.10) is used for slight slope rivers, Equation (2.11) is used on medium slope rivers.

$$k_2 = \frac{10.046U^{2.696}}{H^{3.902}} \quad (2.11)$$

and

$$k_2 = \frac{1.923U^{1.325}}{H^{2.006}} \quad (2.12)$$

where U is mean stream velocity and H = mean stream depth..

2.6.3 The Nigerian k_2 model

In Nigeria, scanty research has been done in this regard (Omole *et al*., 2012). For example, Agunwamba *et al.,* 2007 calculated k_2 for Amadi creek in Port Harcourt, Rivers State, Nigeria. In this very study, k_2 was estimated in Equation (2.13).

$$K_2 = \frac{11.6325U^{1.6954}}{R^{0.0016}} \quad (2.13)$$

Where: U = stream flow velocity (m/s) and R = hydraulic radius (m) of the stream.

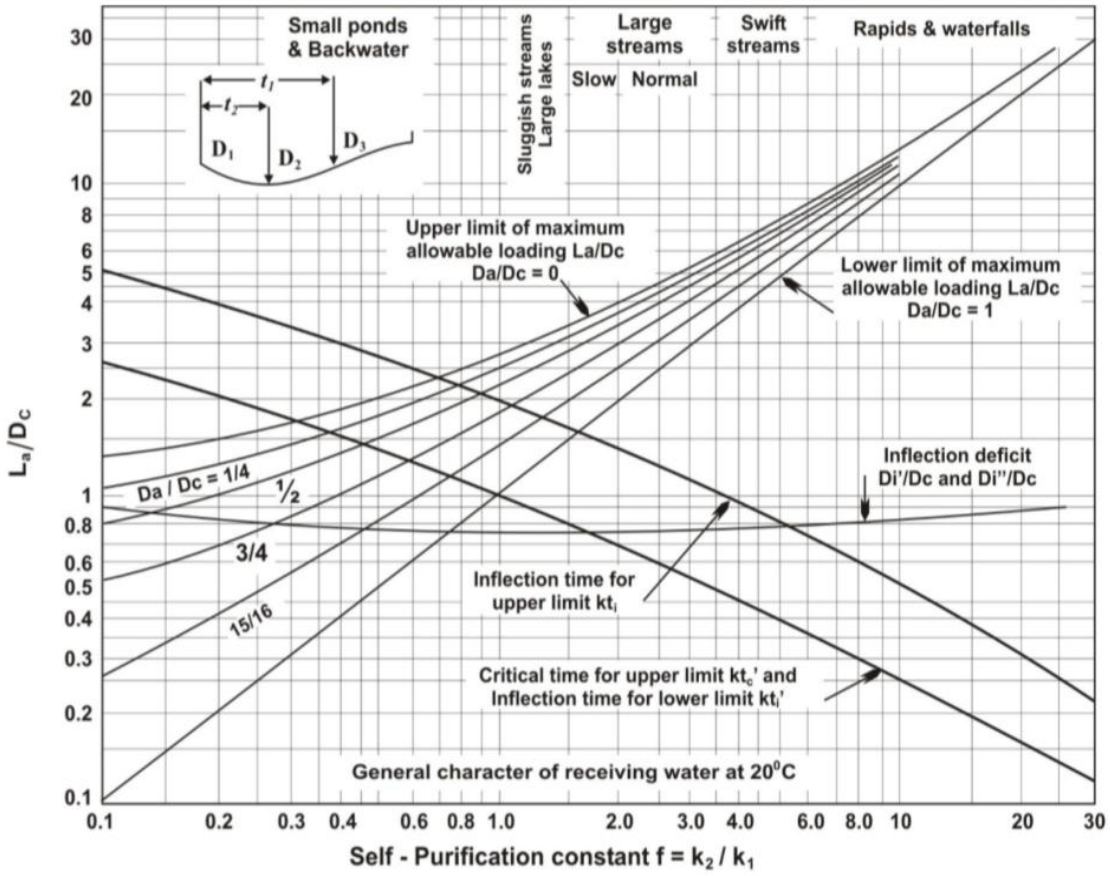


Figure 4: Monograph of the Self-purification Factor f (Fair et al, 1968).

The Figure above is the monograph of the self-purification factor f. The Equations on the monograph were sourced from Fair *et al.*, where $\boldsymbol{C_c}$, is the critical dissolved oxygen concentration (minimum acceptable). The initial dissolved oxygen deficit: Da (mg/L) is derived from subtracting C_a from C_s; where C_a is the initial dissolved oxygen concentration (prior to discharge point) and Cs is the DO saturation value. L_a is the maximum allowable concentration of BOD.

2.7 Statistical Data Analysis using Matlab, Excel, etc. as Tools towards generating useful Parameters.

When raw data is obtained from the field, it makes no meaning until some mathematical analyses are performed on them in order to obtain some information and interpretation. Data itself is varied in form. There are four different types of data namely: Nominal, Ordinal, Interval and Ratio data (Vowler, 2007 and Brower *et al.,* 1997). While Nominal and Ordinal data are categorical, interval and Ratio data are continuous.

2.7.1 Some Relevant Statistical Operations.

Five relevant statistical operations are discussed;

2.7.1.1Correlation

If the association between two continuous variables is of interest, then correlation should be used. For normally distributed data, Pearson's correlation coefficient, r, can be used. The coefficient of determination, R^2, is the proportion of variance explained by the association. When the data is not normally distributed, Spearman's rank correlation can be used. Kendall's tau can also be used if there are many ties (identical values) in the data (Vowler, 2007).

2.7.1.2 Regression analysis: - Regression analysis is used to predict a continuous dependent variable from a number of independent variables. Usually, it is used with naturally-occurring variables and sometimes with experimentally manipulated variables (Tabacknick and Fidell, 1989; U.S. Navy, 1999). The process of regression analysis include: Checking for the number of cases, checking the accuracy of data entry, looking for missing data, checking for outliers and checking for normality. Regression analysis also has an assumption of linearity (Kruskal and Tanur, 1978). Linearity means that there is a straight line relationship between the Independent Variables (IV) and the dependent variables (DV). This assumption is important because regression analysis only tests for a linear relationship between the IV and DV. Any nonlinear relationship between the IV and DV is ignored (Kruskal and Tanur, 1978). One can test for linearity between an IV and the DV by looking at a bivariate scatterplot (i.e., a graph with the IV on one axis and the DV on the other). If the two variables are linearly related, the scatter plot will be oval. The general form of a simple linear regression is given by (Draper and Smith, 1998):

$$y_i = \alpha + \beta x_i + \varepsilon_i \qquad (2.14)$$

Where; α is the intercept, β is the slope and ε is the error term which picks up the unpredictable part of the response variable, y_i. The *x*'s and the *y*'s are the data quantities from the sample or population in question, and α and β are the unknown parameters to be estimated from the data.

2.7.1.4 Multiple Regression Analysis

Standard multiple regression has the same idea as simple linear regression, except now one has several independent variables predicting the dependent variables. In addition to telling one the predictive value of the overall model, standard multiple regression shows how well each independent variable predicts the dependent variable, controlling for each of the other independent variables (Kotsiantis and Pintelas, 2005).

The significance levels given for each independent variable indicates whether the particular independent variable is a significant predictor of the dependent variable, over and above the other independent variables. Because of this, an independent variable that is a significant predictor of a dependent variable in simple linear regression may not be significant in multiple regression (i.e., when other independent variables are added into the equation). This could happen because the variance that the first independent variable shares with the dependent variable could overlap with the variance that is shared between the second independent variable and the dependent variable. Consequently, the first independent variable is no longer uniquely predictive and thus would not show up as being significant in the multiple regression. Because of this, it is possible to get a highly significant R^2, but have none of the independent variables being significant (Lindley, 1987).

2.7.1.4 *Least Square Method* (Schilling and Sandra, 2000)

When the number of samples is large or if the dependent variable contains measurement noise (variations in data value taken under similar conditions), it is often better to find a function f that approximates the data by minimizing an error criterion such as

$$E = \sum_{k=1}^{n} [f(x_k) - y_k]^2 \qquad (2.15)$$

A method that minimizes E is called least squares method. This approach is best when the representation of the underlying trend of data is the objective.

2.7.1.5. *Non-linear Regression*

In scientific applications there is usually relevant theory for constructing a mechanistic model. Often such models are nonlinear in the unknown parameters. Nonlinear models are more difficult to fit, requiring iterative methods that start with an initial guess of the unknown parameters. Each iteration alters the current guess until the algorithm converges (Dos Santos and Porta Nova, 2007; Berthouex and Brown, 2002).

2.7.2 Statistical Software

Some of the most commonly used statistical software is the Microsoft Excel, Stata, SAS, SPSS and MATLAB statistical toolbox (U.S. Navy, 1999; Nelson, 2002; SUAC, 2005). In addition to the basic spreadsheet functions, the Analysis ToolPak in Excel contains procedures such as ANOVA, correlations, descriptive statistics, histograms, percentiles, regression, and t-tests. The primary reason for using Excel for statistical data analysis is because it is so widely available. Statistical data analysis in Excel is however not recommended for analyzing datasets with a large sample size or a large number of variables, performing advanced

statistical analyses, or for projects in which a number of procedures need to be performed (Nelson, 2002; SUAC, 2005).

While Excel can do the regression procedure, it does not report standardized coefficients, important regression diagnostics or information about co-linearity. For this reason, it is recommended that users who are doing anything more than exploratory research use a statistical software package such as SPSS, SAS or MATLAB statistical toolbox for regression analysis (SUAC, 2005).

2.7.3 Model Calibration and Validation in Water Quality Data

Mathematical models can be classified as theoretical or empirical. Theoretical models are ideal for situations where all the underlying processes are well understood and are not time varied (Chatterjee and Hadi, 2006; Montgomerry and Runger, 2003; Chapman, 1992). An example of this are the equations of motion put forward by Sir Isaac Newton. The underlying processes are well understood and the models developed are as useful today as 200 years ago. However, theoretical models are generally more complex, require significant time periods of observation for calibration, require too many parameters and variables for measurement and extended time frames for model validation. These requirements therefore limit the usefulness of theoretical models in water quality modelling processes. Empirical models (statistically based models) on the other hand are helpful in establishing the relationship between time variable parameters (Chapman, 1992). They require comparatively lesser time frames and variables for calibration. They are very powerful tools in the explanation of cause-effect relationships between parameters and are still useful even when there is insufficient information.

Empirical models however are not directly transferable to other geographic locations or to different time scales (Chapman, 1992). This is because empirical models are based on data generated from surveys of specific sites. Water quality parameters are place and time variable and therefore not subject to universal laws (Berthouex and Brown, 2002). The knowledge of aquatic systems is yet to be fully understood; therefore empirical methods are more realistic in the effort to understand it (Chapman, 1992). The validation of a model describes the numeric means of measuring the accuracy of the model and/or comparing its performance. If, for instance, two models are being compared, the model with the least error estimate could be deemed as the better model in the circumstances. Error estimation methods include standard error (SE), normal mean error (NME), mean multiplicative error (MME) and correlation statistics (Jha *et al.,* 2005).

2.7.3.1 *Sum of Squares Due to Error.*

This statistic measures the total deviation of the response values from the fit to the response values. It is also called the summed square of residuals and is usually labelled as SSE. A value closer to 0 indicates a better fit (MATLAB, 2004).

$$SSE = \sum_1^n w_i(y_i - \hat{y}_i)^2 \quad (2.16)$$

2.7.3.2 *The R-Square*.

This statistic measures how successful the fit is in explaining the variation of the data. Put another way, R-square is the square of the correlation between the response values and the predicted response values (MATLAB, 2004). It is also called the square of the multiple correlation coefficient and the coefficient of multiple determination. R-square is defined as the ratio of the sum of squares of the regression (SSR) and the total sum of squares (SST). SSR is defined as

$$R^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{SST} \quad (2.17)$$

Where

$$SST = SSR + SSE \quad (2.18)$$

and

SSE is as defined in Equation 2.16.

$$SSR = \sum_1^n w_i(\hat{y}_i - \bar{y})^2 \quad (2.19)$$

And

$$SST = \sum_1^n w_i(y_i - \bar{y})^2 \quad (2.20)$$

R-square can take on any value between 0 and 1, with a value closer to 1 indicating a better fit. For example, an R^2 value of 0.8234 means that the fit explains 82.34% of the total variation in the data about the average. If the number of fitted coefficients in the model is increased, R-square might increase although the fit may not improve. To avoid this situation, the degrees of freedom adjusted R-square statistic described below should be used. Note that it is possible to get a negative R-square for equations that do not contain a constant term. If R-square is defined as the proportion of variance explained by the fit, and if the fit is actually worse than just fitting a horizontal line, then R-square is negative. In this case, R-square cannot be interpreted as the square of a correlation.

2.7.3.3 *Degrees of Freedom Adjusted R-Square.*

This statistic uses the R-square statistic defined above, and adjusts it based on the residual degrees of freedom (MATLAB, 2004). The residual degrees of freedom is defined as the

number of response values, n minus the number of fitted coefficients, m estimated from the response values.

$$v = n - m \tag{2.21}$$

where v indicates the number of independent pieces of information involving the n data points that are required to calculate the sum of squares. Note that if parameters are bounded and one or more of the estimates are at their bounds, then those estimates are regarded as fixed. The degrees of freedom are increased by the number of such parameters. The adjusted R-square statistic is generally the best indicator of the fit quality when you add additional coefficients to your model.

$$AdjustedR^2 = 1 - \frac{SSE(n-1)}{SST(v)} \tag{2.22}$$

The adjusted R-square statistic can take on any value less than or equal to 1, with a value closer to 1 indicating a better fit.

2.7.3.4 *Root Mean Squared Error (RMSE).*

The Root Mean Squared Error statistic is also known as the fit standard error and the standard error of the regression (MATLAB, 2004).

$$RMSE = s = \sqrt{MSE} \tag{2.23}$$

where MSE is the mean square error or the residual mean square

$$MSE = \frac{SSE}{v} \tag{2.24}$$

An RMSE value closer to 0 indicates a better fit.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials/Equipment

The river was navigated with the aid of a paddled boat. Three Assistants were employed. While, two Assistants concentrated on steering the boat, another Assistant helped in holding the other end of the measuring tape, one person carried the water samples from the river. Other materials that were used and the mode of use are presented below.

The following equipment were used for this research work:

i Hand held Garmin GPS Map 78s was used to determine the sampling point's distances.

ii An orange which was used to measure the flow velocity in a relatively uniform stretch of the River.

iii All glass wares were manufactured by Pyrex.

iv A stop watch: used to time the orange traveling from one measured point of the river to another

v BOD bottles

vi Conical flask

vii Dissolved Oxygen Meter by The Yellow Spring Instrument Model 57 was used to measure dissolved oxygen

viii pH meter (Jenway 3505, UK) with a pH range of 0 to 14 ± 0.001.

ix Tape rule: used to measure the length, surface width and depth of the river

x Sterile transfer pipettes (dropper pipettes)

xi Sterile test-tubes for serial dilution.

3.2 Reagents

All reagents used were of analytical grade and they are;

xvii. Ammonia-free water.

xviii. Nessler's reagent.

xix. Rochell's salt solution.

xx. Mercury tetraoxosulphate (vi).

xxi. Sulphuric acid.

xxii. Potassium chromate.

xxiii. Distilled water.

xxiv. Ferroin indicator.

xxv. Hydrochloric acid.

xxvi. Standard iodine solution.

xxvii. Potassium Iodide.

xxviii. Iodine.

xxix. Standard sodium thiosulphate solution.

xxx. Starch solution.

xxxi. Zinc sulphide.

xxxii. Silver nitrate solution.

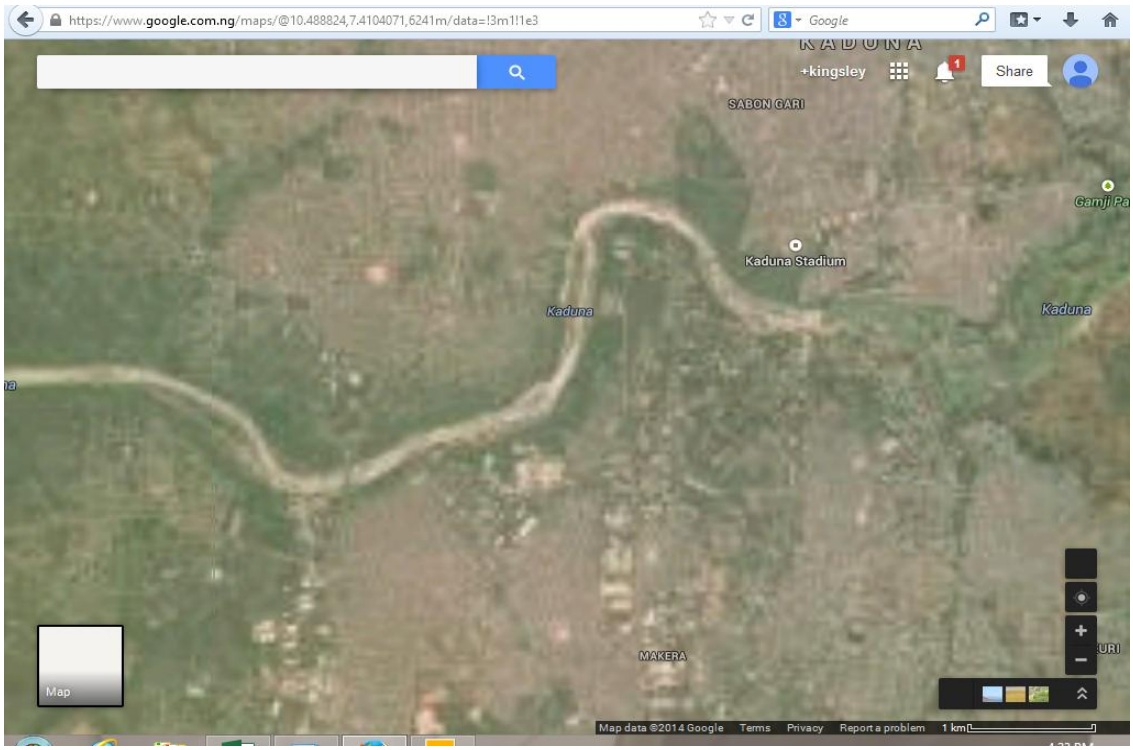


Plate 1a: Aerial and Satellite view of Kaduna from stadium to Kudenda Mountain showing River Kaduna.

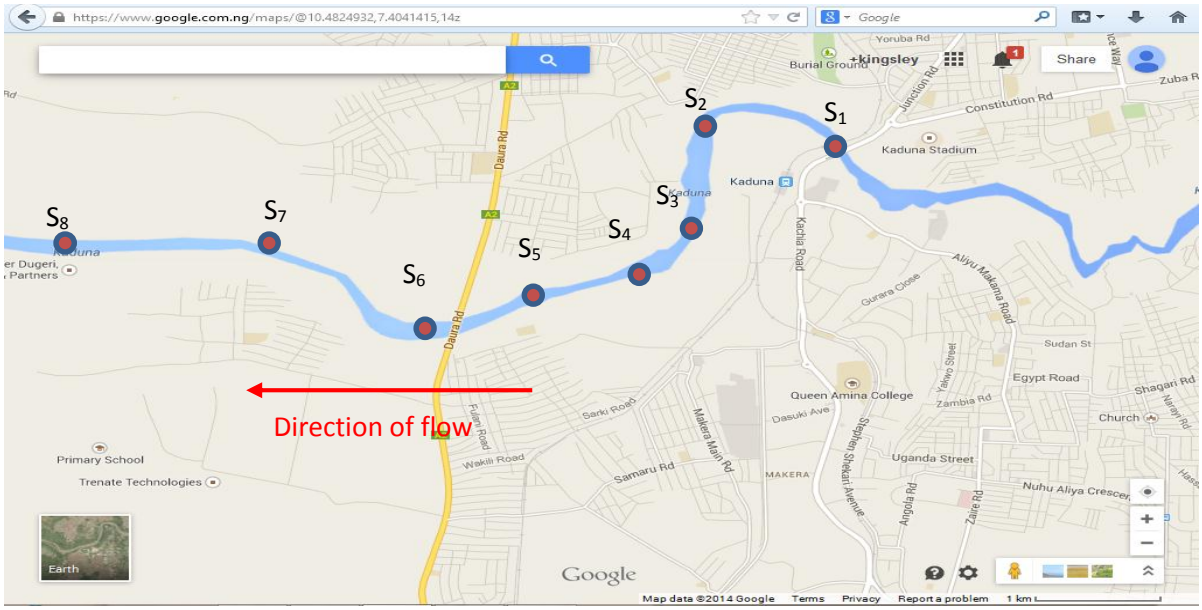


Plate 1b: Aerial and Satellite Photograph of Kaduna from Kachia Bridge to Kudenda Mountain showing the Sampling Points on River Kaduna

Table 3.1: Details of Sampling Stations

Sampling Stations	Station Description	Inter-station Distance (km)
S1	0.3km after Kachia road bridge	0.3
S2	Kaduna south water intake, station market Effluent discharge	2.6
S3	Just before Nigerian Breweries and Coca-Cola Water intake of which there are few domestic effluent Discharge points	3.4
S4	Nigerian breweries discharge point along which it carries several domestic discharge effluents	3.4
S5	Major Domestic effluent discharge point along which it carries waste from the Kakuri abattoir.	4.6
S6	Just after the Nnamdi Azikiwe Express bridge with few domestic discharge points	4.8
S7	Just after the IBBI major effluent discharge point	5.3
S8	Just after a sand quarrying point.	8.0

3.3 Methods

This section details the procedure carried out during the course of the study. Figure 3.1 presents the flow of the procedure

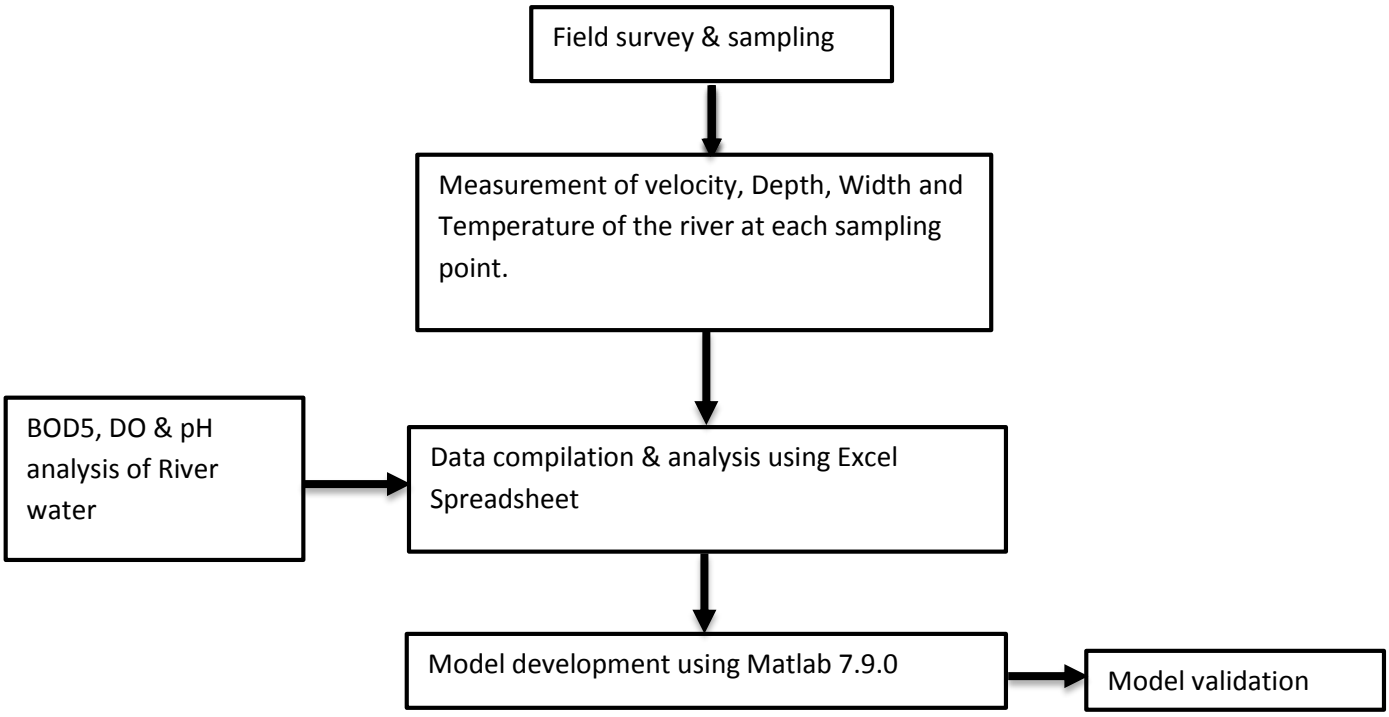


Figure 3.1: Sequence of activities for the work

3.3.1 Field Activities & Sampling Collection.

The field activities consisted of two distinct activities namely observation visits and the field sampling visits.

This exercise led to the familiarity with the people, determination of the sources of waste discharge into the river and the identification of the sampling points that was to be marked out for the research.

At this stage, repeated visits were made to collect data. Some of the parameters were determined in-situ while others were determined in the laboratory. The parameters determined in-situ were further sub-divided into two, namely: physical water quality parameters and hydraulic parameters. The physical parameter that was determined in-situ is temperature. The hydraulic parameters that were determined in-situ were stream velocity, river depth and width using the instruments mentioned in Table 3.1. Only three parameters, pH, DO and BOD, were determined in the laboratory. These were classified as chemical water quality parameters. In order to capture the climatic conditions of both the dry and rainy seasons, samplings were carried out in the following months:

iii. Rainy season: June & July (2014).

iv. Dry Season: February, March, April and May (2014)

It is going to be extremely cumbersome or practically impossible to collect data from every part of the river along the selected segment. Although, taking samples every day of the selected months under study would capture the prevailing conditions better, but it will also mean that the cost of carrying out this research will be way off beyond my reach. Considering some related works (Agunwamba *et al*., 2007, Omole *et al*., 2010, Chiejine *et al*., 2014), samples were taken once a month in other to capture the prevailing conditions of their studied river. As an improvement on the related works, the samples were taken bi-monthly when carrying out this study.

On the sampling dates, the team assembled at the river side by 7:15am when the exercises was scheduled to start. At each sampling point on the selected segment, two assistants stretched the tape across the width of the river to determine the width and remained in position. The depth was measured using a rope with a metal tied at the tip of the rope at three different but equal intervals measured along the stretched out tape, e.g. ¼ distance ½ distance and ¾ distance. Also, velocity was obtained at the interval where depth measurements were obtained. The float method was used to determine the velocity across the selected segment and this was done with the aid of a 2-5 meter rope, an orange and a stop watch. Time taken by the float (orange) to go to a fixed distance was measured. (www.geography-site.co.uk/../vel.html, 2007). This is because it floats is round and so less likely to get caught up on things, not easily influenced by the ambient air and it is also cheap if one loses it. 2-5 meter of the river was measured using a rope, the orange was then dropped at the point of interest i.e. at ¼, ½ and ¾ across the sampling points and a stopwatch was then used to determine how long it took to go to the specified distance. This was repeated at least 3 times and average speed = Distance/time gave the unit in meters per second. The water bottles that were used were thoroughly washed and rinsed with the river water before taking the samples for pH, DO and BOD. These samples were collected carefully from the point where the mid-stream velocity is taken, tightly sealed and stored in a cooler containing iced blocks which was transported to the laboratory within 12 hours from the collection time. Finally, the ambient (air) and water temperature at that location was recorded using a mercury-in-glass thermometer. All recordings were done on paper and were later transferred to the excel spreadsheet on the laptop computer the next day.

3.3.3 DO and BOD_5 Determination

All laboratory analyses were carried out at the Public Health Engineering laboratory, Department of Water Resources & Environmental Engineering, A.B.U. Zaria. The DO of all

water samples were determined using titrimetric method (Azide modification) (APHA, 1992). The water samples meant for BOD_5 determination were stored in the Gallenkamp series cooled incubator for 5 days which was set at 20 degree Celsius constant temperature. On the 5th day, the samples were brought out of the incubator and the remaining DO measured again using titrimetric method. The difference between the initial DO and final DO was taken as the BOD value. All values that were obtained were transferred to excel spreadsheet for computation.

3.3.4 Data Analysis

An average of six months data were used to determine the model equation. Thus, the re-aeration coefficient model was obtained which represent the final output of this work.

Hydraulic data include depth, stream velocity and width. The river is assumed to have a semi-circular section, the hydraulic Radius was calculated using the formula:

$$\frac{\frac{1}{2}Area}{\frac{1}{2}Perimeter} = \frac{\frac{\pi d^2}{8}}{\frac{\pi d}{2}} = \frac{d}{4} = \frac{r}{2} \qquad (3.1)$$

Source: Omole *et al.,* (2007)

Where d = diameter of a circle (mean depth).

The mean velocity, v, refers to the average of the three different velocity measurements taken at each cross-section. This was also applied in determining the mean depth.

3.3.5 Hydraulic Radius

The hydraulic radius, whose relationship is defined by equation (3.1), was determined using the principles and assumptions described by Agunwamba *et al.,* (2001) below:

i. The stream channel is semi-circular in shape.

ii. There were no oxygen sinks in the system.

iii. The stream is uniformly mixed.

3.3.6 Ultimate BOD and De-oxygenation rate k_1

The ultimate BOD, Lo, was computed for each reach of the six model months. Its values were then inserted in the programmed excel sheet for the determination of k_1.

3.3.7 Saturation DO and the Upstream and Downstream DO deficits

At each sampling point, the temperature was used to read off the saturation DO (Table 2.2). These values were inserted in the programmed excel sheet. They were further used in the determination of the upstream and downstream DO deficits.

3.3.8 Time of travel

Phase one was the extraction of the time of travel, t, the coefficient of de-oxygenation, k_1 and the coefficient of re-aeration, k_2 values from the experimental data. This was computed with the Excel spreadsheet. The time of travel, *t*, was computed from velocity and distance travelled as follows:

$$Time\ (days) = \frac{Distance\ (km)}{velocity\ (km/hr)} \times \frac{1\ day}{24hrs} \quad (3.2)$$

The primary aim of the study was to evaluate the factors affecting the self-purification capacity of the said river and also developing an empirical expression for the reaeration constant that can be used together with a de-oxygenation coefficient. The de-oxygenation coefficient, k_1 (day^{-1}), was computed from the equation 3.2 (Appendix 3) (Weiner *et al*., 2003).

$$L = L_o 10^{-k_1 t} \quad (3.3)$$

Where L = instantaneous BOD, L_o = ultimate BOD and t = time in days. Therefore,

$$k_1 = \frac{1}{t}\log\frac{L_o}{L} \quad (3.4)$$

Experimental k_2 (day^{-1}) was determined using Equation (3.4) (Agunwamba *et al.,* 2007)

$$k_2 = \frac{(\log D_0 - \log D)}{t} \quad (3.5)$$

Which is also the same as

$$k_2 = \frac{\left(\log\frac{D_o}{D}\right)}{t} \quad (3.6)$$

where D_o is the initial DO deficit at point of pollution at the upstream and D is DO deficit at any point downstream of the point of pollution. When these two coefficients are known, then the self-purification capacity, *f*, of any stream can be derived by the equation $f = k_2/k_1$ which in turn be used in Equation 2.2 (the equation for predicting DO content along the river).

3.3.9 Re-aeration Coefficient Model

The modelling was undertaken with the aid of MATLAB statistics toolbox using a nonlinear regression and the model was statistically validated. Full residual analysis was carried out in both the MATLAB and Excel Spreadsheet. The equation with the best result was chosen based on the statistic indicator; coefficient of determination, R^2.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Tables 4.1a – 4.6b are the results of the hydraulic and physico-chemical data obtained in the process of carrying out this research.

Table 4.1a: Hydraulic Data for February, 2014.

Sampling points	Mean velocity (m/s)	Hydraulic radius (m)	Mean depth (m)	Volumetric flow rate (m^3/s)
S1	0.18	0.8133	1.6266	60.6
S2	0.1413	0.9150	1.8300	64.1
S3	0.1533	0.9583	1.9166	82.87
S4	0.2566	0.6500	1.300	0.71
S5	0.1386	0.3700	0.7400	9.63
S6	0.2333	0.5533	1.1066	3.6
S7	0.2033	0.4283	0.8566	45.6
S8	0.2733	0.6150	1.2300	97.5

Average mean velocity, depth and discharge for the month of February, 2014 were found to be respectively 0.1975m/s, 1.33m and 61.1m^3/s.

Table 4.1b: Physico-Chemical Parameters for February, 2014.

Sampling Points	Ambient Temperature (^OC)	Water Temperature (^OC)	BOD (mg/L)	DO (mg/L)	pH
S1	20	24	8	2.8	6.7
S2	20	24	11	6.8	6.8
S3	22	23	21	5.8	6.4
S4	21	23	23	6.8	6.8
S5	20	23	21	6.0	6.7
S6	18	22	19	5.3	6.7
S7	19	23	26	6.0	7.3
S8	24	22	20	5.5	6.5

Table 4.2a: Hydraulic Data for March, 2014.

Sampling Points	Mean Velocity (m/s)	Hydraulic Radius (m)	Mean Depth (m)	Volumetric flow rate (m^3/s)
S1	0.3900	0.7583	1.5166	91.8294
S2	0.3466	0.8600	1.7200	110.9056
S3	0.4766	0.9133	1.8266	245.5405
S4	0.3466	0.6333	1.2666	69.8152
S5	0.1100	0.3250	0.6500	10.3523
S6	0.2366	0.5266	1.0533	24.3056

S7	0.2733	0.4166	0.8333	44.7583
S8	0.3966	0.6700	1.3400	115.6217

Average mean velocity, depth and discharge for the month of March, 2014 are respectively 0.32m/s, 1.28m and 77.5m^3/s.

Table 4.2b: Physico-Chemical Parameters for March, 2014.

Sampling Points	**Ambient Temperature (^oC)**	**Water Temperature (^oC)**	**BOD_5 (mg/L)**	**DO (mg/L)**	**pH**
S_1	25	25	10	3.6	6.2
S_2	23	22	13	4.5	6.1
S_3	23	20	28	8.0	6.3
S_4	24	23	29	8.0	6.1
S_5	25	24	26	6.8	6.2
S_6	23	23	25	7.3	6.2
S_7	24	24	27	7.4	6.8
S_8	29	23	24	7.3	6.7

Table 4.3a: Hydraulic Data for April, 2014.

Sampling Points	**Mean Velocity (m/s)**	**Hydraulic Radius (m)**	**Mean Depth (m)**	**Volumetric flow rate (m^3/s)**
S1	0.0686	0.7433	1.4866	15.5423
S2	0.1193	0.8100	1.6200	34.2176
S3	0.1180	0.5916	1.1833	28.6946
S4	0.2466	0.6150	1.2300	45.7375
S5	0.1266	0.3133	0.6266	10.7160
S6	0.1733	0.500	1.000	15.0800

S7	0.2466	0.3933	0.7866	35.2191
S8	0.1566	0.6633	1.3266	42.7120

Average mean velocity, depth and discharge for the month of April, 2014 are respectively 0.157m/s, 1.16m and 40m^3/s.

Table 4.3b: Physico-Chemical Parameters for April, 2014.

Sampling Points	**Ambient Temperature (^OC)**	**Water Temperature (^OC)**	**BOD_5 (mg/L)**	**DO (mg/L)**	**pH**
S1	24	23	9.0	3.3	6.1
S2	22	22	12	3.5	6.0
S3	22	23	26	7.2	6.2
S4	22	24	24	8.0	6.1
S5	23	23	22	7.0	6.1
S6	23	24	23	5.8	6.2
S7	24	24	20	5.2	6.5
S8	26	25	22	6.5	6.6

Table 4.4a: Hydraulic Data for May, 2014.

Sampling Points	**Mean Velocity (m/s)**	**Hydraulic Radius (m)**	**Mean Depth (m)**	**Volumetric flow rate (m^3/s)**
S1	0.2366	0.8633	1.7266	62.5226
S2	0.2433	0.9100	1.8200	80.3803
S3	0.1420	0.6366	1.2733	37.1571
S4	0.3266	0.6400	1.2800	63.6608
S5	0.2200	0.5900	1.1800	35.4354
S6	0.1153	0.5716	1.1433	11.9666
S7	0.1196	0.4566	0.9133	19.0993
S8	0.1380	0.8133	1.6266	46.1306

Average mean velocity, depth and discharge for the month of May, 2014 are respectively 0.193m/s, 1.37m and 44.5m^3/s.

Table 4.4b: Physico-Chemical Parameters for May, 2014.

Sampling Points	Ambient Temperature (^OC)	Water Temperature (^OC)	BOD (mg/L)	DO (mg/L)	pH
S1	23	23	8.0	3.8	6.4
S2	23	22	7.0	4.0	6.3
S3	25	23	7.0	3.5	6.5
S4	26	25	6.0	3.8	6.3
S5	26	25	8.0	3.0	6.2
S6	25	24	9.0	3.5	6.4
S7	27	24	21	5.5	6.6
S8	26	23	13	5.0	6.6

Table 4.5a: Hydraulic Data for June, 2014.

Sampling Points	Mean Velocity (m/s)	Hydraulic Radius (m)	Mean Depth (m)	Volumetric flow rate (m^3/s)
S1	0.1866	1.8866	3.7733	111.4642
S2	0.3166	1.9783	3.9566	235.8667
S3	0.2566	1.6400	3.2800	178.0548
S4	0.2466	1.8066	3.6133	142.3834
S5	0.2800	1.6033	3.2066	126.5992
S6	0.2333	1.6050	3.2100	72.4657
S7	0.3333	1.1733	2.3466	140.8000
S8	0.3766	1.8733	3.7466	297.4197

Average mean velocity, depth and discharge for the month of June, 2014 are respectively 0.28m/s, 3.4m and 213.1m^3/s.

Table 4.5b: Physico-Chemical Parameters for June, 2014.

Sampling Points	Ambient Temperature (^oC)	Water Temperature (^oC)	BOD_5 (mg/L)	DO (mg/L)	pH
S1	24	19	7	3.5	6.6
S2	24	19	7	4	6.6
S3	25	19	6	3.5	6.5
S4	26	22	6	3.3	6.4
S5	26	23	8	4	6.8
S6	26	22	14	5	6.6
S7	26	24	21	5.7	6.7
S8	27	24	12	5.5	6.8

Table 4.6a: Hydraulic Data for July, 2014.

Sampling points	Mean Velocity (m/s)	Hydraulic Radius (m)	Mean Depth (m)	Volumetric flow rate (m^3/s)
S1	0.3300	2.1233	4.2466	227.0268
S2	0.2900	2.2733	4.5466	252.1695
S3	0.3566	1.8466	3.6933	283.5464
S4	0.3433	1.9100	3.8200	212.4684
S5	0.3400	1.8900	3.7800	184.1049
S6	0.3933	1.9083	3.8166	148.6210
S7	0.3933	1.4450	2.8900	208.02220
S8	0.3166	2.1400	4.2800	288.6860

Average mean velocity, depth and discharge for the month of July, 2014 are respectively 0.35m/s, 3.88m and 306.9m^3/s.

Table 4.6b: Physico-Chemical Parameters for July, 2014.

Sampling Point	Ambient Temperature (^{O}C)	Water Temperature (^{O}C)	BOD_5 (mg/L)	DO (mg/L)	pH
S1	23	20	40	3.2	6.5
S2	23	19	6.0	3.0	6.7
S3	24	19	8.0	3.8	6.7
S4	23	20	8.0	3.8	6.4
S5	22	20	9.0	4.0	6.3
S6	23	21	5.0	2.6	6.5
S7	24	22	17	5.7	6.2
S8	24	22	19	6.5	6.4

4.2 Monthly Variations in DO, Temperature, BOD, pH

For a dynamic system, the physical parameters of the river such as DO, temperature, BOD and pH changes with time.

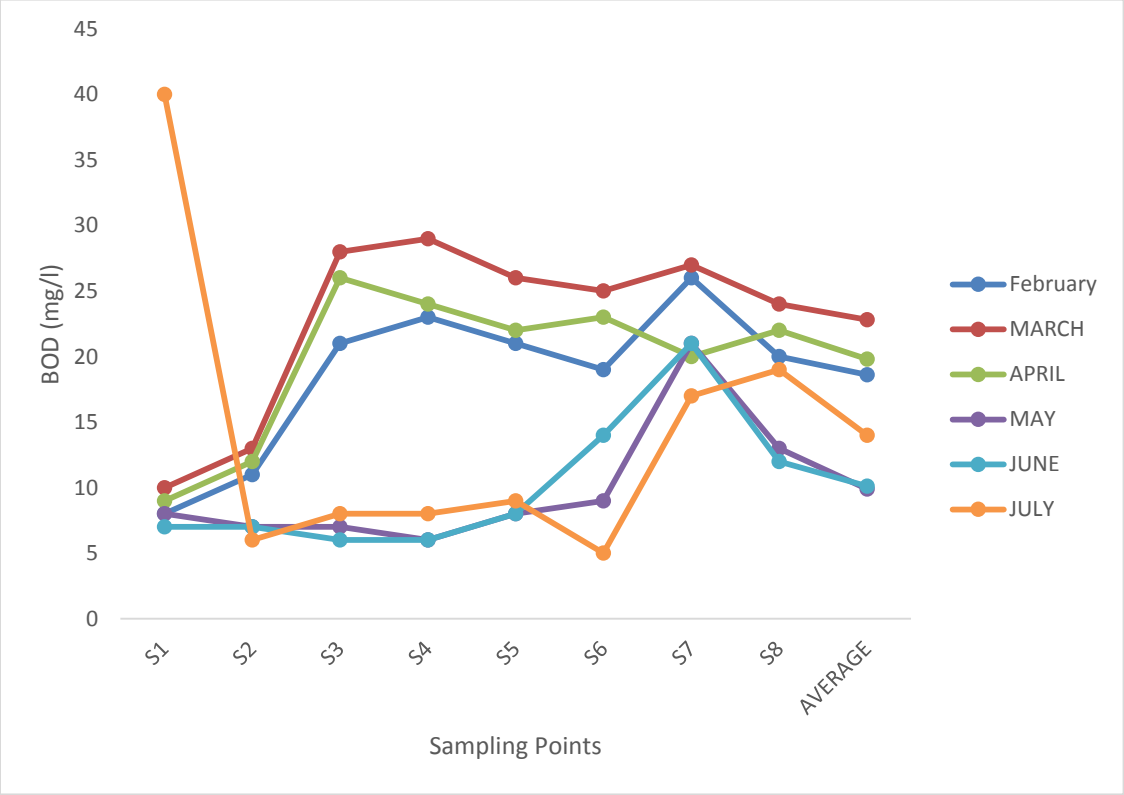


Figure 4.1a: BOD_5 Values at Each Sampling Point For The Months Of February, March, April, May, June & July.

Fig4.1a presents the variation of BOD between the sampling points for the consecutive months of interest. BOD directly affects the amount of dissolved oxygen in rivers. The greater the BOD, the more rapidly oxygen is depleted. This means less oxygen is available to aquatic organisms (microbes). This is because of aerobic microbial and biochemical degradation of organic matter present in the water. The consequences of high BOD are the same as those for low DO: many aquatic organisms become stressed, suffocate, and die. The overall mean BOD values is between 9.9mg/L and 22.8mg/L. It can be seen from the results in figure 4.1a that the assimilative capacity and the maximum allowable BOD are higher during the rainy season for the period and the segments studied. This conforms to reality consequent upon dilution factor. The rainy season supplies the river with fresh water thus increasing the river volume. The fresh water passed through the atmosphere dissolving atmospheric oxygen in the course of its descent. This makes the DO level to be farther away from the critical point due to the relatively sufficient DO in the river before the introduction of the wastewater. Chiejine *et al*., (2014) reported similar observations. This high dilution factor could also be the reason why at S1 in the month of July, there is a sharp drop in the BOD from 40mg/L down to about 5mg/L. The volume of the effluent discharged close to S1 is very low when compared with the width to depth ratio of the river body.

Furthermore, an earlier study by Igboanugo *et al*., (2013) analysed the relationship between the heavy metals and the other pollution determining parameters. It was discovered that heavy metals, namely Cadmium (Cd), Copper (Cu), Iron (Fe) and Lead (Pb) correlate negatively with pH and DO on the one hand but positively with BOD and COD. One possible interpretation of this correlation is that the presence of heavy metals tends to cause oxidation reaction that depletes dissolved oxygen (DO) in the river. Therefore the more the heavy-metal-bearing effluents are injected into the river, the more the oxygen consumed. As the loading abates, so do the oxygen consumed proportionately decrease.

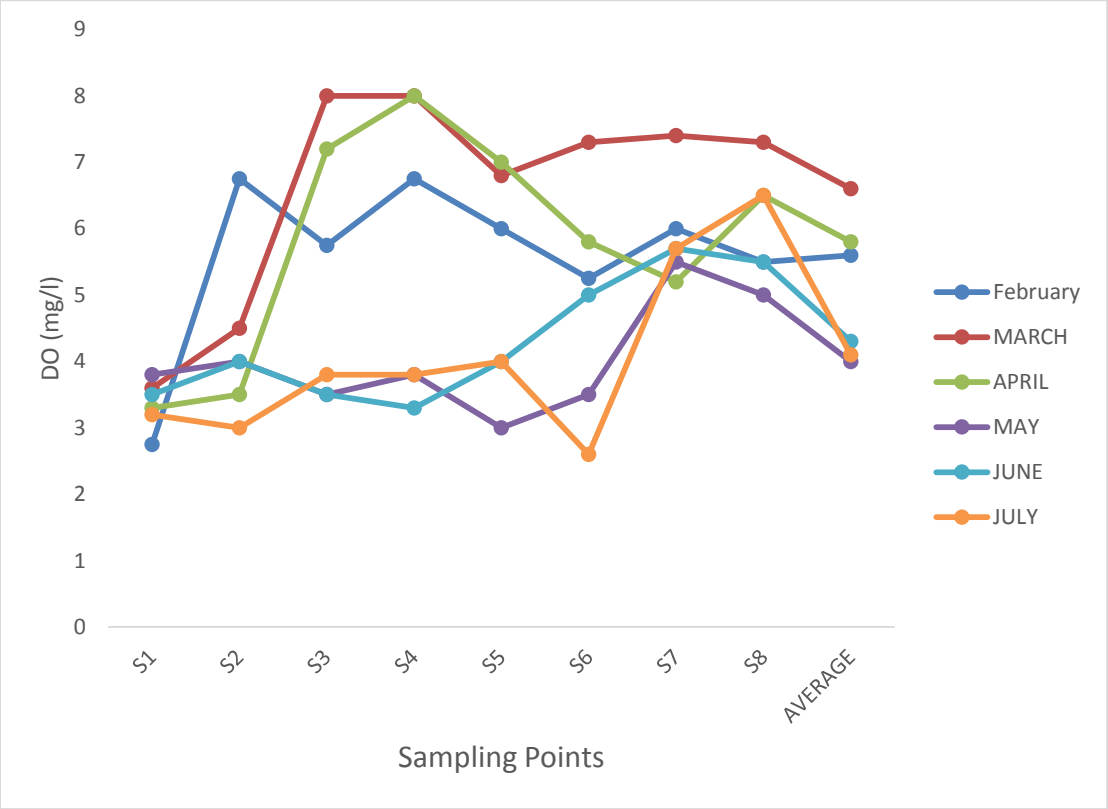


Figure 4.1b: DO at Each Sampling Point For The Months Of February, March, April, May, June & July.

Fig 4.1b presents the variation of DO between the sampling points for the consecutive months of interest. The lowest values of dissolved oxygen were found to be 2.5mg/L at S1 and 2.6mg/L at S6 in the month February and July respectively. From S1 in the month February, there is recovery in the DO oxygen content of the river. It rises until it reaches a value of about 6.8mg/L. The reason could be attributed to lower temperature at that period of the year which enhances or increases the capacity of the water to hold more oxygen thus increasing the amount of oxygen per liter of the river water. Also it was found that the volume of the effluent discharge from the point source around station market was very low and almost insignificant when compared to the volume of the river. What this translates to is that there is less nutrient for the organic microbes which means less oxygen will be consumed in that process. Since the oxygen consumed is less than the oxygen added via reaeration, there is thus an increase in the DO content of the water at that region. There is a decline in DO from point S2 to S3. This is attributed to very low velocity observed in that region which reduces the mixing capacity of the river thus lowering the rate at which oxygen is replenished or added to the river. Furthermore, the average DO oxygen in that studied month was found to be less than 5mg/L

which according to Rao et al., (2005), DFID, (1999) and WHO, indicates that the DO is lower than the available standard of 8-10 mg/L. This means that the aquatic animals are been stressed and that the river is slightly polluted at this month. Taking a closer look at the month of July, while rainfall may dilute and weaken the effects of point source pollution, it also increases the contribution of non-point sources or diffuse pollution through land runoff from and leaches from refuse dumps, which may account for the low dissolved oxygen observed at point S1-S6. There is sharp increase in DO value of the river from point S6-S7 which is as a result of reduction in the number non-point sources around this region and the subsequent increase in velocity which increases the distribution across the river. This is similar to what Chiejine *et al.,* (2014) observed.

Judging from the results in comparison with these standards, River Kaduna can be said to be not fit for direct human consumption without treatment. However, when considering the average mean dissolved oxygen across the eight sampling points and within the six months under study, it was found to be in the range 4.1mg/L to 6.6mg/L, thus ensuring that the river may pose a threat to the survival of the aquatic biota but at certain points, the aquatic biota may not be very stressed. (Omole *et al.,* 2010).

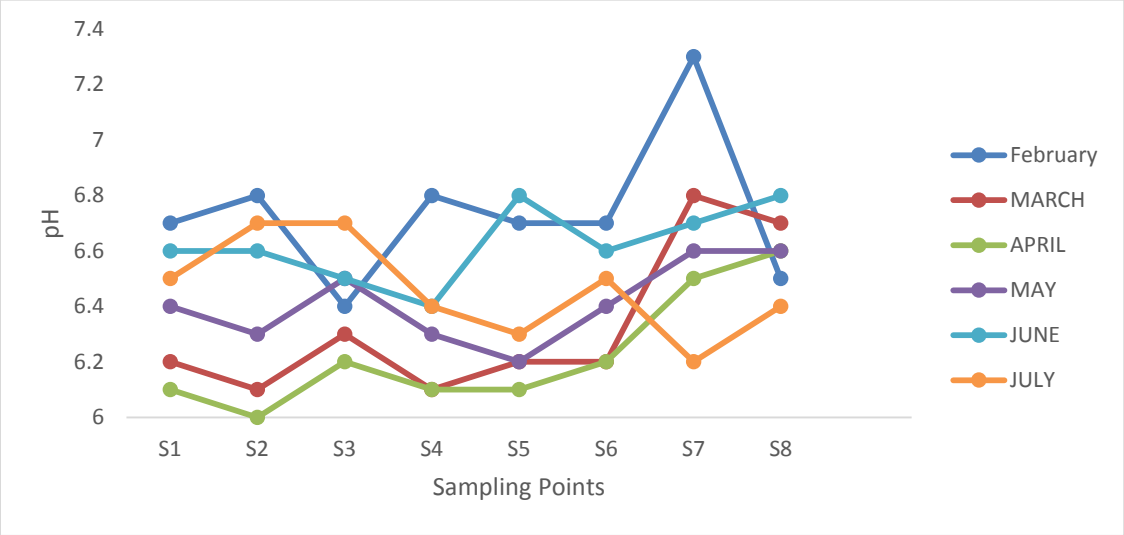


Figure 4.1c: pH Values at Each Sampling Point for the Months of February, March, April, May, June & July.

The pH values from this research are not significantly different and are within the accepted limits although, some values were found to be very slightly acidic (6.0). According to WHO (2011), there is no health-based guideline value for pH, although 6.5 – 8.5 is proposed for drinking water. The pH of River Kaduna might not pose any negative effects on the inhabitant biota because most aquatic animals prefer a pH range of 6.5 - 8.0 which is slightly acidic and slightly alkaline. For instance, Lawson (2011) reported that aquatic shrimps and crabs require optimum pH range of 6.8 - 8.7 for maximum growth and reproduction. The lowest mean value of pH was found to be in the month of July and this may be attributed to the amount of acid precipitation that falls in the watershed. Acid rain is caused by nitrogen oxides (NOx) and sulfur oxides (SOx) in the air combining with water vapor. These pollutants are primarily from automobile and coal-fired power plant emissions. Acid rain is responsible for many of our first order streams becoming acidic. A similar situation was noticed by Oguejiofor (1995) and Emeaso (2008).

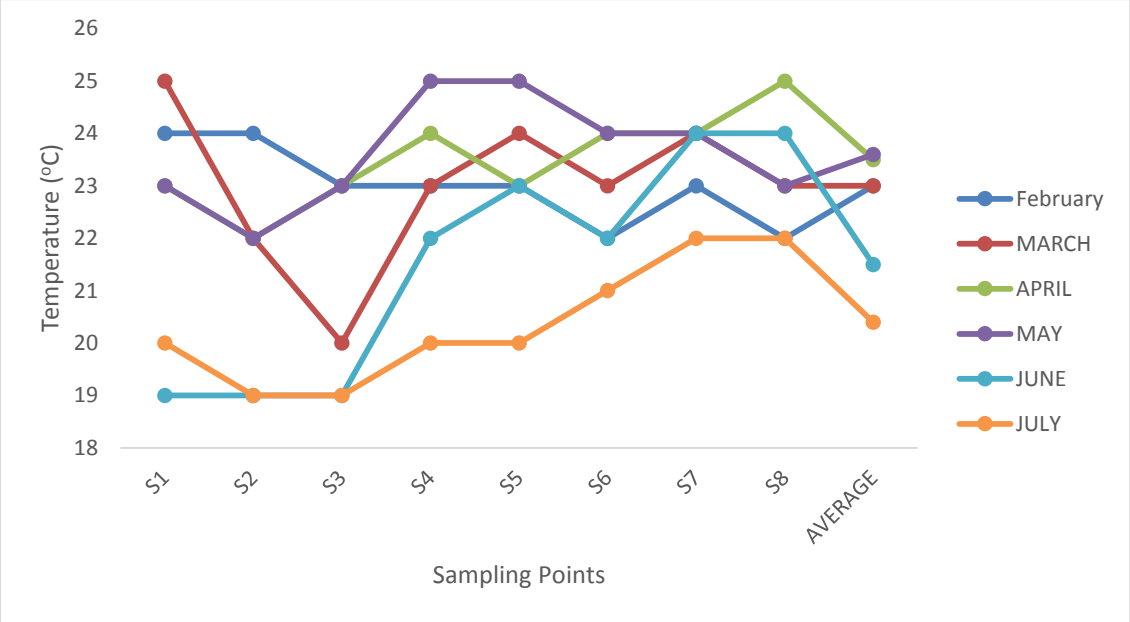


Figure 4.1d: Temperature Profile at Each Sampling Point For The Months Of February, March, April, May, June & July.

The mean water temperature obtained within the sampling period were found to be ranged 23.6°C to 20.4°C. This may not pose any danger to the aquatic organisms. Temperature of the water is probably the most important environmental variable since it affects metabolic activities, growth, feeding, reproduction, distribution and migratory behaviours of aquatic organisms Ikenna *et al.* (2008) made similar observation for River Romi in Kaduna.

Warmer temperatures decrease oxygen solubility in water while at the same time increasing metabolic rates that affect BOD decay, sediment oxygen demand, nitrification, photosynthesis, and respiration (Minnesota Pollution Control Agency 2005). This is because temperature influences enzymatic reactions through hormonal and nervous control to digestion, from respiration and osmoregulation to all aspects of an organism's performance and behaviours. High and low temperature that are lethal to individual organism of a specie determines the distribution and abundance of its population. The colder the water, the more oxygen it can hold. Therefore, DO concentrations at one location can vary as a result temperature variations. For instance, at the same sampling point in the month of June, the DO was found to be 5.5mg/L when the temperature was 24 ^{o}C and 6.5mg/L when the temperature dropped to 22 ^{o}C. This can be seen from the solubility data in Weiner et al., (2003), when the temperature is 24^{o}C, the DO is 8.4mg/L, but at a lower temperature of 22^{o}C, the DO increases to 8.7mg/L.

4.3 Determination of k_2

The computation of the independent variables as stated in equation (3.5) for the consecutive months starting from February through to July was carried out using the Excel Spread sheet and this can be seen in Appendix II. (Derick G. 1995).

The k_2 values were determined using equation (3.5) and are as presented in Tables 4.7a– 4.7f.

Table 4.7a: Modelling Parameters for the Month of February

Sampling Points	Hydraulic Radius (m)	Mean Velocity (m/s)	k_1 (per day)	k_2 (per day)	Self- purification factor $f=k_2/k_1$
S1	0.8133	0.1800	6.2956	37.7722	6.0
S2	0.9150	0.1413	0.5820	1.0097	1.7
S3	0.9583	0.1533	0.5175	1.7466	3.4
S4	0.6500	0.2566	0.8630	1.7108	2.0
S5	0.3700	0.1386	0.3480	1.0714	3.1
S6	0.5533	0.2333	0.6020	2.2401	3.7
S7	0.4283	0.2033	0.4417	1.3601	3.1
S8	0.6150	0.2733	0.4235	1.4801	3.5

Table 4.7b: Modelling Parameters for the Month of March

Sampling Points	Hydraulic Radius (m)	Mean Velocity (m/s)	k_1 (per day)	k_2 (per day)	Self- purification factor $f=k_2/k_1$
S1	0.7583	0.3900	12.6408	73.0549	5.8
S2	0.8600	0.3466	1.6459	7.0979	4.3
S3	0.9133	0.4766	1.9707	0.9452	0.5
S4	0.6333	0.3466	1.1655	0.3580	0.3
S5	0.3250	0.1100	0.2567	0.4180	1.6
S6	0.5266	0.2366	0.5693	0.4813	0.8
S7	0.4166	0.2733	0.5522	0.1823	0.3
S8	0.6700	0.3966	0.5730	0.4845	0.8

Table 4.7c: Modelling Parameters for the Month of April

Sampling Points	Hydraulic Radius (m)	Mean Velocity (m/s)	k_1 (per day)	k_2 (per day)	Self- purification factor $f=k_2/k_1$
S1	0.7433	0.0686	2.5790	13.8612	5.4
S2	0.8100	0.1193	0.5666	2.8069	5.0
S3	0.5916	0.1180	0.3982	0.4318	1.1
S4	0.6150	0.2466	0.7714	0.2547	0.3
S5	0.3133	0.1266	0.3178	0.4814	1.5
S6	0.500	0.1733	0.3879	1.2840	3.3
S7	0.3933	0.2466	0.4984	2.0085	4.0
S8	0.6633	0.1566	0.1953	0.4287	2.2

Table 4.7d: Modelling Parameters for the Month of May

Sampling Points	Hydraulic Radius (m)	Mean Velocity (m/s)	k_1 (per day)	k_2 (per day)	Self- purification factor $f=k_2/k_1$
S1	0.8633	0.2366	8.8888	44.9356	5.1
S2	0.9100	0.2433	1.1553	5.3726	4.7
S3	0.6366	0.1420	0.4792	2.5162	5.3
S4	0.6400	0.3266	0.9478	5.3237	5.6
S5	0.5900	0.2200	0.4764	2.9670	6.2
S6	0.5716	0.1153	0.2581	1.4210	5.5
S7	0.4566	0.1196	0.2418	0.8919	3.7
S8	0.8133	0.1380	0.1993	0.8229	4.1

Table 4.7e: Modelling Parameters for the Month of June

Sampling Points	Hydraulic Radius (m)	Mean Velocity (m/s)	k_1 (per day)	k_2 (per day)	Self- purification factor $f=k_2/k_1$
S1	1.8866	0.1866	9.0670	39.7180	4.4
S2	1.9783	0.3166	1.8302	7.5346	4.2
S3	1.6400	0.2566	1.1202	4.9071	4.4
S4	1.8066	0.2466	0.9074	4.5073	5.0
S5	1.6033	0.2800	0.7247	3.4554	4.8
S6	1.6050	0.2333	0.6141	2.3667	3.9
S7	1.1733	0.3333	0.7028	2.3177	3.3
S8	1.8733	0.3766	0.5281	1.8670	3.5

Table 4.7f: Modelling Parameters for the Month July

Sampling Points	Hydraulic Radius (m)	Mean Velocity (m/s)	k_1 (per day)	k_2 (per day)	Self- purification factor $f=k_2/k_1$
S1	2.1233	0.3300	15.1838	70.8985	4.7

S2	2.2733	0.2900	1.6756	7.6153	4.5
S3	1.8466	0.3566	1.5709	6.6130	4.2
S4	1.9100	0.3433	1.4141	6.2041	4.4
S5	1.8900	0.3400	1.0452	4.4796	4.3
S6	1.9083	0.3933	1.0858	5.6125	5.2
S7	1.4450	0.3933	0.9163	3.0250	3.3
S8	2.1400	0.3166	0.4905	1.1623	2.4

4.3.1 Average Stream Velocity

The average stream velocity is an important factor in both the reaeration constant and the time of travel along the stream. Examining Table 4.7a - 4.7f, we observed that as the velocity increases, the reaeration coefficient also increases, implying an increased rate of oxygen transfer from the atmosphere to the water. The velocity also affects the temporal distribution of the DO because an increase in velocity implies less time taken for the DO to spread. This transfer occurs at the air/water interface. The transfer of DO from the atmosphere to the surface of the water body is controlled by the transfer rate and the DO deficit. The transfer rate depends on the turbulence of water near the water surface, which is generally estimated from the water velocity, depth and other hydraulic parameters such as density and kinematic viscosity. The presence of rocks along the water course in this studied region enhances mixing. The velocity also affects the spatial distribution of the dissolved oxygen, because an increased velocity means it will take less time for the oxygen to spread. Thus, the combined effect of these two relationships results in a lower overall oxygen deficit due to the increased reaeration coefficient, with a more widespread effect of the dissolved oxygen deficit. Longe (2008) and Omole *et al*., (2011) reported similar observation in River Illo, Ota and River Atuwara Ogun State respectively.

4.3.2 Average Hydraulic Radius (Water Depth)

The reaeration term is inversely proportional to water depth. As the depth increases, the reaeration coefficient becomes smaller, and the volumetric amount of oxygen produced by the phytoplankton becomes smaller. This is because solar radiation is affected by the depth, in other words, as the depth increases, the amount of solar radiation that gets to the phytoplankton is reduced. Due to the effects of depth on the reaeration coefficient and

phytoplankton oxygen production, and the constant BOD concentration at each depth, we would expect that that the DO sag curve should drop lower with increasing depth due to the time it will take for oxygen at the top to diffuse to the bottom of the river. (Derick, (1995), Agunwamba et al., (2007)).

4.3.3 The fair Ratio (f)

The fair ratio f, which is the ratio of the re-aeration coefficient to the de-oxygenation coefficient is the indices used in determining the self-purification capacity for this study. Table 4.4a-4.4f shows the model parameters and the self- purification factors (fair ratio) for the months of February to July, 2014.

The average values of the fair ratio (f) in all the studied months was greater than unity which means that reaeration predominates de-aeration across the stretch of the river studied. Chiejine *et al*., (2014). The average fair ratio for the month of February was found to be 3.3 which was higher than the months of March and April with average f values of 1.8 and 2.8 respectively. The reason for these values could be as a result of less pollution activities in the month of February which is suggested by the lower BOD values generated in that month and also slight decrease in temperature occasioned by the harmattan weather when compared with the months of March and April, since the lower the temperature, the higher the river capacity to hold oxygen, leading to a corresponding increase in DO. The month of March seems to be the most polluted month since most of the f values in the sampling point calculated were less than unity which implies that the de-oxygenation rate was greater than the re-oxygenation rate as reported by Omole *et al*., (2013) and Chiejine *et al*., (2014)

The raining season provides the river with sufficient water for dilution Agunwamba *et al*. (2006). This makes the dissolved oxygen to be farther away from the critical point due to the availability of relatively sufficient DO in the river before the introduction of wastewater, thus making the fair ratio to be higher. Although, the fair ratio of June (4.16) was slightly higher than that of July (4.11). This could be as a result of increase in waste discharge by Nigerian Breweries Trikania, in the month of July at sampling point 6 and 7 which increased the deoxygenation rate and thereby subsequently affecting the fair ratio.

Generally, the average fair ratio (f) of the studied section of river Kaduna was found to be greater than unity which implies that, reaeration is greater than deoxygenation. The values, although considered to be still within limits of self-purification allowable for Nigeria, needs to be put in constant check to avoid deterioration especially in view of what was discharged at the sampling point 6 and 7 in the month of June and July.

4.4 Model Parameters

The experimental parameters that are needed for the model are re-aeration coefficient, k_2, velocity, u, in meters per second and Hydraulic Radius, H in meters. These values were sorted out for each month and taken to the MATLAB environment for simulations that produced the model of the form written in equation 4.3 (equation 3.5).

$$k_2 = a\frac{U^b}{H^c} \tag{4.3}$$

The model parameters a, b and c are the unknown values of the function that must be determined. Since b and c are in a non-linear position with respect to the defined relationships, a non-linear regression was done to determine the parameters. This gave rise to the simulated values presented in Tables 4.8

Table 4.8: Model Output for the various Months

S/N	MONTH	a	B	C	FIT TYPE
1	February	0.20	-0.62	0.16	5^{TH} Polynomial
2	March	0.55	-0.60	-0.17	6^{TH} Polynomial
3	April	0.40	2.52	0.27	4^{TH} Polynomial
4	May	0.10	-2.03	0.46	6^{TH} Polynomial
5	June	67.99	2.41	2.34	6^{TH} Polynomial
6	July	1.54	-1.54	-1.48	6^{TH} Polynomial

4.4.1 The Model

Following the model output, in Table 4.8, model validation was done based on the use of R^2 statistic parameter discussed in section 2.6.4. The model selected (equation 4.4) was based on the output with the best R^2 value. (Table 4.8).

$$K_2 = 67.99\frac{U^{2.41}}{H^{2.34}} \tag{4.4}$$

This model passed with a 6^{TH} polynomial fit to the response values with an R^2 value of 0.814 (Table 4.8).

Table 4.9: R-squared values of six (6) models when tested with experimentally generated River Kaduna data.

Months	k_2 River Kaduna	k_2 Agunwamba *et al.,*	k_2 Omole *et al.,*	k_2 Streeter & Phelps	k_2 Garg *et al.,*	k_2 Jha *et al.,*	k_2 Bach & Lee
February	0.8481	0.5482	0.5569	0.7444	0.6627	0.6978	0.8036
March	0.5142	0.5636	0.5402	0.9507	0.7834	0.2698	0.3319
April	0.8748	0.9118	0.912	0.6777	0.5301	0.9303	0.9299
May	0.515	0.8626	0.8709	0.3406	0.1798	0.8045	0.491
June	0.3956	0.7291	0.7286	0.4161	0.4085	0.6632	0.4430
July	0.6552	0.6202	0.6247	0.6759	0.6854	0.6772	0.6468

The order of performance of these models was based on their R-squared value. It was observed that no single model performed best throughout the months studied but there was rather variation in the order of their performances Omole *et al.* (2012). For instance, in the month of February, the k_2 (Kaduna) model performed best when compared with other models since it had the highest R-squared value of 0.8481. Similarly, the Streeter and Phelps model had the highest R-squared of 0.9507 which shows that the model was the best in predicting the March data. Also, Jha *et al.,* had the best R-square value (0.9303) in the month of April. Omole's model performed better in the month of May and June with their respective R-squared value being 0.8709 and 0.7286. The best performing model in the month of July was found to be Jha *et al*., which had an R-squared value 0.6854. Generally, Jha *et al*., and Omole *et al*., performed reasonably better for the months under study when considering their average performances. The generated Kaduna reaeration model relatively performed better in the month of January and also performed above 50% in all the studied months. Though some of this models were theoretical, others were empirically generated. The reason behind the

performance of other models being better than the Kaduna model could come from the fact that some of this models were developed by using re-analyses of multiple existing data.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the present study, the following conclusions are made:

vii. The dissolve oxygen profile clearly indicates that there is self-purification going on in the segment studied.

viii. The minimum DO values for this segment were found to 2.5mg/L and 2.6mg/L which indicates that the aquatic life present are adversely affected when compared with the available standards of (4-5)mg/L..

ix. The pH values indicate slight acidity most especially during the raining season thus favouring the oxidation of heavy metals, thus reducing DO.

x. An empirical expression has been developed for the re-aeration coefficient model based on the field data obtained from River Kaduna, Nigeria. The model was statistically validated and producing the expression $k_2 = 67.99 \frac{U^{2.41}}{H^{2.34}}$

xi. The average fair ratio (f value) of the studied locations were found to be greater than unity which shows that reaeration predominates de-aeration.

xii. Based on its physical and chemical characteristics, River Kaduna is unsafe as portable water without treatment, for human consumption.

5.2 Recommendations

This section presents recommendation emanating from this research.

5.3.1: Recommendation for maintaining/improving water quality of River Kaduna.

i. The observed frequent fluctuations in DO deficit make the predictive capacity of k_2 model very difficult since the modified Streeter-Phelps equation was designed for exponential DO recovery shapes and not for sinusoidal curves.

ii. Boats fitted with a mobile laboratory should be acquired which will help to reduce fatigue and errors introduced through the time lapse between sampling and laboratory work.

iii. The cost of comprehensive water quality survey is enormous, thus, individuals, non-governmental and governmental agencies should be sensitized on the need for sponsorship.

iv. A more serious approach should be demonstrated by the Nigerian authorities (who are the primary custodians) to scientific monitoring, preservation and protection of our aquatic environment like some other countries have been doing. Considering the large dependency for domestic, economic, recreational, industrial and infrastructural purposes.

v. The citizenry should be sensitized on the dangers of using raw water from River Kaduna and other polluted rivers.

vi. The k_2 model as a function of pH should be studied to reduce the error generated in the study model

5.3.2: Recommendation for Future Research

i. A more systematic study to develop f values based on fundamental ideas in Chemical Engineering with a view to developing a dimensionless correlation.

ii. Comparative study of reaeration of stream bordered by vegetation.

iii A more comprehensive study where confirmatory data are obtained to strengthen assertions made in this study/other studies.

iv A comprehensive study of the effect of pH on the dissolved oxygen profile of a stream.

5.3 Contributions to Knowledge

1. The study has been able to gather data from a section of River Kaduna (Doka-Kudenda)

2. The study has developed a model that can be of use in the area of reaeration water quality modelling of River Kaduna in Nigeria.

3. The study has been able to evaluate the self-purification factors of the studied Segment in River Kaduna.

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APPENDIX 1

MATLAB CODE FOR OBTAINING THE REAERATION COEFFICIENT

FUNCTION FILE FOR THE RESEARCH MODEL

```
function NonLinearRegression

clear all
clc
% Model for Computing Reaeration coeficient
%kmod gives the predicted value of reaeration constant
%Hydraulic Radius (H) is (Stream depth/2)(m)
%U is the average stream velocity in m/s
% All negative values removed
%K2 value is per day i.e actual computation

% Data for the month February,2014.

data = [1.577172738 0.744727495 0.089731428
0.004229796 0.849755398 0.038578906
0.242194516 0.814363423 0.018483406
0.233221221 0.59063053  0.187086643
0.029988042 0.858027924 0.431798276
0.350281384 0.632023215 0.257013167
0.133577738 0.69179142  0.368218127
0.170291637 0.563307402 0.211124884
];

K2 = data(:,1);
U = data(:,2);
H = data(:,3);

% initial guess for XO is written below
X0 = [1.6255 0.3769 0.363]';
% X0 = [1 1 1]';
% Setting iteration limits
options = optimset('Display', 'iter', 'MaxIter',1e6, 'TolFun', 1e-16, 'TolX', 1e-16, 'MaxFunEval',1e6)
% Solving using Regression Analysis
X = lsqcurvefit(@ReaerationModel,X0,[U H],K2,[],[],options)

a = X(1); b = X(2); c = X(3);

K2mod = ReaerationModel(X,[U H])
% Plotting a graph of the experimental values against the predicted values
%Checking for the R-Square value

 plot(K2,K2mod,'o')

% Display Result
```

```
function K2 = ReaerationModel(par,xdata)

    a = par(1);
    b = par(2);
    c = par(3);

    U = xdata(:,1);
    H = xdata(:,2);

    K2 = a.*U.^b./H.^c;
end
end
```

APPENDIX I

MODEL OUTPUT FROM MATLAB

Model Output for February

Iteration	Func-count	f(x)	step	optimality	CG-iterations
0	4	87.2716		284	

1	8	1.95376	1.45577	1.2	0
2	12	1.82912	1.346	0.649	0
3	16	1.80205	0.718748	0.0847	0
4	20	1.80025	0.282205	0.0212	0
5	24	1.7999	0.155042	0.00753	0
6	28	1.79982	0.0875002	0.00436	0
7	32	1.7998	0.0515409	0.000961	0
8	36	1.79979	0.0311071	0.000593	0
9	40	1.79979	0.0193128	0.000207	0
10	44	1.79979	0.0122667	9.68e-005	0
11	48	1.79979	0.00793464	0.000163	0
12	52	1.79979	0.00520922	0.000116	0

X =

0.2000
-0.6178
0.1598

K2mod =

0.3528
0.3721
0.4297
0.3620
0.2515
0.3300
0.2947
0.3656

Model Output for March

Iteration	Func-count	f(x)	Norm of step	First-order optimality	CG-iterations
0	4	31.8574		85.5	
1	8	2.61442	1.07974	3.06	0
2	12	2.21442	0.644437	0.268	0
3	16	2.20556	0.210999	0.000464	0
4	20	2.20556	0.00485796	2.99e-005	0
5	24	2.20556	0.000392744	3.61e-006	0
6	28	2.20556	3.46442e-005	2.16e-006	0

7	32	2.20556	4.6769e-006	8.9e-007	0
8	36	2.20556	1.26624e-006	3.46e-007	0
9	40	2.20556	3.58708e-007	1.19e-007	0
10	44	2.20556	1.50324e-007	2.94e-008	0
11	48	2.20556	1.87958e-007	2.94e-008	0

X =

0.5454
-0.5986
-0.1661

K2mod =

0.6551
0.5520
0.6283
0.6635
0.4965
0.5839
0.6549
0.7042

Model Output for April

Iteration	Func-count	f(x)	Norm of step	First-order optimality	CG-iterations
0	4	41.5942		86.6	
1	8	0.456678	1.29911	0.903	0
2	12	0.332005	0.84858	0.0634	0
3	16	0.303239	0.579318	0.0197	0
4	20	0.29675	0.291955	0.00712	0
5	24	0.295441	0.135686	0.00307	0
6	28	0.29519	0.0603116	0.00132	0
7	32	0.295143	0.0262581	0.000563	0
8	36	0.295134	0.0113059	0.000241	0
9	40	0.295133	0.00484686	0.000103	0
10	44	0.295133	0.00207337	4.39e-005	0
11	48	0.295133	0.000886268	1.88e-005	0
12	52	0.295133	0.000378642	8.02e-006	0

X =

0.3991

2.5201
0.2667

K2mod =

1.0093
0.6176
0.4906
0.1724
0.3647
0.2763
0.1449
0.3660

Model Output for May

Iteration	Func-count	f(x)	Norm of step	First-order optimality	CG-iterations
0	4	52.9144		140	
1	8	3.47798	1.68694	9.28	0
2	12	3.47798	10	9.28	0
3	16	3.47798	2.5	9.28	0
4	20	1.28732	0.625	3.61	0
5	24	1.28732	1.17908	3.61	0
6	28	1.03558	0.294771	0.624	0
7	32	0.939582	0.589541	1.63	0
8	36	0.917196	0.494893	1.87	0
9	40	0.908197	0.15352	0.325	0
10	44	0.907707	0.056259	0.0119	0
11	48	0.907691	0.0169611	0.00225	0
12	52	0.90769	0.00509473	0.000185	0

X =

0.0957
-2.0261
0.4600

K2mod =

0.8771
1.1189
0.2830
0.8787
0.4407
0.2089
0.1852
0.3937

Model Output for June

Iteration	Func-count	f(x)	Norm of step	First-order optimality	CG-iterations
0	4	24.9624		58.3	
1	8	2.75591	0.648069	7.62	0
2	12	0.652358	1.10008	0.298	0
3	16	0.652358	2.07962	0.298	0
4	20	0.580748	0.519904	0.157	0
5	24	0.514721	1.03981	0.367	0
6	28	0.456991	1.03981	0.206	0
7	32	0.425899	2.07962	0.43	0
8	36	0.377923	2.07962	0.222	0
9	40	0.368354	4.15923	0.464	0
10	44	0.332533	1.03981	0.00454	0
11	48	0.323499	2.07962	0.0629	0

X =

67.9979
2.4074
-2.3422

K2mod =

1.5535
0.7400
0.5220
0.8502
0.3990
0.5535
0.0222
0.4107

MODEL OUTPUT FOR JULY

Iteration	Func-count	f(x)	Norm of step	First-order optimality	CG-iterations
0	4	12.7724		24.4	
1	8	1.94072	1.12375	1.77	0
2	12	1.60956	1.20438	0.0593	0
3	16	1.59854	0.540488	0.145	0
4	20	1.59492	0.144128	0.0127	0
5	24	1.59489	0.0175849	0.000117	0
6	28	1.59489	0.00221247	1.4e-005	0
7	32	1.59489	0.000296963	2.01e-006	0
8	36	1.59489	4.32552e-005	3.24e-007	0
9	40	1.59489	5.87612e-006	3e-008	0
10	44	1.59489	1.55184e-006	1.72e-008	0
11	48	1.59489	2.07397e-007	1.43e-008	0

X =

1.5369
-1.5392
-1.4751

K2mod =

0.9102
0.8731
0.7523
0.7698
0.7410
0.9472
0.4130
0.8737

APPENDIX II

A: Data Sheet for the Month of February

SAMPLING POINTS	V1 (m/s)	V2 (m/s)	V3 (m/s)	MEAN VELOCITY (m/s)	Average time (days)	D1 (m)	D2 (m)	D3 (m)	MEAN DEPTH (m)
S1	0.17	0.21	0.16	0.18	0.019910083	1.75	2.18	0.95	1.626666667
S2	0.112	0.19	0.122	0.141333333	0.215376048	0.59	1.45	3.45	1.83
S3	0.16	0.15	0.15	0.153333333	0.260416667	0.72	1.58	3.45	1.916666667
S4	0.26	0.3	0.21	0.256666667	0.156159812	0.86	1.62	1.42	1.3
S5	0.18	0.22	0.016	0.138666667	0.387286325	0.48	1.21	0.53	0.74
S6	0.21	0.28	0.21	0.233333333	0.240079365	0.88	1.52	0.92	1.106666667
S7	0.19	0.25	0.17	0.203333333	0.305100182	0.46	1.15	0.96	0.856666667
S8	0.24	0.32	0.26	0.273333333	0.341294038	1.22	1.55	0.92	1.23

B: Data Sheet for the Month of February

Hydraulic Radius (m)	RELATIVE DISTANCE	BOD (mg/l)	DO(mg/l)	DO (saturated) (mg/l)	Dissolved Oxygen Deficit (mg/l)	pH
0.813333333	0.31	8	2.75	8.4	5.65	6.7
0.915	2.63	11	6.75	8.4	1.65	6.8
0.958333333	3.45	21	5.75	8.6	2.85	6.4
0.65	3.463	23	6.75	8.6	1.85	6.8

0.37	4.64	21	6	8.6	2.6	6.7
0.553333333	4.84	19	5.25	8.7	3.45	6.7
0.428333333	5.36	26	6	8.6	2.6	7.3
0.615	8.06	20	5.5	8.7	3.2	6.5

C: Data Sheet for the Month of February

TEMP W	ki= (0.1*(1.047)^(T-20)	Lo= L/(1-10^(-ki*t)	Lo/L	log(Lo/L)	k1= 1/t*Log(Lo/L)	Log of DOD	k2= 1/t*((DoD) (per day)
24	0.120167417	10.6767021	1.334587762	0.125347138	6.295661102	0.752048448	37.77223978
24	0.120167417	14.68046538	1.334587762	0.125347138	0.581992005	0.217483944	1.009787049
23	0.114773082	28.64034174	1.363825797	0.134758901	0.51747418	0.45484486	1.746604262
23	0.114773082	31.36799333	1.363825797	0.134758901	0.862955064	0.267171728	1.710886587
23	0.114773082	28.64034174	1.363825797	0.134758901	0.347956776	0.414973348	1.071489803
22	0.1096209	26.50192988	1.394838415	0.1445239	0.601983846	0.537819095	2.240172098
23	0.114773082	35.45947072	1.363825797	0.134758901	0.441687383	0.414973348	1.3601216
22	0.1096209	27.8967683	1.394838415	0.1445239	0.423458612	0.505149978	1.480101971

D: Data Sheet for the Month of March

SAMPLING POINTS	V1 (m/s)	V2 (m/s)	V3 (m/s)	MEAN VELOCITY (m/s)	Average time (days)	D1 (m)	D2 (m)	D3 (m)	MEAN DEPTH (m)
S1	0.35	0.44	0.38	0.39	0.009199905	1.69	2.02	0.84	1.516666667
S2	0.3	0.38	0.36	0.346666667	0.087807158	0.52	1.41	3.23	1.72
S3	0.42	0.55	0.46	0.476666667	0.083770396	0.71	1.55	3.22	1.826666667
S4	0.33	0.4	0.31	0.346666667	0.115618323	0.84	1.58	1.38	1.266666667
S5	0.1	0.12	0.11	0.11	0.488215488	0.4	1.12	0.43	0.65
S6	0.21	0.28	0.22	0.236666667	0.236697966	0.82	1.48	0.86	1.053333333
S7	0.24	0.3	0.28	0.273333333	0.22696477	0.46	1.14	0.9	0.833333333
S8	0.37	0.44	0.38	0.396666667	0.235177404	1.24	1.58	1.2	1.34

E: Data Sheet for the Month of February

Hydraulic Radius (m)	RELATIVE DISTANCE	BOD (mg/l)	DO(mg/l)	DO (saturated) (mg/l)	Dissolved Oxygen Deficit (mg/l)	pH
0.758333333	0.31	10	3.6	8.3	4.7	6.2
0.86	2.63	13	4.5	8.7	4.2	6.1
0.913333333	3.45	28	8	9.1	1.2	6.3
0.633333333	3.463	29	8	8.6	1.1	6.1
0.325	4.64	26	6.8	8.4	1.6	6.2
0.526666667	4.84	25	7.3	8.6	1.3	6.2
0.416666667	5.36	27	7.4	8.4	1.1	6.8
0.67	8.06	24	7.3	8.6	1.3	6.7

F: Data Sheet for the Month of February

TEMP W	ki= (0.1*(1.047)^(T-20)	Lo= L/(1-10^(-ki*t)	Lo/L	log(Lo/L)	k1= 1/t*Log(Lo/L)	Log of DOD	k2= 1/t*((DoD) (per day)
25	0.125815286	13.07056165	1.307056165	0.11629425	12.6408098	0.672097858	73.0548691
22	0.1096209	18.13289939	1.394838415	0.1445239	1.645923894	0.62324929	7.097932603
20	0.1	40.94930828	1.462475296	0.165088539	1.970726485	0.079181246	0.945217518
23	0.114773082	39.55094811	1.363825797	0.134758901	1.165549697	0.041392685	0.358011466
24	0.120167417	34.69928182	1.334587762	0.125347138	0.256745518	0.204119983	0.418094033
23	0.114773082	34.09564493	1.363825797	0.134758901	0.569328514	0.113943352	0.481387121
24	0.120167417	36.03386958	1.334587762	0.125347138	0.552275749	0.041392685	0.182374935
23	0.114773082	32.73181913	1.363825797	0.134758901	0.57300956	0.113943352	0.484499574

G: Data Sheet for the Month of April

SAMPLING POINTS	V1 (m/s)	V2 (m/s)	V3 (m/s)	MEAN VELOCITY (m/s)	Average time (days)	D1 (m)	D2 (m)	D3 (m)	MEAN DEPTH (m)
S1	0.063	0.076	0.067	0.068666667	0.052251888	1.62	2	0.84	1.486666667
S2	0.111	0.128	0.119	0.119333333	0.255082247	0.5	1.36	3	1.62
S3	0.12	0.15	0.084	0.118	0.338394539	0.7	1.55	1.3	1.183333333
S4	0.24	0.26	0.24	0.246666667	0.162490616	0.8	1.54	1.35	1.23
S5	0.1	0.16	0.12	0.126666667	0.423976608	0.4	1.1	0.38	0.626666667
S6	0.18	0.18	0.16	0.173333333	0.323183761	0.78	1.4	0.82	1
S7	0.24	0.26	0.24	0.246666667	0.251501502	0.42	1.14	0.8	0.786666667

S8	0.15	0.18	0.14	0.156666667	0.595449173	1.22	1.56	1.2	1.326666667

H: Data Sheet for the Month of April

Hydraulic Radius (m)	RELATIVE DISTANCE	BOD (mg/l)	DO(mg/l)	DO (saturated) (mg/l)	Dissolved Oxygen Deficit (mg/l)	pH
0.743333333	0.31	9	3.3	8.6	5.3	6.1
0.81	2.63	12	3.5	8.7	5.2	6
0.591666667	3.45	26	7.2	8.6	1.4	6.2
0.615	3.463	24	8	8.4	1.1	6.1
0.313333333	4.64	22	7	8.6	1.6	6.1
0.5	4.84	23	5.8	8.4	2.6	6.2
0.393333333	5.36	20	5.2	8.4	3.2	6.5
0.663333333	8.06	22	6.5	8.3	1.8	6.6

I: Data Sheet for the Month of April

TEMP W	ki= (0.1*(1.047)^(T-20)	Lo= L/(1-10^(-ki*t)	Lo/L	log(Lo/L)	k1= 1/t*Log(Lo/L)	Log of DOD	k2= 1/t*((DoD) (per day)
23	0.114773082	12.27443217	1.363825797	0.134758901	2.579024541	0.72427587	13.86123832
22	0.1096209	16.73806098	1.394838415	0.1445239	0.566577648	0.716003344	2.806950903
23	0.114773082	35.45947072	1.363825797	0.134758901	0.39823013	0.146128036	0.431827406
24	0.120167417	32.03010629	1.334587762	0.125347138	0.771411553	0.041392685	0.254738928
23	0.114773082	30.00416754	1.363825797	0.134758901	0.317845132	0.204119983	0.481441614
24	0.120167417	30.69551853	1.334587762	0.125347138	0.38785098	0.414973348	1.284016706
24	0.120167417	26.69175525	1.334587762	0.125347138	0.498395188	0.505149978	2.00853663
25	0.125815286	28.75523562	1.307056165	0.11629425	0.195305082	0.255272505	0.428705785

J: Data Sheet for the Month of May

SAMPLING POINTS	V1 (m/s)	V2 (m/s)	V3 (m/s)	MEAN VELOCITY (m/s)	Average time (days)	D1 (m)	D2 (m)	D3 (m)	MEAN DEPTH (m)
S1	0.22	0.27	0.22	0.236666667	0.015160407	1.68	2.5	1	1.726666667
S2	0.2	0.28	0.25	0.243333333	0.125095129	0.54	1.42	3.5	1.82
S3	0.143	0.171	0.112	0.142	0.281201095	0.76	1.64	1.42	1.273333333
S4	0.33	0.35	0.3	0.326666667	0.122696995	0.88	1.58	1.38	1.28
S5	0.21	0.24	0.21	0.22	0.244107744	0.48	1.62	1.44	1.18
S6	0.102	0.131	0.113	0.115333333	0.485709698	0.83	1.6	1	1.143333333
S7	0.114	0.138	0.107	0.119666667	0.518415351	0.47	1.34	0.93	0.913333333
S8	0.134	0.142	0.138	0.138	0.675993022	1.53	1.77	1.58	1.626666667

K: Data Sheet for the Month of May

Hydraulic Radius (m)	RELATIVE DISTANCE	BOD (mg/l)	DO(mg/l)	DO (saturated) (mg/l)	Dissolved Oxygen Deficit (mg/l)	pH
0.863333333	0.31	8	3.8	8.6	4.8	6.4
0.91	2.63	7	4	8.7	4.7	6.3
0.636666667	3.45	7	3.5	8.6	5.1	6.5
0.64	3.463	6	3.8	8.3	4.5	6.3
0.59	4.64	8	3	8.3	5.3	6.2
0.571666667	4.84	9	3.5	8.4	4.9	6.4
0.456666667	5.36	21	5.5	8.4	2.9	6.6
0.813333333	8.06	13	5	8.6	3.6	6.6

L: Data Sheet for the Month of May

TEMP W	ki= (0.1*(1.047)^(T-20)	Lo= L/(1-10^(-ki*t)	Lo/L	log(Lo/L)	k1= 1/t*Log(Lo/L)	Log of DOD	k2= 1/t*((DoD) (per day)
23	0.114773082	10.91060638	1.363825797	0.134758901	8.88887099	0.681241237	44.93555104
22	0.1096209	9.763868904	1.394838415	0.1445239	1.155311964	0.672097858	5.372694055
23	0.114773082	9.546780579	1.363825797	0.134758901	0.479226088	0.707570176	2.516242602
25	0.125815286	7.842336987	1.307056165	0.11629425	0.947816605	0.653212514	5.323785732
25	0.125815286	10.45644932	1.307056165	0.11629425	0.476405409	0.72427587	2.967033562
24	0.120167417	12.01128986	1.334587762	0.125347138	0.258070075	0.69019608	1.421005351
24	0.120167417	28.02634301	1.334587762	0.125347138	0.241789017	0.462397998	0.891945034
23	0.114773082	17.72973536	1.363825797	0.134758901	0.199349544	0.556302501	0.822941188

M: Data Sheet for the Month of June

SAMPLING POINTS	V1 (m/s)	V2 (m/s)	V3 (m/s)	MEAN VELOCITY (m/s)	Average time (days)	D1 (m)	D2 (m)	D3 (m)	MEAN DEPTH (m)
S1	0.19	0.21	0.16	0.186666667	0.01922123	3.46	4.6	3.26	3.773333333
S2	0.3	0.4	0.25	0.316666667	0.096125731	2.84	3.63	5.4	3.956666667
S3	0.24	0.29	0.24	0.256666667	0.155573593	2.84	3.52	3.48	3.28
S4	0.2	0.3	0.24	0.246666667	0.162490616	3.88	3.58	3.38	3.613333333
S5	0.25	0.3	0.29	0.28	0.191798942	2.46	3.68	3.48	3.206666667
S6	0.16	0.3	0.24	0.233333333	0.240079365	2.83	3.6	3.2	3.21
S7	0.3	0.4	0.3	0.333333333	0.186111111	2.48	2.36	2.2	2.346666667
S8	0.35	0.4	0.38	0.376666667	0.2476647	3.62	3.79	3.83	3.746666667

N: Data Sheet for the Month of June

Hydraulic Radius (m)	RELATIVE DISTANCE	BOD (mg/l)	DO(mg/l)	DO (saturated) (mg/l)	Dissolved Oxygen Deficit (mg/l)	pH
1.886666667	0.31	7	3.5	9.3	5.8	6.6
1.978333333	2.63	7	4	9.3	5.3	6.6
1.64	3.45	6	3.5	9.3	5.8	6.5
1.806666667	3.463	6	3.3	8.7	5.4	6.4
1.603333333	4.64	8	4	8.6	4.6	6.8
1.605	4.84	14	5	8.7	3.7	6.6
1.173333333	5.36	21	5.7	8.4	2.7	6.7
1.873333333	8.06	12	5.5	8.4	2.9	6.8

O: Data Sheet for the Month of June

TEMP W	ki= (0.1*(1.047)^(T-20)	Lo= L/(1-10^(-ki*t)	Lo/L	log(Lo/L)	k1= 1/t*Log(Lo/L)	Log of DOD	k2= 1/t*((DoD) (per day)
19	0.096153846	10.45626877	1.493752681	0.174278698	9.066989804	0.763427994	39.71795703
19	0.096153846	10.45626877	1.493752681	0.174278698	1.813028583	0.72427587	7.534672164
19	0.096153846	8.962516088	1.493752681	0.174278698	1.120233161	0.763427994	4.907182373
22	0.10816	8.425456113	1.404242685	0.14744217	0.907388835	0.73239376	4.507298819
23	0.1124864	11.01753617	1.377192022	0.138994498	0.724688556	0.662757832	3.455482212
22	0.10816	19.6593976	1.404242685	0.14744217	0.614139288	0.568201724	2.366724537
24	0.116985856	28.38061433	1.351457825	0.130802497	0.702819388	0.431363764	2.317775449
24	0.116985856	16.2174939	1.351457825	0.130802497	0.528143483	0.462397998	1.867032313

P: Data Sheet for the Month of July

SAMPLING POINTS	V1 (m/s)	V2 (m/s)	V3 (m/s)	MEAN VELOCITY (m/s)	Average time (days)	D1 (m)	D2 (m)	D3 (m)	MEAN DEPTH (m)
S1	0.33	0.4	0.26	0.33	0.010872615	3.88	5.2	3.66	4.246666667
S2	0.28	0.3	0.29	0.29	0.104964879	3.42	4.22	6	4.546666667
S3	0.33	0.4	0.34	0.356666667	0.111954829	3.43	4.21	3.44	3.693333333
S4	0.28	0.4	0.35	0.343333333	0.116740831	3.46	4.13	3.87	3.82
S5	0.34	0.4	0.28	0.34	0.15795207	3.05	4.21	4.08	3.78
S6	0.45	0.4	0.33	0.393333333	0.142419962	3.42	4.21	3.82	3.816666667
S7	0.45	0.4	0.33	0.393333333	0.157721281	3.01	2.96	2.7	2.89
S8	0.3	0.33	0.32	0.316666667	0.294590643	4.12	4.29	4.43	4.28

Q: Data Sheet for the Month of July

Hydraulic Radius (m)	RELATIVE DISTANCE	BOD (mg/l)	DO(mg/l)	DO (saturated) (mg/l)	Dissolved Oxygen Deficit (mg/l)	WIDTH(m)	pH
2.123333333	0.31	40	3.2	9.1	5.9	216	6.5
2.273333333	2.63	6	3	9.3	6.3	255	6.7
1.846666667	3.45	8	3.8	9.3	5.5	287	6.7
1.91	3.463	8	3.8	9.1	5.3	216	6.4
1.89	4.64	9	4	9.1	5.1	191	6.3
1.908333333	4.84	5	2.6	8.9	6.3	132	6.5
1.445	5.36	17	5.7	8.7	3	244	6.2
2.14	8.06	19	6.5	8.7	2.2	284	6.4

Q: Data Sheet for the Month of July

TEMP W	ki= (0.1*(1.047)^(T-20)	Lo= L/(1-10^(-ki*t)	Lo/L	log(Lo/L)	k1= 1/t*Log(Lo/L)	Log of DOD	k2= 1/t*((DoD) (per day)
20	0.1	58.49901182	1.462475296	0.165088539	15.1838852	0.770852012	70.89849212
19	0.095510984	8.995511015	1.499251836	0.175874589	1.675556543	0.799340549	7.615314375
19	0.095510984	11.99401469	1.499251836	0.175874589	1.570942418	0.740362689	6.613048301
20	0.1	11.69980236	1.462475296	0.165088539	1.414145657	0.72427587	6.204134968
20	0.1	13.16227766	1.462475296	0.165088539	1.045181231	0.707570176	4.479651184
21	0.1047	7.138483896	1.427696779	0.15463598	1.085774615	0.799340549	5.612559759
22	0.1096209	23.71225305	1.394838415	0.1445239	0.916324665	0.477121255	3.025091179
22	0.1096209	26.50192988	1.394838415	0.1445239	0.490592295	0.342422681	1.16236781