EVALUATION OF WATER QUALITY MODELLING PARAMETERS: TOWARDS THE EVOLVEMENT OF RE-AERATION COEFFICIENT FOR RIVERS IN THE NIGERIAN ENVIRONMENT

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DECLARATION

I, David Olugbenga Omole, declare that this thesis was done entirely by me under the supervision of Dr. E.O. Longe (Major Supervisor) of the Department of Civil and Environmental Engineering, University of Lagos, Akoka-Yaba, Lagos State and Dr. I.K. Adewumi (Co-Supervisor) of the Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife, Osun State. The thesis has not been presented, either wholly or partly, for any degree elsewhere before. All sources of scholarly information used in this thesis were duly acknowledged.

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Omole, D.O.

CERTIFICATION

This thesis titled ***Evaluation of Water Quality Modelling Parameters: Towards the Evolvement of Re-aeration Coefficient for Rivers in the Nigerian Environment*** carried out by Omole, David Olugbenga under our joint supervision meets the regulation governing the award of the degree of Doctor of Philosophy (PhD) in Civil Engineering of the Covenant University, Ota, Ogun State, Nigeria. We certify that it has not been submitted for the degree of PhD or any other degree in this or any other University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This work is dedicated to my wife, Folasade and my sons, Ayoola, Ikeoluwa and Iyanuoluwa who gave up so much personal comfort for the sake of this work.

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ABBREVIATIONS AND SYMBOLS

1. DO – Dissolved Oxygen
2. BOD - Biochemical Oxygen Demand
3. QUAL – Stream Water Quality models
4. CORMIX – Cornell Mixing Zone Expert
5. WASP – Watershed Quality Analysis Simulation Programme
6. FEPA – Federal Environmental Protection Agency
7. USEPA – United States Environmental Protection Agency
8. USGS – United States Geological Society
9. UNESCO – United Nations Education, Scientific and Cultural Organization
10. DV – Dependent Variable
11. IV – Independent Variable
12. ANOVA – Analysis of Variance
13. SSE – Error Sum of Squares
14. SSR – Residual sum of squares
15. SST – Total sum of squares
16. R^2 – correlation coefficient
17. Adj. R^2 – Adjusted Correlation coefficient
18. RMSE – Root mean square error
19. APHA - American Public Health Association
20. SPSS – Statistical Package for Social Sciences
21. MATLAB – Matrix Laboratory software
22. GPS – Global Positioning System
23. k_2 – re-aeration coefficient
24. k_1 – de-oxygenation coefficient
25. f – self purification factor
26. $\hat{\sigma}^2$ - estimated variance
27. mg/l – milligram per litre

ABSTRACT

This study was carried out on River Atuwara in Ota, Ogun State, Nigeria with the aim of developing a coefficient of re-aeration model applicable to River Atuwara and other rivers in the Nigerian environment. This was achieved by sourcing for data once every month from 22 sampling locations of interest within a pre-selected segment of the river over a period covering the dry and wet seasons. The data collected include hydraulic data (depth, width, velocity and time of travel) and water quality data such as Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD). Excel Spreadsheet and MATLAB were used for data processing. Regression analysis was carried out where stream velocity and depth were the regressors and the re-aeration constant k_2 (as a function of BOD, DO and Temperature) was the dependent variable.

A coefficient of re-aeration, k_2, (Atuwara re-aeration model) was developed and validated statistically. Its performance was also verified by comparing the model with 10 other internationally recognized models. It was found that even though Atuwara model performed better than Agunwamba model and most of the other well cited models, both Atuwara model and Agunwamba model could be safely adopted for future water quality modelling researches in the Nigerian environment.

Results of detailed water analysis of samples from River Atuwara shows high level of pollution hence it is unfit for human consumption without adequate treatment. It is recommended that River Atuwara and similar rivers in the country should be regularly monitored for quality control.

CHAPTER ONE

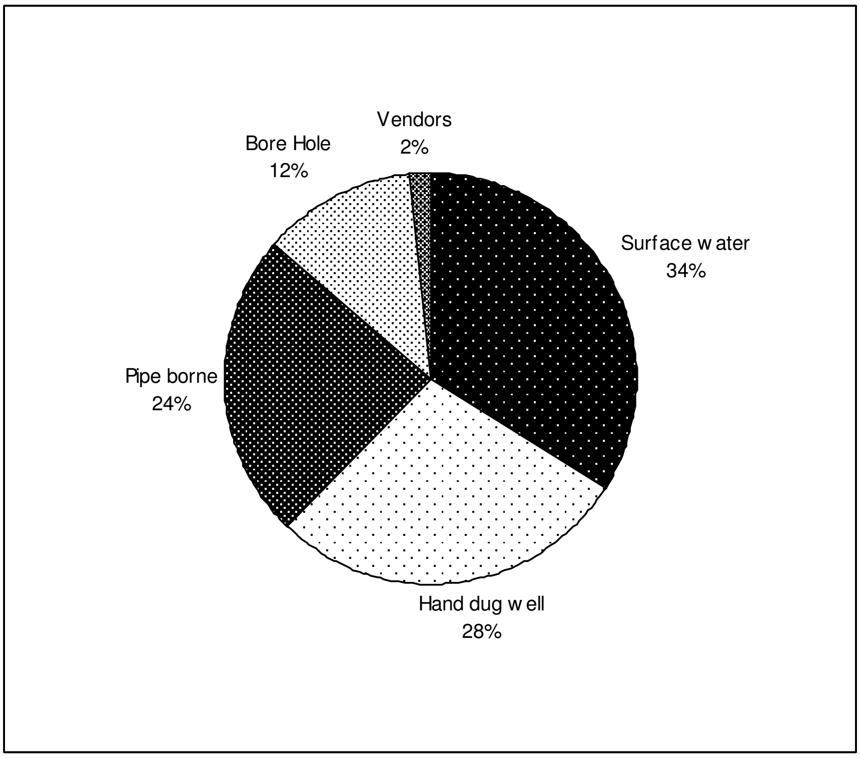
INTRODUCTION

1.1 Background Information

Fresh water sources can be broadly categorized into groundwater and surface water (Chapman, 1992). Surface water can again be sub-divided into ‘‘running’’ surface water bodies and ‘‘stationary’’ surface water bodies. Examples of the former include rivers, streams, and brooks while examples of the latter include lakes and ponds. The most abused of all surface water bodies are the running surface water bodies because people tend to believe that by disposing their wastes into these running water, they have been rid of their waste disposal problems. In spite of its relative abundance, water is still a very scarce resource when it is needed in its fresh form because 97.5% of all available water is salt water (Krantz and Kifferstein, 2007; UNESCO, 2006). Of the remaining 2.5%, 70% of it is frozen in the polar ice caps. The other 30% is mostly present as soil moisture or is trapped in underground aquifers. In the end, only 0.007% of all water on earth is readily accessible as fresh water for direct human use (UNESCO, 2006; Krantz and Kifferstein, 2007).

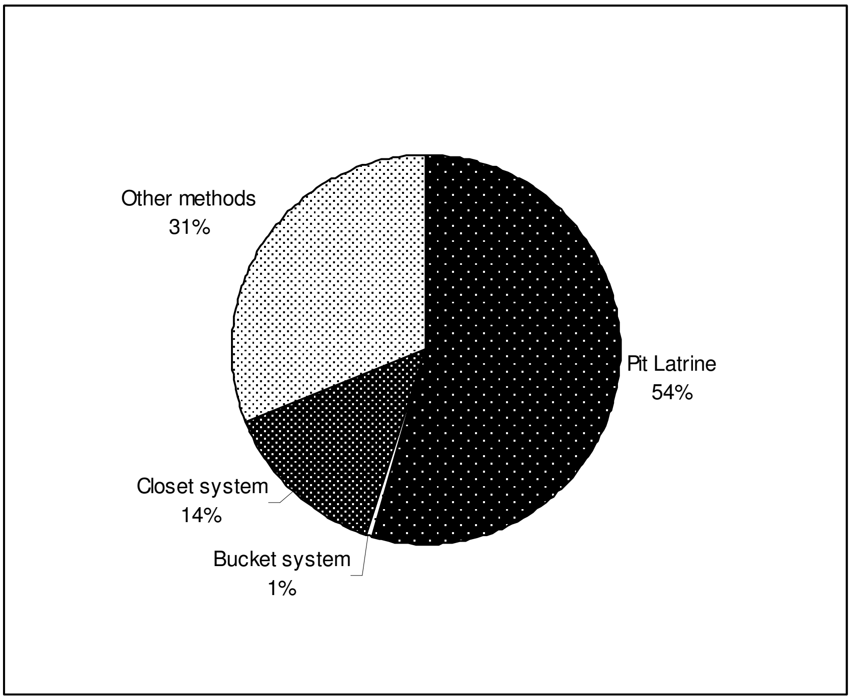
1.1.1 Water Sources Distribution in Nigeria

Record shows that 29% of Nigerians live in the rural areas, 33% reside in small towns and 38% live in the urban areas (FGN, 2000). World Bank (2005) also revealed that 91% of Nigerians living in the rural areas (which translate to 37 million Nigerians, using the 2006 census data) had no access whatsoever to treated water. Most Nigerians derive their water from surface water (springs/stream/rivers), hand dug wells, rain harvesting, pipe borne water, boreholes and vendors (FGN, 2000). It is estimated that 48% (about 67 million) Nigerians harness surface water for their domestic needs, 57% (79 million) use groundwater, 20% (27.8 million) harvest rain, 14% (19.5 million) have access to pipe borne water while 14% use boreholes (FGN, 2000). According to Ahianba *et al.*, (2008) 33.82% (47.3 million) Nigerians depend exclusively on surface water for their domestic water supply, 28.27% (39.3 million) on hand dug well sources, 24.38% (33.9 million) on pipe borne water, 11.83% (16.4 million) on borehole water and 1.7% (2.4 million) on water vendors (Fig. 1.1). Another interesting statistic suggests that 54.6% (75.9 million) Nigerians use pit latrines exclusively, 13.71% (1.91 million) use water closet exclusively, 0.58% (806, 200) use the bucket system and 31.16% (43.3 million) Nigerians use other unsanitary methods (Fig 1.2). Some of these unsanitary methods include defecating in open fields and disposal into surface water bodies (Ahianba *et al*, 2008). When rain falls, all the defecations disposed on land get washed down into the surface water bodies as non-point source pollution. This is beside the pollution being discharged into surface water bodies by industries. It can be inferred, therefore, that 47.3 million Nigerians are potentially at risk of epidemic outbreak if our surface waters are not adequately protected through legislations guided by scientific facts.



Source: Ahianba *et al.*, 2008

Figure 1.1 - Nigerian Household distribution by source of water supply



Source: Ahianba *et al.*, 2008

Figure 1.2 - Nigerian Household distribution by Toilet Facilities

It is therefore pertinent that the state of the available freshwater should be well monitored and managed through governmental regulations and proper use. However, proper legislation, monitoring and management cannot be achieved without scientific studies to ascertain the state of pollution and the assimilative capacity of the rivers and streams (Anyata and Nwaiwu, 2000). One of such areas of scientific study is water quality modelling.

1.2 Water Quality Modelling

Aquatic systems are very dynamic in terms of constituents. These constituents have direct impacts on water quality. By extension, these impacts on the water quality affect aquatic and human lives. 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 water quality models have been developed simply because no single model can be representative of all situations (Chapman, 1992). 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.

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, 2008). A prominent dependent variable present within most oxygen prediction models is the self-purification factor, often symbolized by the letter, *f,* and is obtained by the relationship expressed in equation

$$f = \frac{k_2}{k_1} \qquad 1.1$$

Where k_2 = coefficient of re-aeration and k_1 = coefficient of de-oxygenation. k_1 is a function of the effluent (wastewater) discharged into the aquatic body. It can be fully determined by testing the strength of the raw and diluted effluent after it had mixed with the water body (Hammer, 1986). The determination of re-aeration coefficient (k_2) on the other hand is more difficult (Garg, 2006). Therefore, k_2 is the critical term in equation 1.1. This self-purification factor, *f*, describes the unique measure of the ability of each surface water body to cleanse itself of whatever pollution that gets into it. While flowing surface water bodies get self-purified faster than slow moving or stagnant surface water bodies, a factor that contributes significantly to the rate of self-purification is temperature. Temperature is the distinguishing factor that differentiates k_2 in different geographical locations. Since temperature varies from place to place, it is logical that k_2 obtained from experiments performed in the temperate regions cannot be representative of tropical environments. Unfortunately, however, the available management policies and laws available in Nigeria have been based on the adaptation of imported laws from countries where their own laws were formulated based on their own local environmental conditions (Babalobi, 2005; AU, 2006). Temperature is a very unpredictable and dynamic parameter. However, established trends have been studied by scientists in the past who have published isothermal maps that demarcate the entire world into different temperature regimes (Herbertson, 1912; Parkins, 1926; Yongsiri *et al.*, 2004; RWWF, 2007). These regimes can therefore be borrowed to form the basis for experimental work in Nigeria which falls into the tropical region.

1.3 Description of the Study Location

River Atuwara (also known as River Iju) passes through Iju community in Ota, Ogun State Nigeria. Ota is an urban and industrial centre. Ado/Odo Ota Local Government Area (LGA) is the most populous LGA in Ogun State, with a population of 526, 565 (FRN, 2007). It is also the home to several other rivers like Balogun, Illo, Imojiba, Ogun and Abesan. The town is located between Latitude 60 30’N-60 50’N and longitude 30 02’E-30 25’E, with an elevation of 53 m above sea level (Iroham, 2005; Omole, 2010). River Atuwara is located within the Owo catchment area. It is a perennial river. Some rivers empty into it among which is River Balogun (Figure 1.3).

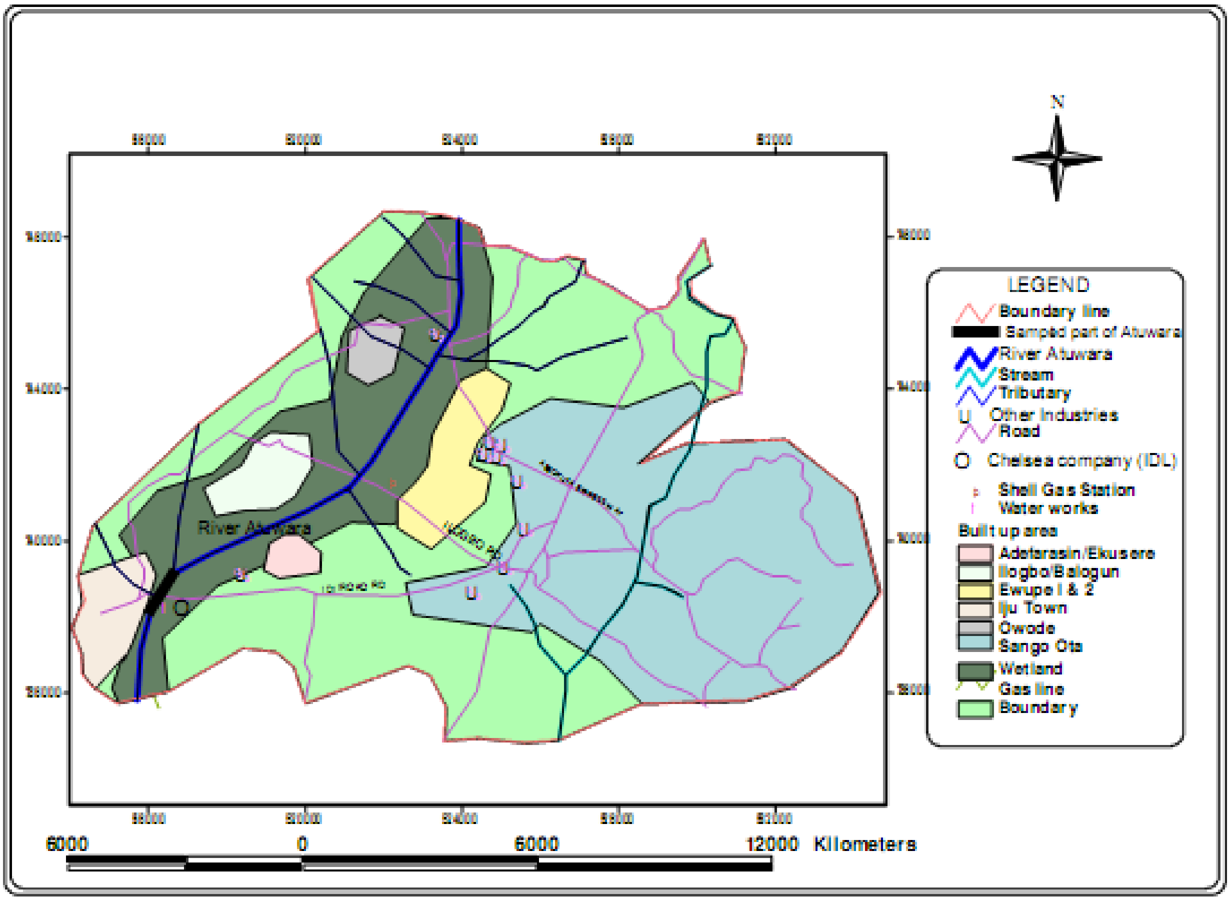


Figure 1.3: General Layout of the Study Area within Ado-Odo/Ota Local Government Area

1.4 Statement of the Problem

There is virtually no available literature on the subject of water quality modelling in Nigeria (Agunwamba *et al.*, 2007). A k_2 model was proposed for the Nigerian context by Agunwamba *et al.,* (2007) following a sampling exercise that was carried out during the rainy season only. In their recommendation, further work that would cut across the two main climatic seasons was proposed. This study therefore is an attempt to bridge this gap.

1.5 Aim of the Study

The aim of this study is to develop an appropriate re-aeration coefficient model that adequately represents rivers in the Nigerian environment and to propose a methodology that can be used in this pursuit.

1.6 Objectives of the Study

1. To acquire data on the hydrographic and physico-chemical parameters of River Atuwara in Ota, Ogun State, Nigeria that cut across the rainy and dry seasons.
2. To model the reaeration coefficient (k_2) based on the data obtained from the study of River Atuwara and to validate the same statistically.
3. To consider the relative suitability of the newly developed model to the existing models with respect to the Nigerian environment.

1.7 Significance of Study

At present, little research work has been carried out on water quality modelling in Nigeria. The research is therefore an attempt to bridge this existing gap.

1. A re-aeration coefficient model which reflected the existing local conditions was developed.

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

3. The research findings have been made available to all the stakeholders. This include: (a) the private citizens (so that they can be more alert to their responsibility of protecting their environment and guarding their health).

(b) the polluters (so that they can know that their activities have a direct impact on human lives and the environment) and

(c) the government (through their regulatory agencies, so that they can realise the impact of defaulters of pollution standards on people and the environment).

1.8 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 sampled reach was limited to 1.3km. The second aspect of this research work was the laboratory analyses of the raw water samples for physical, chemical and bacteriological characteristics. The final aspect of this study was the development of the k_2 model based on the data collected. Data recording and handling were carried out with the aid of Microsoft Excel while the modelling was done with the use of using MATLAB software.

CHAPTER TWO

LITERATURE REVIEW

2.1 Water Quality Modelling as a Field of Study

The field of water quality modelling was founded by the duo of Streeter and Phelps through their pioneering work published in 1925 (Villeneuve *et al.*, 1998; Streeter and Phelps, 1925). They raised 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 predicting model was given as:-

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

where $\frac{dD(t)}{dt}$ = the rate of change of the Dissolved Oxygen content (DO) of the river with time, k_1 = de-oxygenation constant, L(t) = BOD at the instantaneous time, t, k_2 = re-aeration constant 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; Fair *et al.*, 1971; Waite and Freeman, 1977).

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

where D = instantaneous DO, L_a = initial BOD, *f* is as previously defined in equation 1.1 (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°C is given in Table 2.1. Based on the original work by Streeter and Phelps, some models and software have been developed. These include the QUAL2E (stream water quality model used in the modelling of conventional pollutants such as nitrogen, phosphorus, DO, BOD, Sediment Oxygen Demand, Algae, pH, periphyton and pathogens), AQUATOX (used to predict fate of various pollutants such as nutrients and organic chemicals and their effect on the ecosystem including fish, invertebrates and aquatic plants), CORMIX (Cornell mixing zone expert system, designed for environmental impact assessment of mixing zones resulting from wastewater discharge from point sources) and WASP (water quality analysis simulation programme, used for modelling contaminant fate and transport in surface waters) (USEPA, 2007). While some of these software (such as QUAL2E) are very effective in predicting chemical pollutants, they are limited when it comes to assessing the effects on living aquatic life. This significant limitation was eliminated through the development of other software such as AQUATOX and CORMIX.

Table 2.1: The self-purification factor, *f*, of different water bodies at 20°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	1.5 - 2.0
4	Large streams of normal velocity	2.0 – 3.0
4	Swift stream	3.0 – 5.0
5	Rapids/ Water falls	Over 5.0

Source: Garg (2006)

2.2 Re-aeration Coefficient

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 de-oxygenation 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, 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°C - 0°C (Table 2.2).

Table 2.2: Solubility of Oxygen in water

Temperature (°C)	Dissolved Oxygen (mg/L)
0	14.6
1	14.2
2	13.9
3	13.5
4	13.1
5	12.8
6	12.5
7	12.1
8	11.8
9	11.6
10	11.3
11	11.0
12	10.8
13	10.5
14	10.3
15	10.1
16	9.9
17	9.7
18	9.5
19	9.3
20	9.1
21	8.9
22	8.7
23	8.6
24	8.4
25	8.3
26	8.1
27	8.0
28	7.8
29	7.7
30	7.6

Courtesy: 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 (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 (Al-Zboon and Al-Suhaili, 2009**;** Agunwamba *et al.*, 2007; Lin and Lee, 2007; Mehrdadi *et al.,* 2006; Park and Lee, 2002; Jha *et al.,* 2001; Baecheler, 1999; Churchill *et al.,* 1962). 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 (Alam *et al.,* 2007; Jha *et al,* 2005*;* Garg, 2006). 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

$$k_2 = c\frac{V^n}{H^m} \qquad 2.3a$$

where

V = velocity of flow

H = Hydraulic Radius

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.

$$k_2 = \frac{a_1 U^{b1} C_{e1}}{R^{d1}} \qquad 2.3b$$

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.

$$k_2 = \frac{5.026U^{0.969}(1.024)^{T-20}}{R^{1.673}} \qquad 2.4$$

where T is different from 20^{o}C.

Other k_2 models that have been used for computations include (Garg, 2006)

$$k_R(20) = \frac{3.9\sqrt{v}}{y^{1.5}} \qquad 2.5$$

reported by Garg (2006) where k_R = coefficient of re-aeration at 20^{o}C = 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:

$$k_R(T) = k_R(20)[1.016]^{T-20^0} \qquad 2.6$$

Tchobanoglous and Burton, (1991) reported two models. They are O'Connor and Dobbins (1958) and Wilcock (1988) model. O'Connor and Dobbins (1958) model is of the form:

$$k_2 = \frac{(D_oU)^{\frac{1}{2}}}{H^{\frac{3}{2}}} \qquad 2.7$$

where D_o = molecular diffusion coefficient for oxygen in water = 1.76 x 10^{-4} m^2/d at 20^{o}C to be multiplied by $1.037^{\,T-20^0C}$ for other temperatures, U = water current velocity. H= river depth. O'Connor and Dobbins (1958) model is based on surface renewal of re-aeration.

and Wilcock (1988) model, is of the form:

$$k_2 = C_e\frac{\Delta L}{t_f} \qquad 2.8$$

where ΔL = change in surface elevation, L; t_f = travel time, T; and C_e = escape coefficient = 0.177 m^{-1} at 20^{o}C. 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.

2.2.1 The Indian k_2 model

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

$$k_2 = 5.792 \frac{V^{0.5}}{H^{0.25}} \qquad 2.9$$

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 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 velocity 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.* 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. The refinement of the of the two earlier mentioned models to produce Jha *et al.* 2001 model clearly demonstrates that the inclusion of slope in model development appears to be a waste of effort since velocity is a function of slope.

2.2.2 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:

$$k_2 = \frac{10.046U^{2.696}}{H^{3.902}} \tag{2.10}$$

and

$$k_2 = \frac{1.923U^{1.325}}{H^{2.006}} \tag{2.11}$$

where U is mean stream velocity and H = mean stream depth. While equation 2.10 is used for slight slope rivers, equation 2.11 is used on medium slope rivers. However, it is expected that one model should have been sufficient for both models. The mention of slope as the reason for the adoption of two models is uncalled for since the basic laws of motion confirms that slope and velocity are directly proportional and interdependent.

2.2.3 The Nigerian k_2 model

In Nigeria, little known research has been done in this regard. However, Agunwamba *et al.,* 2007 calculated k_2 for Amadi creek in Port Harcourt, Rivers State, Nigeria. In this very study, k_2 was estimated as:

$$k_2 = \frac{11.6325U^{1.0954}}{R^{0.0016}} \qquad 2.12$$

where U = stream flow velocity (m/s) and R = hydraulic radius (m) of the stream. For this research, 30 data sets (two sets of 15 data from each location) were acquired over a period of 3 months (July – October, 2002) covering a distance of 2.8 km at 200 m interval. Field measured parameters included creek depth (m), width (m), water temperature (degree Celsius) and flow velocity. Data validation was based on comparison with equation 2.4. From their results, the authors observed that the predicted values of k_2 (using equation 2.4) were far lower than the experimentally determined k_2 values. Thereafter, Agunwamba *et al.*, (2007) used multiple regression analysis method to generate equation 2.12, which gave a result with lesser difference between the predicted and the experimentally determined values than equation 2.4. However, the model developed from this process was limited by the fact that data used for this research was taken during one of the two major climatic seasons of the region. The model would probably have had higher predictive capacity if sampling had been designed to cover both dry and rainy seasons.

2.3 Water Laws and Standards

Legislations are made after ascertaining the quality of water sources by identifying the common pollutants, causes, effects and mitigation measures. It is the data obtained from water quality assessments that lead to water quality standards and ultimately, legislations and regulations (Anyata and Nwaiwu, 2000). There are no fixed standards with regards to water quality. It is the use to which the water is to be put that determines the quality standard that must be imposed (Anyata and Nwaiwu, 2000). For example, water meant for human consumption, food and pharmaceutical industrial purposes has higher standards than water for fish production. Different countries and regions of the world have adopted suitable standards including the WHO standard, the European Community (EC) Limits, the US Limits, the USSR

Limits and of course, the Nigerian Limits as specified in the FEPA Guidelines and Standards for Environmental Pollution in Nigeria (FEPA, 1991). However, standards are of little or no effects when they are not adequately backed up by functional legislations. The bane of the Nigerian society has been the lack of political will to enforce legislations, which will be used to derive the necessary standards for public good.

While potable water supply may not be available in the nearest future to majority of the ever increasing citizenry of Nigeria, certain actions can be taken to ensure that the available resource is well managed and kept relatively safe through the instrument of scientific water quality assessment, design and specifications, regulations and public enlightenment. Developed countries have certain water laws that give water use rights to deserving individuals. For example, the Colorado State Government has some conditions attached to the issuance of these water use rights (CDPHE, 2005). Some of these conditions are:

(i) That the water should be put to beneficial use

(ii) That the use to which the water is put upstream by the prior user does not adversely impact on the quality of the water that gets downstream to the next user.

In addition, the Riparian law of the Colorado State Government says that anyone owning a piece of land adjacent to a surface water source can make beneficial use of the water but has no right to divert it (CDPHE, 2005). Moreover, the riparian owner can only use the water on the site and has no right to pollute the water beyond specified standards. The Appropriation law subsequently came into effect when more beneficial uses for water came up but the users could not secure land adjacent to surface water sources. They were thus enabled by law to remove and transport the water from the source to the point of use. These two laws are common water laws which confer property rights and not ownership rights. According to a Department for International Development (DFID) sponsored research on water rights, law and use in five African Countries also revealed that water related laws have still got a long way to go with respect to sophistication and implementation (Howsam, 1999).

The core essence of water quality modelling today is largely for the purposes of legislation and regulations. For instance, the widely recognized and utilized QUAL2 model derives directly from the U.S. regulatory framework for which it was developed and for which it is generally functional (Shanahan *et al*, 1998). This QUAL2 model made equation 2.2 very popular because it was the basis for the code that made QUAL2. However, the widespread availability and relative ease of access to QUAL2 encourages use that sometimes falls short of this implicit expectation (Shanahan *et al*, 1998). Few other countries have established water quality management laws of their own of which water quality modelling is as integral a part of the process as is the practice in the U.S. (Shanahan *et al*, 1998; U.S. Navy, 1999). Alternative modelling standards have yet to emerge in most other countries as most nations simply adopt the entire U.S. models without looking carefully at the context in which it was developed. Consequently, the operating standard for river water quality modelling is QUAL2 in U.S., Europe and most parts of the rest of the world (Shanahan *et al*, 1998). In typical stream DO model applications, k_2 is a very sensitive and critical constituent and is often taken to be a constant which is determined by calibrating it to each data set. However, intermittent discharges such as those associated with urban drainage, combined sewer overflows, or rainfall-derived nonpoint sources cause variations in stream flow and consequently in k_2. The implication of this type of change is that the determined k_2 under such peculiar conditions likely results in a value that is not transferable to other conditions. This difficulty is pronounced in small rivers, where calibration of k_2 is generally a problem (McCutcheon, 1989; Shanahan *et al*, 1998).

2.4 Statistical Analysis

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 viz 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.

2.4.1 Some Relevant Statistical Operations:

i. Correlation: – 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).

ii. 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 assumptions 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):

$$y_i = \alpha + \beta x_i + \varepsilon_i \qquad 2.13$$

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.

iii. 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).

iv. 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

$$E = \sum_{k=1}^{n} [f(x_k) - y_k]^2 \qquad 2.14$$

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

v. 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).

2.4.2 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).

2.4.3 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).

2.4.3.1 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).

$$\mathrm{SSE}=\sum_{1}^{n} w_i (y_i - \hat{y}_i)^2 \qquad 2.15$$

2.4.3.2 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

$$\mathrm{R}^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{SST} \qquad 2.16$$

Where

$$\mathrm{SST} = \mathrm{SSR}+\mathrm{SSE} \qquad 2.17$$

and

SSE is as defined in equation 2.15;

$$\mathrm{SSR} = \sum_{1}^{n} w_i (\hat{y}_i - \bar{y})^2 \qquad 2.18$$

and

$$\mathrm{SST} = \sum_{1}^{n} w_i (y_i - \bar{y})^2 \qquad 2.19$$

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.

2.4.3.3 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.

$$v = n - m \qquad 2.20$$

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.

$$\text{Adjusted } R^2 = 1 - \frac{SSE(n-1)}{SST(v)} \qquad 2.21$$

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.

2.4.3.4 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).

$$\text{RMSE} = \text{s} = \sqrt{MSE} \qquad 2.22$$

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

$$\text{MSE} = \frac{SSE}{v} \qquad 2.23$$

A RMSE value closer to 0 indicates a better fit.

CHAPTER THREE

METHODOLOGY

3.1 Selection of the Study Area

This research work was conducted on the segment of River Atuwara (also known in some quarters as River Iju). It passes through Iju community in Ota, Ogun State, Nigeria (Figure 1.3). The river has several confluences where several other rivers merge with it. The river criss-crosses a distance of about 24 km through the centre of Ota and empties into the Lagoon in Lagos State. Portions of the river can be sighted in communities such as Owode, Ilogbo, Balogun, Elebute and Mesan. The segment which was selected for this study covers a distance of 1.3 km. At the upstream end of this stretch is the point where the effluent discharged from an alcoholic distillery, Intercontinental distilleries enter the river (Plates 3.1 - 3.3). The effluent is a subtle form of pollution because it is colourless. However it has very strong odour and high temperature and it has severely reduced the aquatic life population in the immediate vicinity where it enters river Atuwara. At the downstream end is a village settlement (Iju Village) where people fetch and drink water from the same river (Plate 3.4). Aside from the distillery effluent discharge point, some other waste discharge points were identified along the river course, upstream of the chosen reference point including a place where human wastes are discharged secretly at night to the river bank by a commercial scale sewage tanker driver (Plate 3.5). This happens about twice weekly on average, although its itinerary is not predictable. The tanker was sighted once during the field visits. When rain falls, some of the human wastes get washed into the river. Other sources of waste discharge into the river include a slaughter house, a pig farm, car wash and a soft-drink bottling company several kilometres upstream from the reference point. Whenever this soft drink company discharges its effluent a dark coloration of the river is observed. This bigger pollution could not be selected for the study however because the river has several sections that pass through un-navigable landscape. Furthermore, many communities along the river demand for compensation before allowing navigation and research activities.

Plate 3.1 – The industrial effluent flowing along the road down towards the river

Plate 3.2 – The industrial effluent accumulation (left) from where it seeps into the river body (right)

Plate 3.3 –Industrial Effluent accumulation beside the river body

Plate 3.4 – Villagers of Iju collecting the river water for domestic use

Plate 3.5 – Sewage being taken near the river for disposal

3.2 Determination of Sampling Stations

Twenty two (22) sampling stations were marked out for the data gathering (Figure 3.1-3.2). Wooden pegs that were painted red were used as location markers. The first point is 50 m upstream of the discharge point and it was designated as S22. This is to give an idea of the ambient conditions before a major pollution occurred. The raw effluent was designated S21. The discharge point which is the reference point was designated S20. Sampling stations were generally established at every 100 m. The Hand-held etrex GPS unit was used to establish the sampling distances, elevation, twists and turns of the river. Where confluences were identified (two in number), three sampling points were established close to each other. One sampling point was located on the main river (River Atuwara) upstream of the confluence, the second at the mouth of the effluent river (before it gets to the confluence) while the third was located just below the mixing point where the two rivers converged. It was observed that the Ogun State Water Corporation withdraws water from the river at S4. Other human activities along the river that were observed include dredging of sand from the river bed for construction purposes, laundry, bathing and baptism (by church faithful) etc. The final point (S1) was at Iju Village where villagers fetch water, bathe and do their laundry. Table 3.1 shows the details of the sampling stations.

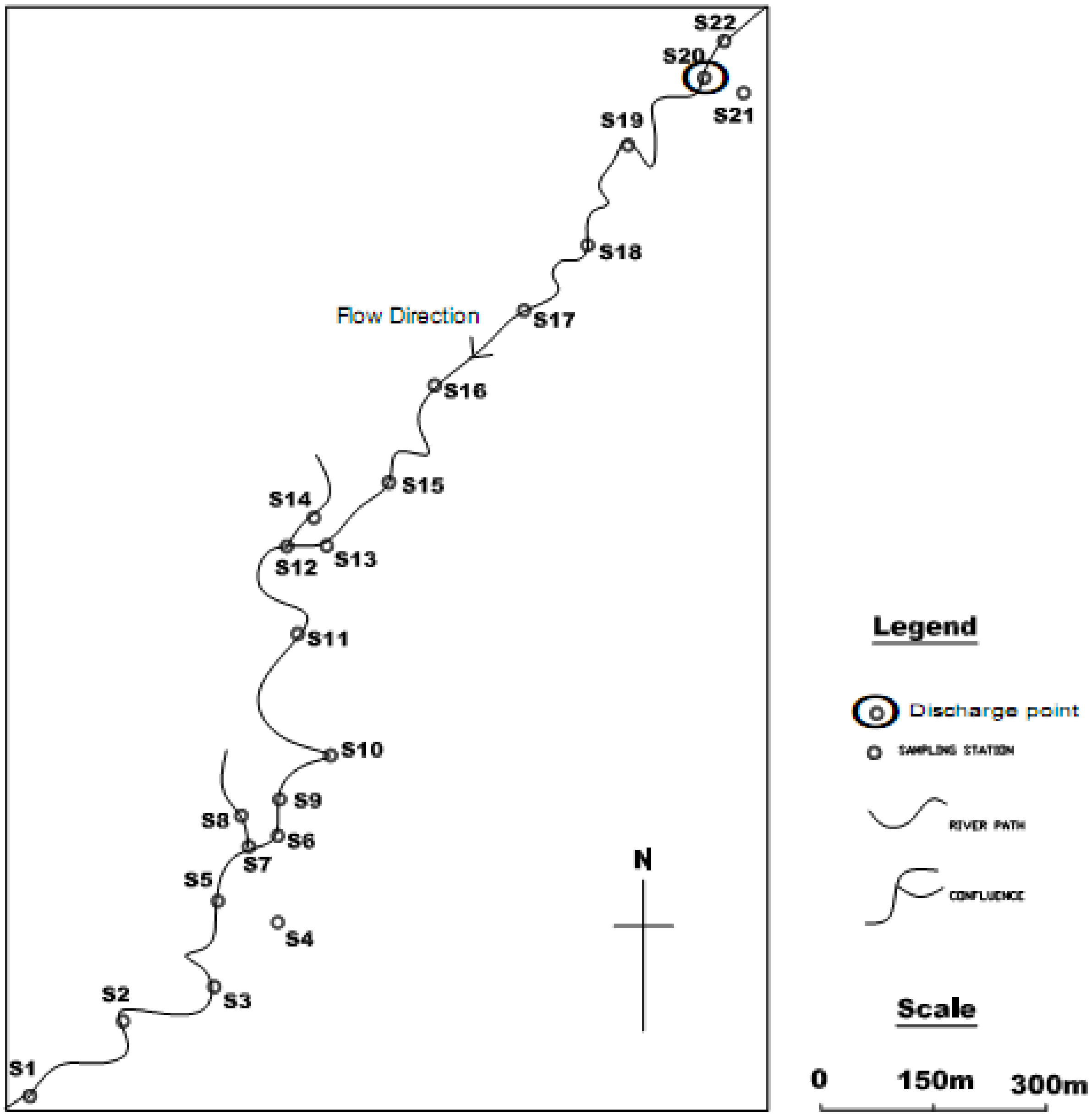


Fig. 3.1: Field Sampling Stations

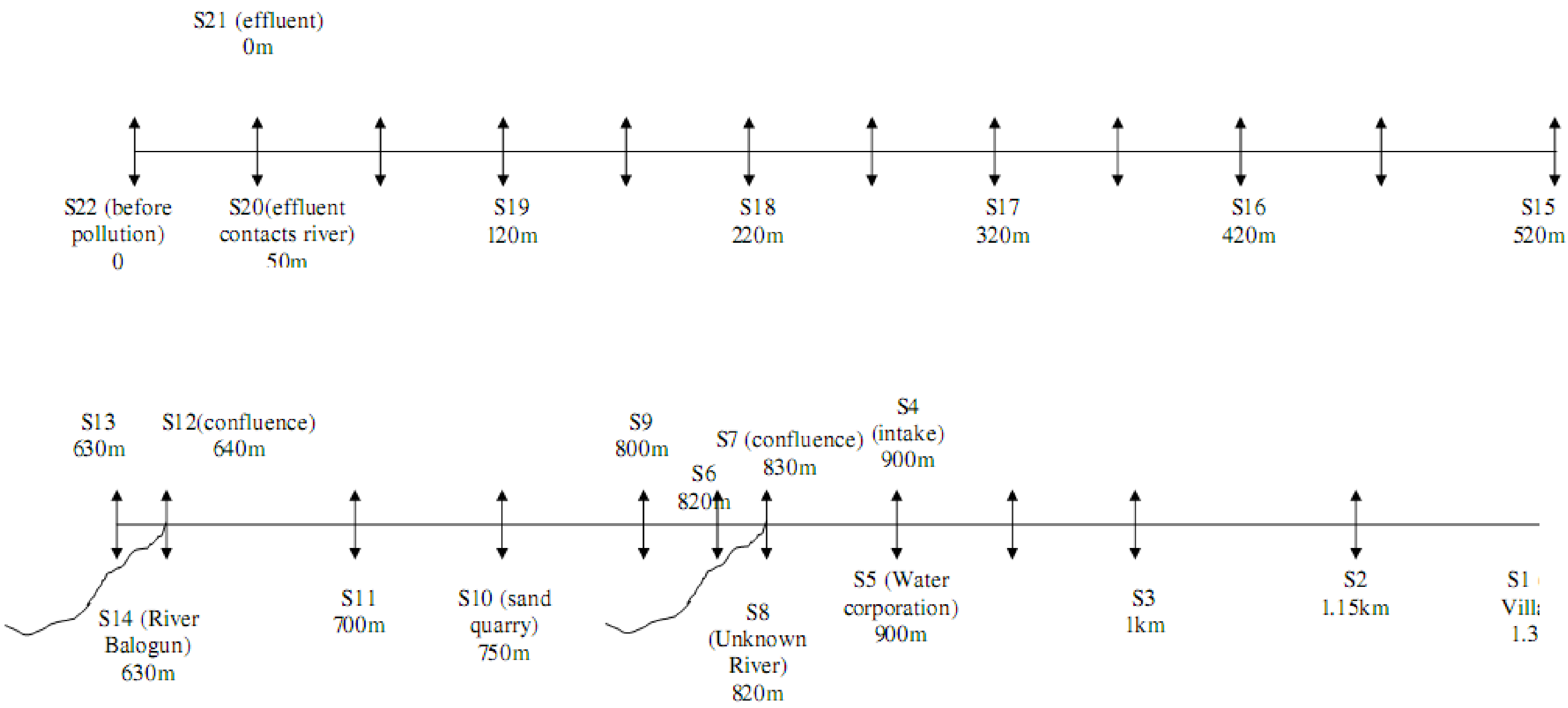


Fig. 3.2: Linear Representation of Sampling Points

Table 3.1: Details of Sampling Stations

S/N	STATION DESCRIPTION	INTER STATION DISTANCE	CUMMULATIVE DISTANCE	ELEVATION (M)	GEOGRAPHIC LOCATION
S1	Iju Villagers source of water	150	1300		N 06° 40.833’ E003° 08.746’
S2	Bamboo growth	150	1150	6	N 06° 40.877’ E003° 08.781’
S3	Bamboo growth	100	1000	9	N 06° 40.891’ E003° 08.825’
S4	Water Corporation (intake)	70	900	14	
S5	Water Corporation (midstream)	70	900		
S6	Confluence 1a (main river, Bridge Area)	10	830	14	
S7	Confluence 1b (meeting point)	20	820	14	N 06° 40.954’ E003° 08.854’
S8	Confluence 1c (Stagnant water; Unknown river)	Ditto	820	14	
S9	After confluence (thick tree root)	50	800		
S10	Sand Quarrying	50	750	9	N 06° 40.975’ E003° 08.892’
S11	Before confluence 2 (plenty pegs)	60	700	10	N 06° 41.039’ E003° 08.895’
S12	Confluence 2b (meeting point)	10	640		
S13	Confluence 2a Main river)	110	630	14	N 06° 41.072’ E003° 08.903’
S14	Confluence 2c (River Balogun)	Ditto	630		
S15	After confluence (sharp bend; overhead plant growth)	100	520	12	N 06° 41.083’ E003° 08.956’
S16	Slight bend	100	420	14	N 06° 41.121’ E003° 08.990’
S17	Groove-like environment	100	320	14	N 06° 41.150’ E003° 09.037’
S18	our peg (station marker)	100	220	13	N 06° 41.178’ E003° 09.080’
S19	Upright peg midstream (mild chelsea influent)	70	120	11	N 06° 41.210’ E003° 09.110’
S20	Main chelsea influent point	50	50	11	
S21	Raw effluent (thick bamboo cover)	Off river	Off river		N 06° 41.241’ E003° 09.135’
S22	50m upstream of chelsea effluent	0	0	17	N 06° 41.249’ E003° 09.142’
S23	Raw effluent along the road				

3.3 Field Activities

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

3.3.1 Field Observation

The purpose of the field observation visit was not just about getting familiar with the river itself but also with the people living around the river as well as the environment hosting the river. This exercise led to:

- The determination of the sources of waste discharge into the river.
- The identification of the sampling points that were marked out for the research.

3.3.2 Field Sampling Visits

This is the stage when repeated visits were made to collect data. Some of the parameters were determined in-situ while others were determined in the laboratory. The parameters that were determined in-situ could be further sub-divided into two namely: physical water quality parameters and hydraulic parameters. The physical parameters that were determined in-situ were pH and 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 two parameters, DO and BOD, were determined in the laboratory. These can be classified as chemical water quality parameters. Table 3.2 was created to enhance easy comprehension of the parameter classification and their relevance to the study. It should be mentioned however that S1, S20 and S21 were fully characterized for a minimum of 17 physico-chemical parameters each. However, this will be once because of the high cost of analysis. In order to capture the climatic conditions of both the dry and rainy seasons, sampling was carried out in the following months:

i. **Rainy season:** April, May, July, August, September (2009)
ii. **Dry Season:** March 2009, January 2010 and February 2010

However for modelling purposes, only July, August and September data were used for the rainy season while January, February and March data were used for the dry season. The samplings were done once in each month.

Table 3.2: Parameters Measured and Relevance to Study

	s/n	Parameter	Relevance to Study
Physico-Chemical Parameters	1	Dissolved Oxygen, DO	A drop in the DO level of any stream is an indication of the presence of pollution. However, the level of DO in the running surface water improves downstream of the point of waste discharge, provided there is no other pollution source downstream. The knowledge of this parameter supplies information on the condition of the surface water body being considered. Since it not realistic to measure every inch of the surface water for the DO content, modelling becomes a very valuable tool in predicting what would likely be the condition of the surface water in any instantaneous location.
	2	BOD	The waste being discharged into the surface water uses up oxygen in order for it to get broken down. The rate at which it is being used up depends on the waste concentration.
	3	Ph	This parameter furnishes general information on the level of acidity or alkalinity of the surface water body.
	4	Temperature	This parameter affects the rate at which atmospheric oxygen gets dissolved in water. The lower the temperature, the higher the DO content.
Hydraulic Parameters	5	Velocity	This parameter also determines the rate of Oxygen dissolution in water. Rapid and turbulent flowing water bodies are generally cleaner than stagnant or laminar flowing water bodies.
	6	River Depth	This parameter also affects the DO content of any water body. Because the atmospheric oxygen can only be in contact with the surface portion of the water body alone, deep water bodies generally have less DO content than shallow water.
	7	River Width	This parameter, together with the river depth supplies information on the river discharge i.e. the volume of water flowing at any point in time. Volume has a direct impact on the dilution power of any surface water body on pollutants as well as atmospheric oxygen.

3.3.2.1 Rationale for Gathering Data Once Every Month

It is practically impossible to collect data from every part of the river along the selected segment every day of the year. Yet there is the need to sample on an all-season basis in order to capture the prevalent temperature and hydrological conditions peculiar to each season of the year in Nigeria. Nigeria has 2 major seasons- Rainy season and dry season. The Rainy season commences around April each year and reaches its peak between June and August. The dry season begins around October and reaches its peak between December and February. The highest ambient temperatures usually occur during the dry season. Therefore, the sampling visits were scheduled to take place days that fall between the 10th to the 20th of each month during the dry season. During the rainy season, the dilution effect occasioned by storm events was the target. Therefore, the day following a major downpour was targeted as the sampling date. However, since the four different people were not on a permanent employment for this project, the goal of fixing sampling exercises within 24 hours of a storm events was difficult to meet. Thus for this research work, an allowance of 72 hours following a storm event was made since at least 2 days prior notice had to be given to the team that worked on the field visits.

3.3.2.2 Activities During the Field Exercises

On the sampling dates, the team assembled at the river side by 7am when the exercises were scheduled to start. At each sampling point, the boat berthed. Two assistants stretched the tape across the width of the river to determine the width and remain in position (Plate 3.9). At the portions where the river was too wide for the boat, the tape was hooked to a nearby tree or shrub and the boat was moved to the other end. The depth was measured using the Speedtech portable sounder (Plate 3.10) at three different but equal intervals measured along the stretched out tape (Figure 3.3). Also, velocity was obtained at the intervals where depth measurements were obtained using a Geopacks flow meter (Plate 3.8). The flow meter requires a full one minute to get an accurate value. Then, the water samples for DO and BOD respectively are collected from the point where the mid-stream velocity was taken and stored away. Likewise, pH was determined at the mid-stream water surface (Plate 3.6). Finally, the ambient (air) and water temperature at that location were recorded using a Eurolab digital thermometer which can function in different media (Plate 3.7). All recordings were done on paper and transferred to the excel spreadsheet on the laptop computer the next day.

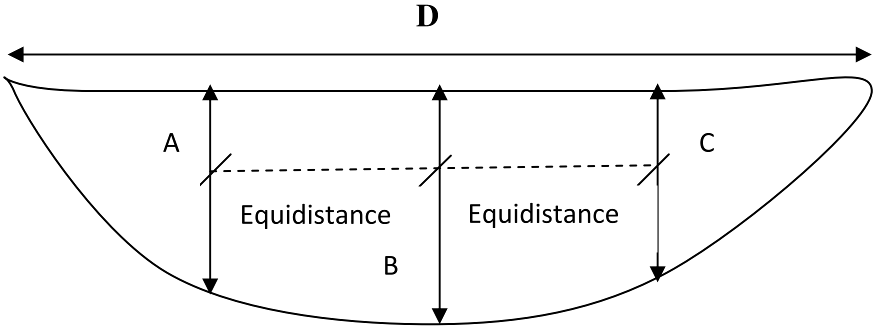


Figure 3.3 - Sampling Cross-section

3.4 Materials

The river was navigated with the aid of a paddled boat. Rain boots and cutlasses were used for safety and for clearing of the water way. Four assistants were employed. While two assistants concentrated on steering the boat, the other two assisted in holding the other end of the measuring tape, cutting obstructing bush and trees and carrying of the water samples from the river to the waiting car. The geographical location of each sampling point was determined through the use of a handheld Garmin eTrex Summit HC GPS unit (Table 3.1). Other materials used and the mode of use are presented in Table 3.3.

Table 3.3 – Parameters, Equipment and Processes of Parameter Determination Schedule for Field Work

	s/n	Parameter	Material Required	Process of Data Capture
Physico-Chemical Parameters	1	Dissolved Oxygen, DO	300 ml DO (Glass) Bottles, concentrated H_2SO_4.	Water samples were obtained in glass bottles and the oxygen content was fixed with two drops of concentrated H_2SO_4. Thereafter, it is stoppered and transported to the laboratory for titrimetric analysis (Environment Canada, 1983).
	2	BOD	300 ml Amber coloured (Glass) bottles, chilled water for preservation.	The obtained water sample was poured into it and stoppered immediately with the cover to prevent exposure to the atmosphere. The chilled water was to keep the samples at 4°C during transportation to the laboratory (Environment Canada, 1983)
	3	pH	pH meter	This equipment, when dipped in the water body gave a reading of the pH value. (Plate 3.6).
	4	Temperature	Eurolab digital Thermometer	The probe was held in the air and the meter was powered. Record of air temperature is taken when the reading stabilizes. Then, the probe was let into the water and the reading taken likewise (Plate 3.7).
Hydraulic Parameters	5	Velocity	Geopacks Stream flow sensor	The impeller of this piece of equipment is let down to the required depth of the stream (which is approximately 2/3 of the depth from the water surface) to measure its flow velocity (Plate 3.8). Velocity was measured at 3 points along each stream cross-section.
	6	River Depth	Speedtech Portable Depth Sounder	The equipment used here looks and works more like torchlight. Its head is dipped in the river. The switch was engaged and the depth flashes on the instrument (Plate 3.9)
	7	River Width	Measuring tape	The measuring tape was stretched across the river with the help of an assistant (Plate 3.10)

Plate 3.6: Field pH meter

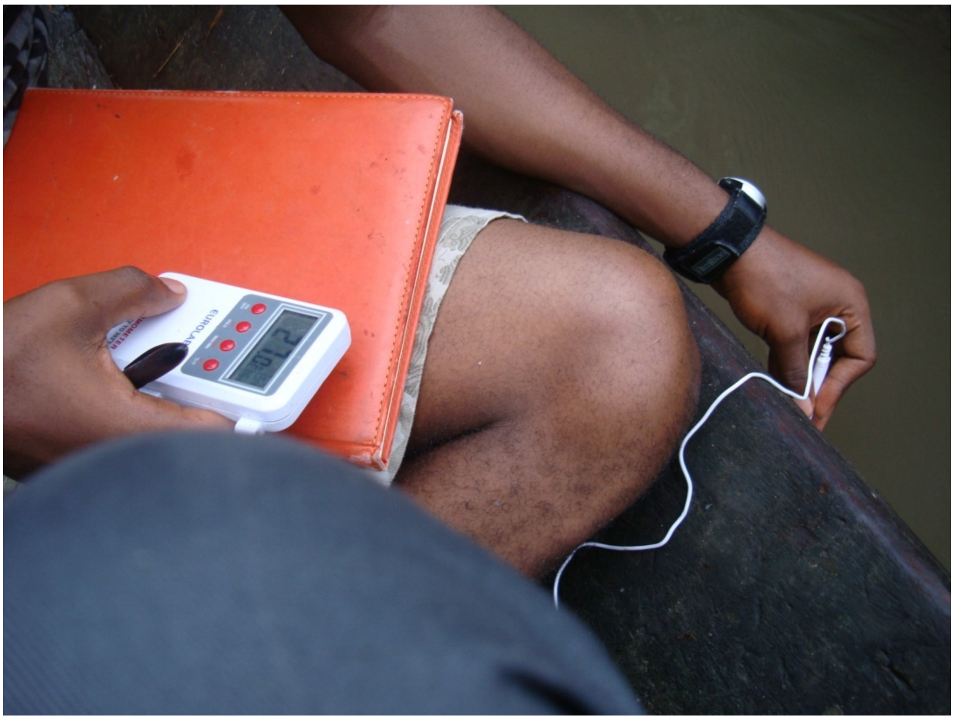


Plate 3.7: Eurolab digital thermometer with sensitive probe

Plate 3.8: Geopacks Stream flow sensor with its pole and fan-like impeller

Plate 3.9 – Measuring the river width with a tape

Plate 3.10: The Speedtech Portable Depth Sounder being used to measure depth

Grab water samples were obtained from the depth where mid-stream velocity was obtained (Table 3.3, item 5).

3.5 Laboratory Analysis

All laboratory analyses were done at Tripple E labortatories, Goodwill House, 278, Ikorodu Road, Lagos State. The DO of all water samples was determined using titrimetric method (Azide modification) (APHA, 1992). The water samples meant for BOD determination were stored in the gallenkamp series cooled incubator for 5 days which had been 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 obtained were transferred to the excel spreadsheet of the Laptop computer.

3.6 Data Analysis

The average of three months data were used (Section 3.2.2) to model for each season. Thus a model was obtained for each season. However, since the dry weather flow represents the worst condition, the dry season model was adopted and presented as the output of this research work.

3.6.1 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 done with excel spreadsheet. The time of travel, *t*, was computed from velocity and distance travelled as follows:

$$\text{t (days)} = \frac{distance\ (km)}{velocity\ (km/hr)} \times \frac{1}{24\,hrs} \qquad (3.1)$$

The primary aim of the study was to model for a k_2 constant that can be used together with a de-oxygenation coefficient, k_1. The de-oxygenation coefficient, k_1 (day^{-1}), was computed from the equation 3.2 (Appendix 3) (Weiner and Matthews, 2003).

$$\text{L} = L_0 10^{-k_1 t} \qquad (3.2)$$

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

$$k_1 = \frac{1}{t}\log\left(\frac{L_o}{L}\right) \qquad (3.3)$$

Experimental k_2 (day^{-1}) was determined from the equation (Agunwamba *et al.,* 2007):

$$k_2 = \frac{(\log D_o - \log D)}{t} \qquad (3.4)$$

which is also the same as:

$$k_2 = \frac{\log\left(\frac{D_o}{D}\right)}{t} \qquad (3.5)$$

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 is used in equation 2.2 (the equation for predicting DO content along the river).

3.6.2 Re-aeration Coefficient Model

The modelling was done with the aid of MATLAB statistics toolbox (Appendices 1A and 1B) using a non linear model (Equation 2.3a).The model was statistically validated and compared with other selected models (Table 4.28). Full residual analysis was carried out in both the MATLAB and Excel Spreadsheet (Appendices 1A, 1B and 2). The equation with the best result was chosen based on statistic indicators such as Standard error, SE and coefficient of determination, R^2.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Data Gathering

Following the procedure outlined in section 3.2.2 to 3.4, data was gathered for eight different months between March 2009 and February 2010. The exact dates when data were gathered are as presented in Table 4.1.

Table 4.1: Dates on which Samples were taken and the conditions on site

s/n	season	date	Significant sampling condition
1	Dry	March 17, 2009	There was no precipitation prior to this date. However, it was drizzling during the sampling exercise
2	Rainy	April 17, 2009	There was precipitation within 24 hours of sampling.
3		May 11, 2009	Precipitation occurred 3 days before sampling on this date.
4		July 15, 2009	There was continuous heavy rainfall between 7thand 11th of the month and light showers for the two days preceding this date.
5		August 21, 2009	There was precipitation within less than 24 hours before this date and continuous drizzling between 18th and 19th of the month.
6		September 16, 2009	There was a heavy rainfall for 3days prior to this date.
7	Dry	January 20, 2010	There was no precipitation for 40 straight days save one which occurred 2 weeks prior to sampling.
8		February 10,2010	There was no form of precipitation for 34 straight days before this sampling date.

It was observed that there was precipitation in all the months of the year under study. This is not unconnected with the geographical location of the study area which falls in the mangrove forest (Figure 2.2) with high proximity to the Atlantic Ocean which is therefore characterized by an almost all-year round rainfall. However, the research results captured the prevalent conditions of the two extreme seasons.

The data obtained on a monthly basis include hydraulic properties of the stream channel, data on the physico-chemical properties of the water samples and temperature of the air in the immediate surroundings of the stream. The ambient temperature is shown in the same table with physico-chemical properties. The sampling stations, designations and station description are as presented in Table 3.1. Therefore, all sampling stations carried their designations such as S1, S2 etc.

4.1.1 Hydraulic Data

Hydraulic data include depth, stream velocity and width measurements as explained and illustrated in section 3.2.2.2. Data for all the eight (8) months are presented in Tables 4.2a-4.2h.

Assuming a semi-circular section, the Hydraulic Radius, H, was calculated using the following formula:

$$H = \frac{\frac{1}{2}Area}{\frac{1}{2}Perimeter} = \frac{\frac{\pi d^2}{8}}{\frac{\pi d}{2}} = \frac{d}{4} = \frac{r}{2} \qquad (4.1)$$

where d = diameter of a circle (mean depth). The mean depth (i.e. the diameter of a circle) at each cross-section was computed and divided by 4 as shown in equation 4.1.

The mean velocity, v, refers to the average of the three different velocity measurements taken at each cross-section.

Table 4.2a: Hydraulic Data for January 2010

S/N	WIDTH (m)	RIVER DEPTH (m)			MEAN DEPTH (m)	Hyd Rad, H (m)	VELOCITY (m/s)			LATITUDINAL MEAN VEL (m/s)
		A	B	C			A	B	C	
S1	10.0	0.61	0.73	0.61	0.650	0.325	0.01	0	0.02	0.013
S2	9.2	1.37	1.8	0.98	1.383	0.692	0.05	0.1	0.06	0.057
S3	6.3	1.13	1.49	0.73	1.117	0.558	0.17	0.2	0.15	0.162
S5	12.8	2.59	4.85	1.25	2.897	1.448	0.22	0.3	0.24	0.237
S6	7.3	0.34	0.49	0.4	0.410	0.205	0.35	0.5	0.4	0.417
S7	9.1	0.9	1.7	1.5	1.367	0.683	0.1	0.3	0.2	0.183
S9	8.3	0.5	0.85	1.45	0.933	0.467	0.25	0.3	0.23	0.270
S10	9.1	2.8	1.8	0.8	1.800	0.900	0.133	0.1	0.1	0.122
S11	7.5	0.64	0.64	0.7	0.660	0.330	0.2	0.3	0.25	0.260
S12	9.6	0.67	1.34	1.04	1.017	0.508	0.4	0.4	0.33	0.377
S13	7.5	0.73	1.13	0.58	0.813	0.407	0.15	0.2	0.16	0.162
S15	8.2	0.27	1.8	1.49	1.188	0.594	0.1	0.3	0.22	0.190
S16	6.7	0.61	1.8	0.67	1.027	0.513	0.25	0.2	0.21	0.220
S17	7.6	0.366	0.91	0.34	0.537	0.269	0.22	0.3	0.21	0.227
S18	8.0	0.671	0.975	0.79	0.812	0.406	0.18	0.2	0.2	0.193
S19	7.0	0.4	0.945	0.67	0.672	0.336	0.29	0.3	0.21	0.250
S20	7.1	0.49	0.762	0.49	0.581	0.290	0.24	0.3	0.25	0.260
S22	5.2	0.64	0.88	0.55	0.690	0.345	0.4	0.4	0.33	0.377

NB: S4 and S21 represent the intake and the raw effluents respectively. They are not along the stream and thus have no hydraulic measurements.

Table 4.2b: Hydraulic Data for February 2010

S/N	WIDTH (m)	RIVER DEPTH (m)			MEAN DEPTH (m)	Hyd Rad, H (m)	VELOCITY (m/s)			LAT.MEAN VELOCITY (m/s)
		A	B	C			A	B	C	
S1	8.2	0.335	0.61	0.27	0.406	0.203	0.01	0.1	0.04	0.033
S2	7.5	0.914	1.615	0.91	1.148	0.574	0.47	0.7	0.55	0.562
S3	5.1	0.488	0.975	0.34	0.599	0.300	0.2	0.2	0.15	0.183
S5	10.5	0.762	4.877	1.55	2.398	1.199	0.23	0.2	0.2	0.217
S6	5.5	0.914	1.219	0.76	0.965	0.483	0.44	0.5	0.35	0.430
S7	7.6	0.945	0.914	0.3	0.721	0.361	0.18	0.2	0.21	0.204
S9	6.4	0.457	0.518	1.43	0.803	0.401	0.21	0.2	0.21	0.214
S10	7.6	4.755	1.829	0.34	2.306	1.153	0.13	0.1	0.11	0.128
S11	5.9	0.518	0.853	0.49	0.620	0.310	0.3	0.3	0.25	0.294
S12	8.1	0.762	0.914	0.27	0.650	0.325	0.18	0.2	0.16	0.180
S13	5.7	0.335	1.067	0.82	0.742	0.371	0.22	0.3	0.2	0.223
S15	6.6	1.433	1.646	0.34	1.138	0.569	0.21	0.2	0.18	0.197
S16	5.9	0.853	1.341	0.27	0.823	0.412	0.28	0.3	0.3	0.298
S17	6.0	0.518	0.732	0.3	0.518	0.259	0.2	0.3	0.25	0.233
S18	6.2	0.335	1.737	1.58	1.219	0.610	0.17	0.2	0.21	0.193
S19	5.5	0.975	0.884	0.34	0.732	0.366	0.19	0.2	0.24	0.210
S20	5.4	0.396	0.579	0.94	0.641	0.320	0.22	0.3	0.2	0.223
S22	3.5	0.457	0.732	0.52	0.569	0.285	0.38	0.4	0.33	0.370

NB: S4 and S21 represent the intake and the raw effluents respectively. They are not along the stream and thus have no hydraulic measurements.

Table 4.2c: Hydraulic Data for March 2009

S/N	WIDTH (m)	DEPTH (FT)			MEAN DEPTH (m)	Hyd Rad, H (m)	VELOCITY (m/s)			LAT. MEAN VEL (m/s)
		A	B	C			A	B	C	
S1	11.6	1.6	2.5	1.8	0.599	0.300	0.01	0	0.03	0.027
S2	10.0	3.9	2.3	2.1	0.843	0.422	0.4	0.4	0.38	0.397
S3	11.2	3.2	4.5	1.5	0.935	0.467	0.25	0.3	0.24	0.253
S5	16.7	4.4	6.4	3.5	1.453	0.726	0.09	0.1	0.1	0.100
S6	7.0	2.9	4.4	3	1.047	0.523	0.75	0.8	0.7	0.753
S7	10.6	4.2	4.2	4.2	1.280	0.640	0.66	0.8	0.68	0.697
S9	9.4	6.1	5.3	2	1.361	0.681	0.11	0.2	0.2	0.153
S10	10.4	1.5	8.1	8.1	1.798	0.899	0.15	0.2	0.17	0.167
S11	7.0	1.5	3.5	5.2	1.036	0.518	0.3	0.4	0.33	0.333
S12	11.2	3.3	3.3	3.3	1.006	0.503	0.3	0.3	0.28	0.307
S13	5.5	3.1	3.2	2.7	0.914	0.457	0.48	0.6	0.45	0.497
S15	9.2	2.5	5.5	6.1	1.433	0.716	0.38	0.4	0.4	0.400
S16	7.2	3.3	5.5	5.5	1.453	0.726	0.1	0.1	0.12	0.117
S17	8.4	1.9	2.8	1.7	0.650	0.325	0.22	0.3	0.2	0.223
S18	8.0	3.7	4.1	1.8	0.975	0.488	0.01	0.1	0.05	0.050
S19	6.9	1.8	2.7	2.1	0.671	0.335	0.2	0.2	0.15	0.190
S20	8.7	1.4	2.7	3.4	0.762	0.381	0.22	0.2	0.18	0.203
S22	5.7	2.1	2.3	3.1	0.762	0.381	0.33	0.4	0.35	0.360

NB: S4 and S21 represent the intake and the raw effluents respectively. They are not along the stream and thus have no hydraulic measurements.

Table 4.2d: Hydraulic Data for April 2009

S/N	**WIDTH (m)**	**RIVER DEPTH (FEET)**			**MEAN DEPTH (m)**	**VELOCITY (m/s)**			**LAT. MEAN VEL (m/s)**
		A	B	C		A	B	C	
S1	10.3	2.0	3.6	2.0	0.772	0.05	0.01	0.05	0.037
S2	11.2	6.2	14.3	1.7	2.256	0.10	0.26	0.22	0.193
S3	10.4	4.3	4.9	3.4	1.280	0.13	0.17	0.11	0.137
S5	12.1	5.4	8.1	3.6	1.737	0.24	0.24	0.20	0.227
S6	8.1	2.9	4.4	5.4	1.290	0.33	0.32	0.25	0.300
S7	10.1	5.4	6.1	3.2	1.494	0.15	0.26	0.20	0.203
S8	7.3	5.2	3.7	2.5	1.158	0.09	0.01	0.02	0.040
S9	9.8	14.8	4.5	2.0	2.164	0.18	0.21	0.15	0.180
S10	9.5	1.9	5.2	9.5	1.687	0.023	0.04	0.01	0.024
S11	8.6	3.0	3.2	3.9	1.026	0.24	0.36	0.20	0.267
S12	7.6	2.1	4.9	4.0	1.118	0.20	0.23	0.25	0.227
S13	8.6	4.9	6.2	4.5	1.585	0.20	0.2	0.18	0.193
S14	3.0	3.4	3.6	2.2	0.935	0.25	0.28	0.23	0.253
S15	7.9	4.1	6.2	14.6	2.530	0.15	0.22	0.20	0.190
S16	7.1	4.7	5.7	6.1	1.676	0.15	0.16	0.15	0.153
S17	7.5	4.0	4.0	3.0	1.118	0.18	0.17	0.20	0.183
S18	9.1	4.8	6.0	1.9	1.290	0.10	0.16	0.12	0.127
S19	7.1	3.1	3.3	1.9	0.843	0.22	0.21	0.13	0.187
S20	8.0	3.3	3.4	3.4	1.026	0.25	0.27	0.22	0.247
S22	7.6	2.3	3.8	3.0	0.925	0.28	0.31	0.20	0.263

NB: S4 and S21 represent the intake and the raw effluents respectively. They are not along the stream and thus have no hydraulic measurements.

Table 4.2e: Hydraulic Data for May 2009

S/N	WIDTH (m)	RIVER DEPTH (FEET)			MEAN DEPTH (m)	VELOCITY (m/s)			
		A	B	C		A	B	C	Mean velocity
S1	11.8	3.6	4.9	3.1	1.179	0.10	0.11	0.10	0.103
S2	13.6	7.2	4.9	4.1	1.646	0.22	0.27	0.24	0.243
S3	11.0	2.4	5.6	5.6	1.382	0.24	0.25	0.23	0.240
S5	13.8	15.9	9.7	4.3	3.038	0.20	0.28	0.26	0.247
S6	9.8	5.0	5.9	2.4	1.351	0.11	0.15	0.14	0.133
S7	13.7	3.8	7.5	4.5	1.605	0.12	0.14	0.13	0.130
S8	7.6	1.3	7.5	2.2	1.118	0.02	0.01	0.05	0.027
S9	10.5	7.2	6.1	3.0	1.656	0.20	0.25	0.22	0.223
S10	16.2	3.3	7.9	1.5	1.290	0.11	0.10	0.09	0.100
S11	9.6	4.1	4.3	5.1	1.372	0.33	0.35	0.30	0.327
S12	7.8	3.7	6.0	3.5	1.341	0.22	0.25	0.20	0.223
S13	4.9	2.2	3.9	5.2	1.148	0.10	0.17	0.15	0.140
S14	2.9	2.8	4.3	5.1	1.240	0.15	0.17	0.20	0.173
S15	9.2	3.4	8.1	8.3	2.012	0.18	0.21	0.22	0.203
S16	6.7	8.4	6.6	2.0	1.727	0.12	0.15	0.10	0.123
S17	8.2	3.3	4.8	4.5	1.280	0.10	0.10	0.12	0.107
S18	6.8	3.7	4.3	1.0	0.914	0.05	0.05	0.02	0.040
S19	10.9	3.8	4.9	2.1	1.097	0.11	0.17	0.15	0.143
S20	7.5	5.9	3.5	3.1	1.270	0.12	0.10	0.10	0.107
S22	7.1	7.1	5.1	4.3	1.676	0.13	0.13	0.15	0.137

NB: S4 and S21 represent the intake and the raw effluents respectively. They are not along the stream and thus have no hydraulic measurements.

Table 4.2f: Hydraulic Data for July 2009

S/N	WIDTH	DEPTH (FT)			MEAN DEPTH (m)	Hyd Rad, H (m)	VELOCITY (m/s)			LATITUDINAL MEAN VEL (m/s)
		A	B	C			A	B	C	
S1	15	5.6	7	7.3	2.022	1.011	0.18	0.2	0.15	0.177
S2	35	8.5	12.6	10.4	3.200	1.600	0.44	0.5	0.50	0.480
S3	50	5.5	14	8.1	2.804	1.402	0.20	0.3	0.25	0.260
S5	20	10.2	13.2	11.7	3.566	1.783	1.20	1.3	1.00	1.150
S6	25	5.5	9.3	8.1	2.327	1.163	0.80	1.0	0.85	0.883
S7	15	10	8.1	9.3	2.784	1.392	1.10	1.0	0.90	1.000
S9	22	9	11	8.6	2.906	1.453	0.77	0.8	0.82	0.797
S10	25	6.3	11.6	9.3	2.764	1.382	0.08	0.1	0.10	0.097
S11	15	6.5	6.8	6.1	1.971	0.986	0.25	0.3	0.20	0.260
S12	50	7.2	7.2	7.2	2.195	1.097	0.25	0.3	0.20	0.233
S13	33	7	7	7	2.134	1.067	0.20	0.3	0.22	0.223
S15	23	10.5	11	9.9	3.190	1.595	0.20	0.3	0.33	0.273
S16	50	8.8	11.3	8.3	2.885	1.443	0.22	0.3	0.22	0.230
S17	30	6	6.6	5.5	1.839	0.920	0.15	0.2	0.10	0.150
S18	23	6.3	6.3	6.3	1.920	0.960	0.12	0.3	0.19	0.187
S19	40	5.6	9.9	7.8	2.367	1.184	0.35	0.4	0.40	0.397
S20	25	6.1	6.1	6.1	1.859	0.930	0.25	0.3	0.25	0.263
S22	20	6.2	9	7.6	2.317	1.158	0.30	0.3	0.25	0.293

NB: S4 and S21 represent the intake and the raw effluents respectively. They are not along the stream and thus have no hydraulic measurements.

Table 4.2g: Hydraulic Data for August

S/N	WIDTH	DEPTH (FT)			MEAN DEPTH (m)	Hyd Rad, H (m)	VELOCITY (m/s)			LATITUDINAL MEAN VEL (m/s)
		A	B	C			A	B	C	
S1	9.1	2.5	4.2	2.4	0.925	0.463	0.18	0.20	0.15	0.177
S2	11.5	6.3	15.3	1.3	2.327	1.163	0.30	0.40	0.25	0.317
S3	8.3	1.6	5.0	6.1	1.290	0.645	0.25	0.30	0.30	0.276
S5	12.5	5.3	10.2	5.3	2.113	1.057	0.20	0.30	0.25	0.261
S6	8.9	2.8	5.2	5.2	1.341	0.671	0.25	0.30	0.30	0.294
S7	9.1	4.3	15.2	6.0	2.591	1.295	0.15	0.30	0.25	0.229
S9	9.8	8.4	4.4	3.4	1.646	0.823	0.40	0.40	0.30	0.367
S10	10.5	2.2	8.8	3.3	1.453	0.726	0.11	0.20	0.15	0.153
S11	8.4	5.0	4.0	2.6	1.179	0.589	0.45	0.50	0.40	0.450
S12	7.7	14.5	5.7	0.9	2.144	1.072	0.40	0.30	0.30	0.338
S13	6.8	1.6	4.4	1.4	0.752	0.376	0.20	0.30	0.18	0.210
S15	9.0	1.9	7.5	15.1	2.489	1.245	0.28	0.30	0.25	0.281
S16	7.0	6.1	5.7	1.8	1.382	0.691	0.20	0.20	0.18	0.201
S17	8.0	3.7	4.5	3.5	1.189	0.594	0.28	0.30	0.25	0.288
S18	8.2	5.5	5.2	2.1	1.301	0.650	0.10	0.10	0.12	0.115
S19	7.6	1.6	4.1	4.8	1.067	0.533	0.20	0.30	0.30	0.278
S20	7.5	3.0	4.4	3.6	1.118	0.559	0.20	0.30	0.25	0.245
S22	5.9	5.9	2.3	5.3	1.372	0.686	0.20	0.30	0.30	0.250

NB: S4 and S21 represent the intake and the raw effluents respectively. They are not along the stream and thus have no hydraulic measurements.

Table 4.2h: Hydraulic Data for September 2009

S/N	WIDTH	DEPTH (FT)			MEAN DEPTH (m)	Hyd Rad, H (m)	VELOCITY (m/s)			LAT. MEAN VEL (m/s)
		A	B	C			A	B	C	
S1	14.0	3.4	5.6	4.1	1.331	0.666	0.15	0.2	0.18	0.171
S2	16.0	2.1	7.8	0.9	1.097	0.549	0.33	0.4	0.25	0.317
S3	15.0	3.6	7.5	6.9	1.829	0.914	0.28	0.3	0.30	0.304
S5	18.0	1.8	10.9	7.1	2.012	1.006	0.33	0.4	0.34	0.357
S6	12.0	7.2	7.6	6.7	2.184	1.092	0.28	0.4	0.35	0.333
S7	15.0	4.5	8.6	2.2	1.555	0.777	0.34	0.4	0.27	0.332
S9	22.0	15.9	5.0	6.2	2.753	1.377	0.45	0.4	0.33	0.393
S10	25.0	3.4	6.7	10.5	2.093	1.047	0.20	0.3	0.30	0.250
S11	10.2	4.2	6.7	6.2	1.737	0.869	0.33	0.4	0.35	0.360
S12		7.1	5.3	2.6	1.524	0.762	0.30	0.3	0.29	0.301
S13	10.3	6.1	6.3	5.9	1.859	0.930	0.24	0.3	0.25	0.251
S15	9.5	2.5	7.0	7.6	1.737	0.869	0.25	0.3	0.28	0.281
S16	7.6	8.5	6.2	1.6	1.656	0.828	0.22	0.3	0.18	0.217
S17	6.3	4.4	5.5	5.8	1.595	0.798	0.30	0.3	0.33	0.321
S18	7.1	5.7	6.8	5.7	1.849	0.925	0.33	0.4	0.30	0.329
S19	8.2	3.3	5.3	6.5	1.534	0.767	0.35	0.4	0.38	0.376
S20	6.0	5.5	5.5	5.2	1.646	0.823	0.32	0.3	0.28	0.311
S22	7.5	3.6	5.8	2.1	1.168	0.584	0.25	0.3	0.27	0.269

NB: S4 and S21 represent the intake and the raw effluents respectively. They are not along the stream and thus have no hydraulic measurements.

4.1.2 Physico-Chemical Data

Tables 4.3a – 4.3h show the Physico-Chemical parameters of the river at every station on a monthly basis. These include temperature, DO, BOD and pH. Being a dynamic system, the physical parameters of the river such as DO and temperature change with time.

Table 4.3a: Physico-Chemical Parameters for January 2010

s/n	**TEMPERATURE (^oC)**		**DO (mg/l)**	**BOD (mg/l)**	**pH**
	AMB	WATER			
S1	20.9	23.9	7.8	24.0	5.6
S2	19.2	23.7	6.8	10.0	5.6
S3	19.3	23.7	7.4	8.0	5.6
S4	18.7	23.6	7.6	18.0	5.6
S5	18.7	23.6	7.2	12.0	5.6
S6	18.6	23.7	8.2	16.0	5.8
S7	18.6	23.7	7.6	14.0	5.6
S8	18.6	24.0	5.8	34.0	5.1
S9	18.4	23.7	6.8	10.0	6.0
S10	18.6	23.7	7.4	18.0	7.2
S11	20.9	23.6	6.8	6.0	5.7
S12	20.6	23.5	7.2	14.0	5.7
S13	21	23.6	8.0	10.0	5.1
S14	21.2	23.3	8.2	26.0	5.9
S15	21.6	23.5	6.4	6.0	5.7
S16	21.2	23.5	8.0	24.0	5.7
S17	21.6	23.5	7.4	10.0	5.7
S18	21.1	23.5	6.0	6.0	5.7
S19	20.7	23.4	6.4	8.0	5.7
S20	21.4	23.4	7.2	8.0	5.7
S21	21.6	23.4	6.4	46.0	4.2
S22	21.7	23.5	7.0	12.0	5.6

Table 4.3b: Physico-Chemical Parameters for February 2010

s/n	TEMPERATURE (^{o}C)		DO (mg/l)	BOD (mg/l)	pH
	AMB	WATER			
S1	28.2	27.4	5.8	4.0	5.8
S2	27.9	27.3	7.4	10.0	5.7
S3	27.5	27.1	6.2	4.0	5.9
S4	27.3	27.3	5.2	4.0	5.9
S5	27.3	27.3	6.4	2.0	5.9
S6	27.3	27.1	5.7	5.0	5.9
S7	27.2	27.1	5.6	2.0	5.9
S8	27.3	27.2	5.8	4.0	5.6
S9	27.2	27.1	6.4	2.0	5.9
S10	26.9	26.9	6.4	4.0	5.9
S11	26.8	27.0	6.4	6.0	5.8
S12	26.7	26.7	7.6	12.0	5.8
S13	26.5	27.0	7.6	10.0	5.8
S14	26.7	26.8	7.6	10.0	5.9
S15	27.0	27.1	6.0	6.0	5.9
S16	26.8	27.1	6.4	2.0	5.8
S17	27.0	27.2	6.8	4.0	5.9
S18	26.6	27.0	6.4	2.0	5.9
S19	26.7	27.1	6.6	8.0	5.9
S20	26.3	27.1	6.2	10.0	5.6
S21	26.5	26.8	0.4	3.0	4.1
S22	26.2	27.0	5.8	4.0	6.2

Table 4.3c: Physico-Chemical Parameters for March 2009

s/n	TEMPERATURE (^oC)		DO (mg/l)	BOD (mg/l)	pH
	AMBIENT	WATER			
S1	31.7	26.5	7.9	60.0	6.55
S2	27.8	26.3	6.5	26.0	6.62
S3	28.2	26.3	6.1	30.0	6.80
S4	29.1	26.6	5.3	18.0	6.27
S5	29.1	26.6	3.7	6.0	7.86
S6	31.1	26.6	6.3	34.0	6.82
S7	31.1	26.6	6.3	30.0	8.16
S8	30.7	26.9	3.3	30.0	6.22
S9	28.6	26.4	6.9	26.0	6.68
S10	32.2	26.8	5.1	38.0	6.61
S11	29.4	26.7	6.3	42.0	7.36
S12	30.0	26.6	6.7	36.0	6.72
S13	29.2	26.8	5.9	32.0	6.70
S14	29.4	26.5	7.1	40.0	5.97
S15	29.9	26.8	8.1	42.0	6.46
S16	28.6	26.8	4.3	14.0	6.65
S17	28.4	26.8	7.7	40.0	6.21
S18	30.3	26.9	6.7	44.0	6.73
S19	29.2	26.8	5.3	42.0	6.69
S20	29.8	27.2	5.9	34.0	6.44
S21	27.2	31.3	0.1	1.0	5.23
S22	29.1	26.9	7.3	40.0	6.49
S23	29.6	26.7	0.1	1.0	5.77

Table 4.3d: Physico-Chemical Parameters for April 2009

S/N	**TEMPERATURE (^{O}C)**		**DO (mg/L)**	**BOD (mg/L)**	**pH**
	AMB	WATER			
S1	28.7	25.8	8.15	35.0	7.43
S2	27.3	25.5	7.55	10.0	7.74
S3	27.0	25.5	5.35	4.0	7.04
S4	29.0	25.5	6.55	18.0	6.52
S5	29.0	25.5	4.15	8.0	6.92
S6	28.2	25.4	7.35	20.0	6.86
S7	28.5	25.4	7.95	38.0	7.02
S8	27.6	26.0	5.15	6.0	6.67
S9	27.0	25.3	3.95	12.0	6.81
S10	27.2	25.5	6.55	14.0	7.27
S11	26.6	25.4	5.15	16.0	6.96
S12	26.6	25.3	6.15	32.0	6.72
S13	26.3	25.3	5.75	4.0	6.88
S14	28.1	25.1	6.15	28.0	6.53
S15	27.4	25.3	7.55	32.0	7.01
S16	26.5	25.3	8.15	52.0	7.08
S17	26.8	25.3	5.55	06.0	7.07
S18	26.2	25.3	7.15	40.0	7.00
S19	26.3	25.2	3.75	2.0	7.04
S20	26.3	25.3	6.75	30.0	6.93
S21	30.0	29.5	4.75	56.0	6.79
S22	26.8	25.3	8.15	38.0	7.05

Table 4.3e: Physico-Chemical Parameters for May 2009

S/N	**TEMPERATURE (^{O}C)**		**DO (mg/L)**	**BOD (mg/L)**	**pH**	**CONDUCTIVITY**
	AMB	WATER				
S1	29.5	25.5	6.44	4.0	NA	74
S2	27.6	25.5	5.44	1.0	6.85	77
S3	26.6	25.5	5.44	1.0	6.8	77
S4	32.3	25.6	5.44	1.0	6.75	77
S5	32.3	25.6	4.94	3.0	6.7	74
S6	28.3	25.6	5.84	1.0	6.9	74
S7	26.5	25.6	6.24	1.0	6.85	65
S8	29.9	25.8	6.24	20.0	6.55	75
S9	27.3	25.6	5.64	12.0	6.9	75
S10	28.7	25.6	5.84	4.0	6.85	77
S11	27.6	25.6	5.84	4.0	6.85	57
S12	27.3	25.7	6.24	1.0	6.55	59
S13	28.4	25.7	6.24	16.0	6.85	86
S14	31.1	25.8	7.44	4.0	6.5	49
S15	30.1	25.7	7.04	12.0	6.85	85
S16	28.3	25.7	7.04	40.0	6.85	85
S17	28.9	25.8	6.24	28.0	6.75	87
S18	29.4	26.0	5.84	20.0	6.85	90
S19	31.2	25.9	7.04	28.0	6.85	86
S20	30.3	26.0	7.44	48.0	6.65	102
S21	28.6	27.8	6.24	20.0	6.55	260
S22	29.5	26.8	8.24	44.0	6.5	97
S23	34.3	33.9	6.24	4.0	6.35	311

Table 4.3f: Physico-Chemical Parameters for July

s/n	**TEMPERATURE (^{o}C)**		**DO (mg/l)**	**BOD (mg/l)**
	AMB	WATER		
S1	27.7	25.0	5.2	2.0
S2	26.2	24.9	5.6	2.0
S3	26.8	25.0	6.4	6.0
S4	27.4	25.2	6.0	2.0
S5	27.4	24.8	5.4	2.0
S6	26.8	24.8	4.8	2.0
S7	26.8	24.8	7.2	2.0
S8	26.8	24.6	5.7	3.0
S9	26.8	25.0	6.8	10.0
S10	27.1	24.9	6.8	4.0
S11	26.5	25.1	7.2	8.0
S12	27.5	25.0	6.2	8.0
S13	27.5	25.1	5.8	2.0
S14	27.5	24.9	5.8	4.0
S15	27.6	25.4	6.6	2.0
S16	27.6	25.1	7.0	6.0
S17	27.3	25.2	5.8	12.0
S18	28.4	25.2	6.4	2.0
S19	26.7	25.2	7.8	10.0
S20	26.5	25.3	8.2	6.0
S21	31.2	29.5	4.2	14.0
S22	26.1	25.3	6.8	4.0

Table 4.3g: Physico-Chemical Parameters for August 2009

s/n	**TEMPERATURE (^oC)**		**DO (mg/l)**	**BOD (mg/l)**	**pH**
	AMB	WATER			
S1	25.5	24.5	7.6	7.6	5.5
S2	24.4	24.5	5.8	26.0	5.5
S3	24.8	24.6	7.4	20.0	5.6
S4	24.6	24.5	6.8	6.0	5.5
S5	24.6	24.5	7.2	10.0	5.5
S6	24.2	24.5	6.8	6.0	5.5
S7	24.4	24.5	6.8	32.0	5.5
S8	24.4	24.5	6.2	12.0	4.8
S9	24.1	24.5	8.2	14.0	5.5
S10	24.2	24.5	6.2	8.0	5.6
S11	24.1	24.5	7.6	20.0	5.5
S12	24.1	24.5	6.0	2.0	5.5
S13	24.0	24.4	8.4	6.0	5.2
S14	24.0	24.5	6.4	6.0	5.6
S15	24.1	24.5	3.6	8.0	5.6
S16	24.0	24.5	7.8	4.0	5.6
S17	24.1	24.5	7.4	6.0	5.6
S18	24.1	24.5	7.8	10.0	5.6
S19	23.8	24.5	8.4	6.0	5.6
S20	23.8	24.4	6.8	4.0	5.7
S21	30.0	24.9	6.2	4.0	5.3
S22	24.4	24.4	7.0	12.0	5.7

Table 4.3h: Physico-Chemical Parameters for September 2009

s/n	**TEMPERATURE (^oC)**		**DO (mg/l)**	**BOD (mg/l)**	**pH**
	AMB	WATER			
S1	25.0	25.0	6.8	12.0	5.4
S2	24.5	24.9	5.8	8.0	5.3
S3	24.5	24.9	5.8	6.0	5.4
S4	24.7	24.9	6.6	16.0	5.3
S5	24.7	24.9	6.5	7.0	5.3
S6	24.8	25.0	6.8	14.0	5.4
S7	24.7	25.0	6.4	6.0	5.5
S8	24.7	24.9	6.6	8.0	5.4
S9	24.8	25.0	5.2	2.0	5.4
S10	25.2	25.1	5.8	14.0	5.4
S11	25.1	25.0	6.0	12.0	5.4
S12	24.8	25.0	6.0	4.0	5.5
S13	24.7	24.9	6.0	6.0	5.4
S14	24.9	25.0	6.8	10.0	5.5
S15	24.9	25.0	6.2	6.0	5.5
S16	25.0	25.0	6.0	4.0	5.5
S17	24.9	25.0	6.6	14.0	5.5
S18	24.9	25.0	7.0	12.0	5.6
S19	24.5	24.5	6.8	10.0	5.6
S20	24.8	25.0	6.2	6.0	5.7
S21	25.1	25.3	4.8	24.0	5.1
S22	25.1	25.0	6.2	2.0	5.9

4.1.3 Monthly Variations in DO, Temperature, Stream Flow and Stream Depth

For a dynamic system, the physical parameters of the river such as DO, temperature, velocity and depth change with time. Some of the flood effects of the rainy season in year 2009 are as shown in Plates 4.1 and 4.2.

Plate 4.1: Sampling Station 10 in Rainy season (August 2009)

Plate 4.2: Sampling Location 10 in Dry season (March 2009)

The mean river velocity for eight months was noted. July had the highest value. Surprisingly however, the river had higher mean flow in the dry months of January, February and March than some months that fall within the rainy season (Figure 4.1).

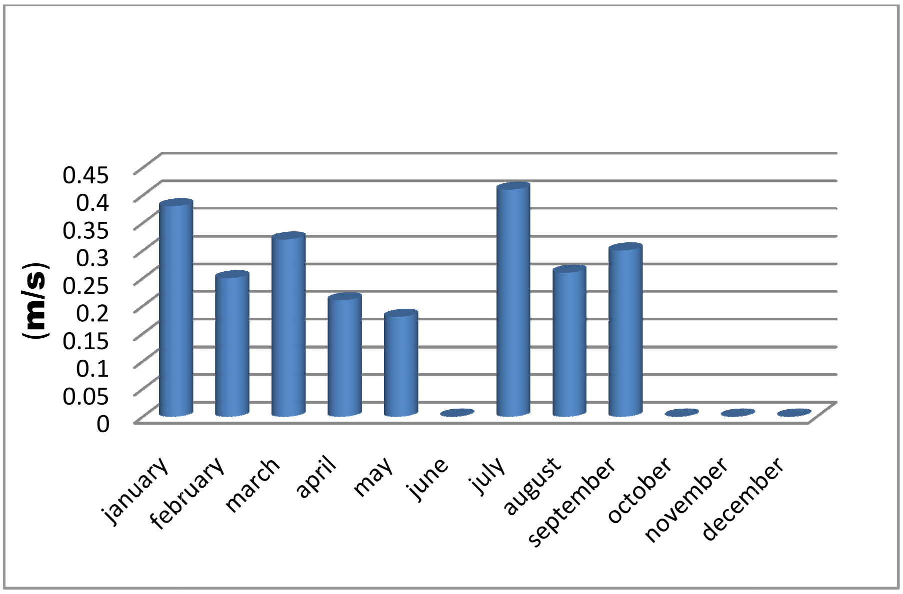


Figure 4.1: An 8-month mean stream velocity record

The geographical location of the research study area falls within the temperature range 24°C – 27°C (Figure 2.3). The data that were gathered during the research period corroborate this fact. The mean air temperature for the period was 26.21°C and the mean water temperature for the period was 25.38°C (Table 4.4). It should be noted however that since all the measurements were done in the morning before 12.00 noon and since most parts of the river body were covered by foliages, the real ambient temperature for the entire region could have been far higher than the recorded temperatures. The month of January was the coldest (20.26°C). This could be attributed to the harmattan weather that was on at the time. The water was also warmer than the air during the sampling period and mists were observed to be rising from the water body.

Table 4.4: Mean Monthly Ambient and Water Temperatures

MONTH	MEAN AMBIENT TEMP (^{o}C)	MEAN WATER TEMP (^{o}C)
January	20.26	23.59
February	27.13	27.09
March	29.55	26.7
April	27.22	25.4
May	29.3	25.74
July	27.10	25.04
August	24.25	24.49
September	24.84	24.97
MEAN VALUE FOR THE RESEARCH PERIOD	26.21	25.38

It should be noted that the dry season recorded both the highest and the lowest ambient temperatures in the months of March and January respectively (Figure 4.2).

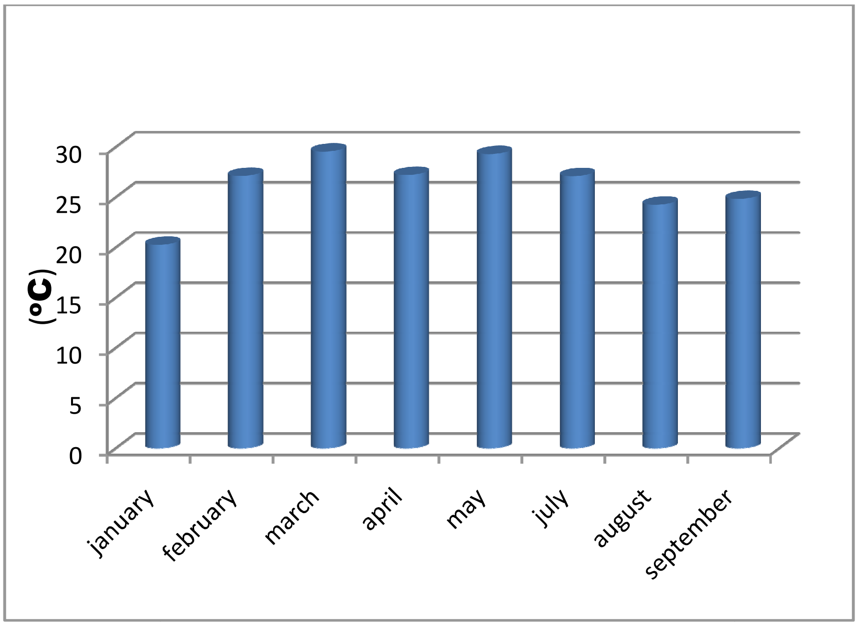


Figure 4.2: An 8-month mean ambient temperature record at the experimental site

Likewise, the dry season also recorded the highest and lowest mean water temperatures in the months of February and January respectively (Figure 4.3).

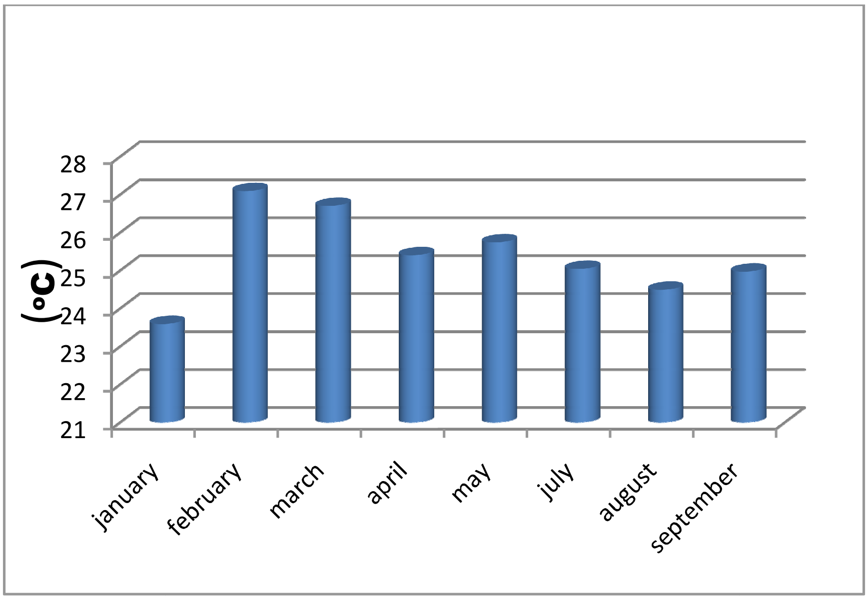


Figure 4.3: An 8-month mean water temperature record at the experimental site

A comparative illustration of the different months and their stream depths is shown in Figure 4.4.

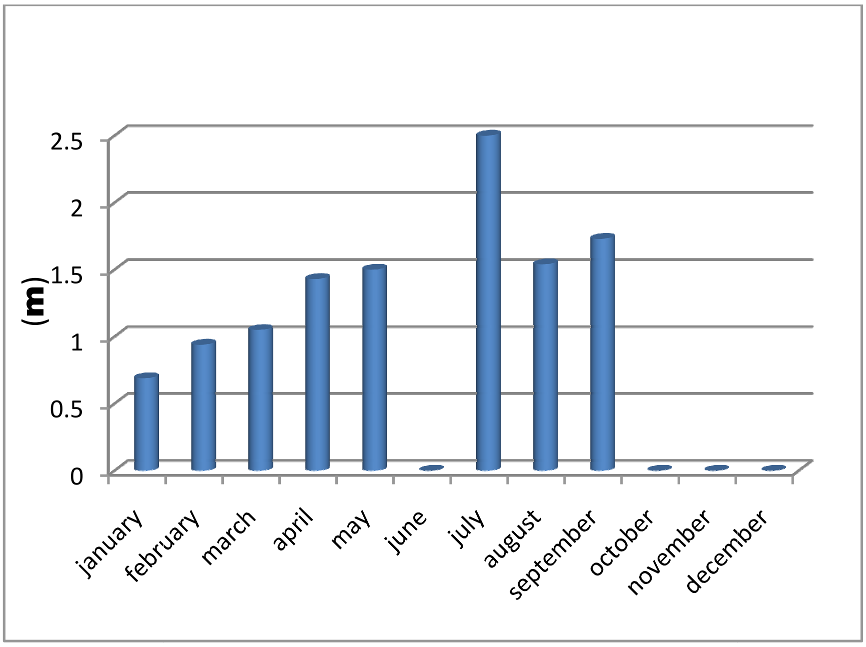


Figure 4.4: An 8-month mean stream depth record at the experimental site

Figure 4.5 compares the DO fluctuations over an 8-month period.

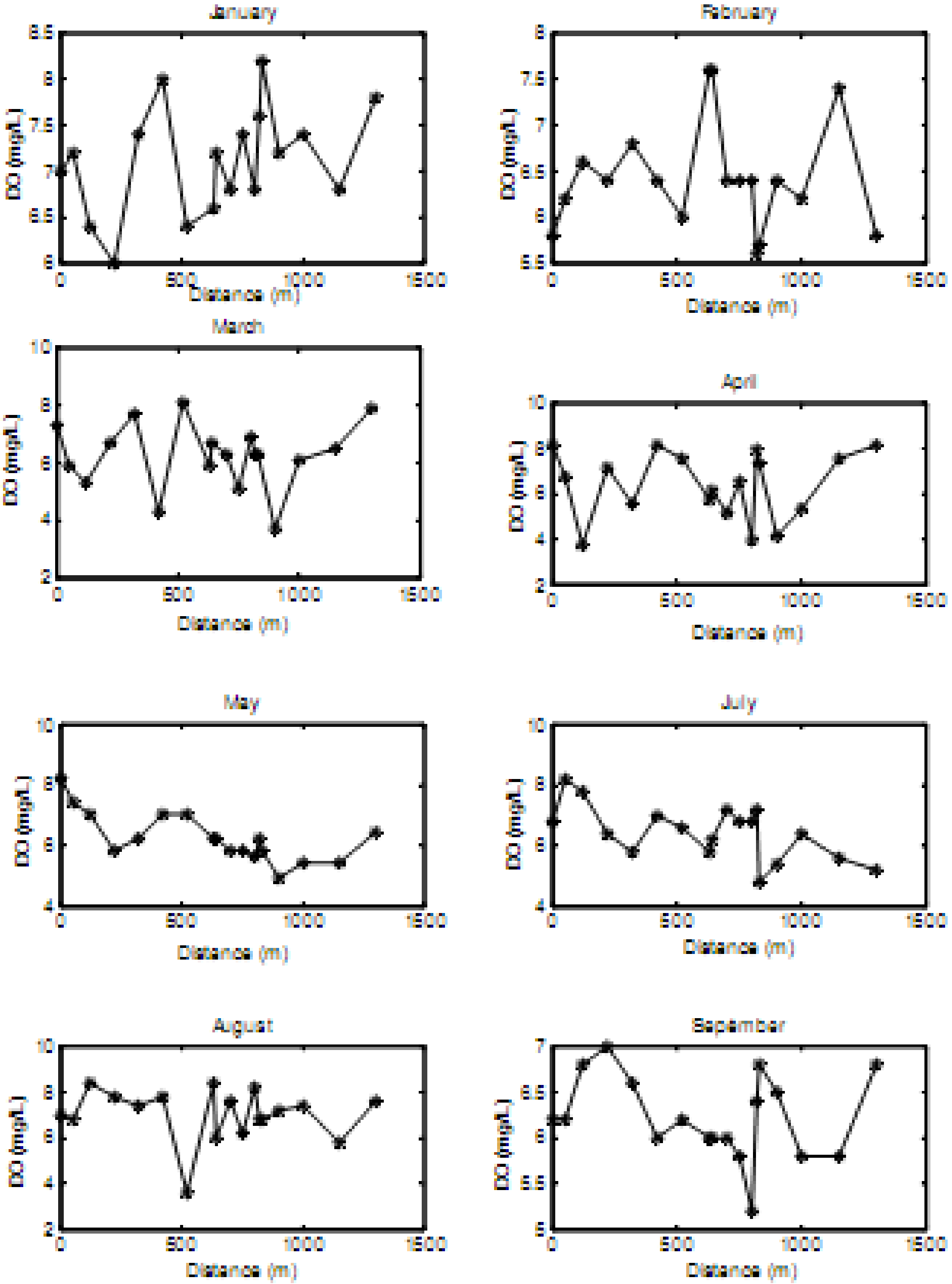


Figure 4.5: DO fluctuations over an 8-month period

4.2 Computation of Measured k_2

Six months (three months for each season) were selected and used in the analysis. These included the three months of the dry season and the three months of the rainy season. The month of May was not used for the modelling because the water analysis was done in a separate laboratory and this introduced measurement errors. Therefore, only July, August and September were adopted for the modelling during the rainy season.

4.2.1 The Mixing Zones

The river section under study had three mixing zones. The first was where the industrial effluent entered the river. The second and third were confluences where two other river merged with River Atuwara (Figure 3.2). The first River that merged with River Atuwara is River Balogun. The second River is unidentified and appeared inactive during the dry season. Since the river under study mixes with these three external sources, the river section was divided into three reaches (Table 4.5). Reach 1 covers a distance of 590 m and is between S20 and the first confluence S12. Reach 2 covers a distance of 180 m and is between the two confluences S7 and S12. Reach 3 which covers a distance of 480 m is between the second confluence S7 and Iju village S1. Since the effluent streams have different physico-chemical properties which they bring into the main river, their points of meeting could be described as the upstream portion of a source of pollution or dilution. It could also be referred to as mixing zone. When mixing takes place, resultant values of physico-chemical parameters at the point of discharge can be calculated from equation 4.2 (Agunwamba *et al.*, 2007; Hammer, M.J., 1986).

$$C = \frac{C_1Q_1 + C_2Q_2}{Q_1 + Q_2} \qquad (4.2)$$

where C represent the mix concentration of BOD, DO or Temperature. C_1 is the concentrations of BOD, DO or Temperature in the main stream. Q_1 is the discharge in cubic meter per second of the main stream. C_2 is the concentration of BOD, DO or Temperature in the effluent or effluent stream. Q_2 is the discharge of the effluent or the effluent stream. For the three months that were modelled, the stream, effluent and mix parameters are given in Tables 4.6 - 4.11. (See Appendix 4 for sample calculation).

Table 4.5: Determination of Reaches for the River

S/N	STATION DESCRIPTION	Reach	Reach Distance (m)	Cumulative Distance (m)
S1	Iju Villagers source of water	3	480	1300
S2	Bamboo growth			1150
S3	Bamboo growth			1000
S4	Water Corporation (intake)			900
S5	Water Corporation (midstream)			900
S6	Confluence 1a (main river, Bridge Area)			830
S7	Confluence 1b (meeting point)	2	180	820
S8	Confluence 1c (Stagnant water; Unknown river)			820
S9	After confluence (thick tree root)			800
S10	Sand Quarrying			750
S11	Before confluence 2 (plenty pegs)			700
S12	Confluence 2b (meeting point)			640
S13	Confluence 2a Main river)	1	590	630
S14	Confluence 2c (River Balogun)			630
S15	After confluence (sharp bend; overhead plant growth)			520
S16	Slight bend			420
S17	Groove-like environment			320
S18	our peg (station marker)			220
S19	Upright peg midstream (mild chelsea influent)			120
S20	Main chelsea influent point			50
S21	Raw effluent (thick bamboo cover)	Section not part of the continuity being modelled.		Off river
S22	50m upstream of Chelsea effluent discharge point			0
S23	Raw effluent along the road			

Table 4.6: Dilution Effects for January 2010

Reach	Stream Parameters						Effluent and River Parameters						Mix Parameters			Q (m^3/s)	D_o (mg/L)	L_o (mg/L)
	BOD_1 (mg/L)	DO_1 (mg/L)	T_1 (^oC)	A_1 (m^2)	V_1 (m/s)	Q_1 (m^3/s)	BOD_2 (mg/L)	DO_2 (mg/L)	T_2 (^oC)	A_2 (m^2)	V_2 (m/s)	Q_2 (m^3/s)	BOD (mg/L)	DO (mg/L)	T (^oC)	Q1+Q2	D_{sat}-DO	
1	12	7	23.4	1.069	0.26	0.278	46	6.4	23.4	0.00063	0.25	0.00016	12.03	7.01	23.4	0.278	1.58	16.1
2	10	6.6	23.6	6.3	0.376	2.37	26	8.2	23.3	3.55	0.151	0.54	12.97	6.9	23.5	2.91	1.68	17.32
3	16	8.2	23.7	3.075	0.42	1.29	34	5.8	24	10.815	0.139	1.5	25.68	6.91	23.9	2.79	1.61	34.47

Table 4.7: Dilution Effects for February 2010

Reach	Stream Parameters						Effluent and River Parameters						Mix Parameters			Q (m^3/s)	D_o (mg/L)	L_o (mg/L)
	BOD_1 (mg/L)	DO_1 (mg/L)	T_1 (^oC)	A_1 (m^2)	V_1 (m/s)	Q_1 (m^3/s)	BOD_2 (mg/L)	DO_2 (mg/L)	T_2 (^oC)	A_2 (m^2)	V_2 (m/s)	Q_2 (m^3/s)	BOD (mg/L)	DO (mg/L)	T (^oC)	Q1+Q2	D_{sat}-DO	
1	4	5.8	27	3.56	0.223	0.793	3	0.4	26.8	0.00126	0.25	0.000315	4	5.8	27	0.7934	2.3	5.57
2	10	7.6	27	3.98	0.223	0.888	10	7.6	26.8	3.52	0.139	0.499	10	7.6	26.9	1.387	0.51	13.93
3	5	5.7	27.1	5.36	0.43	2.31	4	5.8	27.2	7.66	0.01	0.077	4.97	5.7	27.1	2.387	2.39	6.92

Table 4.8: Dilution Effects for March 2009

Reach	Stream Parameters						Effluent and River Parameters						Mix Parameters			Q (m^3/s)	D_o (mg/L)	L_o (mg/L)
	BOD_1 (mg/L)	DO_1 (mg/L)	T_1 (^oC)	A_1 (m^2)	V_1 (m/s)	Q_1 (m^3/s)	BOD_2 (mg/L)	DO_2 (mg/L)	T_2 (^oC)	A_2 (m^2)	V_2 (m/s)	Q_2 (m^3/s)	BOD (mg/L)	DO (mg/L)	T (^oC)	Q1+Q2	D_{sat}-DO	
1	40	7.3	26.9	7.038	0.203	1.429	1	0.1	31.3	0.00098	0.25	0.00025	40	7.3	26.9	1.429	0.81	55.71
2	32	5.9	26.8	4.86	0.203	0.987	40	7.1	26.5	2.49	0.38	0.95	35.97	6.5	26.7	1.93	1.63	50.10
3	30	6.3	26.6	7.8	0.753	5.88	30	3.3	26.9	5.09	0.01	0.051	30	6.28	26.6	5.93	1.86	41.78

Table 4.9: Dilution Effects for July 2009

Reach	**Stream Parameters**						**Effluent/Effluent River Parameters**						**Mix Parameters**			**Q (m^3/s)**	**D_o (mg/L)**	**L_o (mg/L)**
	BOD_1 (mg/L)	DO_1 (mg/L)	T_1 (^oC)	A_1 (m^2)	V_1 (m/s)	Q_1 (m^3/s)	BOD_2 (mg/L)	DO_2 (mg/L)	T_2 (^oC)	A_2 (m^2)	V_2 (m/s)	Q_2 (m^3/s)	BOD (mg/L)	DO (mg/L)	T (^oC)	Q1+Q2	D_{sat}-DO	
1	6	6.8	25.1	42.23	0.263	11.11	14	4.2	29.5	0.00098	0.33	0.000323	6	6.8	25.1	11.11	2.14	7.73
2	2	5.8	25.1	56.26	0.223	12.542	4	5.8	24.9	33	0.25	8.25	2.79	5.8	25.1	20.8	2.54	3.6
3	2	4.8	24.8	60.61	0.883	53.52	3	5.7	24.6	18.65	0.29	5.41	2.33	4.88	24.78	58.93	3.55	3

Table 4.10: Dilution Effects for August 2009

Reach	**Stream Parameters**						**Effluent/Effluent River Parameters**						**Mix Parameters**			**Q (m^3/s)**	**D_o (mg/L)**	**L_o (mg/L)**
	BOD_1 (mg/L)	DO_1 (mg/L)	T_1 (^oC)	A_1 (m^2)	V_1 (m/s)	Q_1 (m^3/s)	BOD_2 (mg/L)	DO_2 (mg/L)	T_2 (^oC)	A_2 (m^2)	V_2 (m/s)	Q_2 (m^3/s)	BOD (mg/L)	DO (mg/L)	T (^oC)	Q1+Q2	D_{sat}-DO	
1	12	7	24.4	11.12	0.245	2.724	4	6.2	24.9	0.0013	0.25	0.0003	12	7	24.4	2.724	1.44	16.11
2	6	8.4	24.5	5.8	0.25	1.45	6	6.4	24.5	25.52	0.2	5.105	6	7.37	24.5	6.56	1.06	8.05
3	6	6.8	24.5	13.97	0.333	4.65	12	6.2	24.5	16.67	0.01	0.167	6.2	6.78	24.5	4.82	1.65	8.32

Table 4.11: Dilution Effects for September 2009

Reach	**Stream Parameters**						**Effluent/Effluent River Parameters**						**Mix Parameters**			**Q (m^3/s)**	**D_o (mg/L)**	**L_o (mg/L)**
	BOD_1 (mg/L)	DO_1 (mg/L)	T_1 (^oC)	A_1 (m^2)	V_1 (m/s)	Q_1 (m^3/s)	BOD_2 (mg/L)	DO_2 (mg/L)	T_2 (^oC)	A_2 (m^2)	V_2 (m/s)	Q_2 (m^3/s)	BOD (mg/L)	DO (mg/L)	T (^oC)	Q1+Q2	D_{sat}-DO	
1	2	6.2	25	10.92	0.33	3.6	24	4.8	25.3	0.00036	0.25	0.00009	2	6.2	25	3.6	2.15	2.58
2	6	6	24.9	18.9	0.263	4.97	10	6.8	25	6.04	0.33	1.99	7.14	6.23	24.9	6.96	2.14	9.20
3	14	6.8	25	25.93	0.385	9.98	8	6.6	24.9	11.88	0.01	0.12	13.93	6.68	25	10.1	1.62	17.95

4.3 Re-arrangement of sampling Stations

Only 18 of the sampling stations and their corresponding data are useful for the modelling. This is because some of the stations do not fall along the straight path of the river from the reference point. For the purpose of modelling, the stations were re-numbered as shown in Table 4.12. Column 1 shows the original numbering while column 2 shows the new numbering.

Table 4.12: Re-arrangement of station numbers

S/N		**STATION DESCRIPTION**	**Reach**	**Distance between Reach (m)**	**Cumulative Distance (m)**
S1	S1	Iju Villagers source of water	3	480	1300
S2	S2	Bamboo growth			1150
S3	S3	Bamboo growth			1000
S4		Water Corporation (intake)			900
S5	S4	Water Corporation (midstream)			900
S6	S5	Confluence 1a (main river, Bridge Area)			830
S7	S6	Confluence 1b (meeting point)	2	180	820
S8		Confluence 1c (Stagnant water; Unknown river)			820
S9	S7	After confluence (thick tree root)			800
S10	S8	Sand Quarrying			750
S11	S9	Before confluence 2 (plenty pegs)			700
S12	S10	Confluence 2b (meeting point)			640
S13	S11	Confluence 2a Main river)	1	590	630
S14		Confluence 2c (River Balogun)			630
S15	S12	After confluence (sharp bend; overhead plant growth)			520
S16	S13	Slight bend			420
S17	S14	Groove-like environment			320
S18	S15	our peg (station marker)			220
S19	S16	Upright peg midstream (mild chelsea influent)			120
S20	S17	Main chelsea influent point			50
S21		Raw effluent (thick bamboo cover)	Section not part of the continuity being modelled.		Off river
S22	S18	50m upstream of Chelsea effluent discharge point			0
S23		Raw effluent along the road			

4.3.1 Time of Travel

The times of travel in days were computed using equation 3.1. Three different times of travels were computed for each month (one for each reach; Tables 4.13 – 4.18). These values were further used in the determination of k_1 and k_2 (Tables 4.19 - 4.24)

Table 4.13: Computation of time of travel on Programmed Excel Spreadsheet for January 2010

	Velocity (m/s)	Route (m)	Distance between Reach (m)	Velocity (km/day)	Average velocity for the Reach (km/day)	Distance (km)	Time of travel (day)
S1	0.013	1300	480	1.152	15.40	0.48	0.0312
S2	0.057	1150		4.954			
S3	0.162	1000		14.026			
S4	0.237	900		20.448			
S5	0.417	830		36.000			
S6	0.183	820		15.84			
S7	0.270	800	180	23.328	20.94	0.18	0.0086
S8	0.122	750		10.541			
S9	0.260	700		22.464			
S10	0.377	640		32.544			
S11	0.162	630	590	13.968	20.29	0.59	0.0291
S12	0.190	520		16.416			
S13	0.220	420		19.008			
S14	0.227	320		19.584			
S15	0.193	220		16.704			
S16	0.250	120		21.600			
S17	0.260	50		22.464			
S18	0.377	0		32.544		0	0

Table 4.14: Computation of time of travel on Programmed Excel Spreadsheet for February 2010

	Velocity (m/s)	**Route (m)**	**Distance between Reach (m)**	**Velocity (km/day)**	**Average velocity for the Reach (km/day)**	**Distance (km)**	**Time of travel (day)**
S1	0.033	1300	480	2.880	23.48	0.48	0.02045
S2	0.562	1150		48.576			
S3	0.183	1000		15.840			
S4	0.217	900		18.784			
S5	0.430	830		37.152			
S6	0.204	820		17.632			
S7	0.214	800	180	18.495	17.63	0.18	0.0102
S8	0.1282	750		11.026			
S9	0.294	700		25.440			
S10	0.180	640		15.552			
S11	0.223	630	590	19.296	18.98	0.59	0.0311
S12	0.197	520		16.992			
S13	0.298	420		25.704			
S14	0.233	320		20.160			
S15	0.193	220		16.704			
S16	0.210	120		18.144			
S17	0.223	50		19.296			
S18	0.370	0		31.968		0	0

Table 4.15: Computation of time of travel on Programmed Excel Spreadsheet for March 2010

	Velocity (m/s)	Route (m)	Distance between Reach (m)	Velocity (km/day)	Average velocity for the Reach (km/day)	Distance (km)	Time of travel (day)
S1	0.027	1300	480	2.304	32.06	0.48	0.0150
S2	0.397	1150		34.272			
S3	0.253	1000		21.888			
S4	0.100	900		8.640			
S5	0.753	830		65.088			
S6	0.697	820		60.192			
S7	0.153	800	180	13.248	28.63	0.18	0.0063
S8	0.167	750		14.400			
S9	0.333	700		28.800			
S10	0.307	640		26.496			
S11	0.497	630	590	42.912	21.46	0.59	0.0275
S12	0.400	520		34.560			
S13	0.117	420		10.080			
S14	0.223	320		19.296			
S15	0.050	220		4.320			
S16	0.190	120		16.416			
S17	0.203	50		17.568			
S18	0.360	0		31.104		0	0

Table 4.16: Computation of time of travel on Programmed Excel Spreadsheet for July 2009

	Velocity (m/s)	**Route (m)**	**Distance between Reach (m)**	**Velocity (km/day)**	**Average velocity for the Reach (km/day)**	**Distance (km)**	**Time of travel (day)**
S1	0.177	1300		15.264			
S2	0.480	1150	480	41.472	56.88	0.48	0.0084
S3	0.260	1000		22.464			
S4	1.150	900		99.360			
S5	0.883	830		76.320			
S6	1.000	820		86.400			
S7	0.797	800	180	68.832	41.24	0.18	0.0089
S8	0.097	750		8.352			
S9	0.260	700		22.464			
S10	0.233	640		20.160			
S11	0.223	630	590	19.296	21.13	0.59	0.0279
S12	0.273	520		23.616			
S13	0.230	420		19.872			
S14	0.150	320		12.960			
S15	0.187	220		16.128			
S16	0.397	120		34.272			
S17	0.263	50		22.752			
S18	0.293	0		25.344		0	0

Table 4.17: Computation of time of travel on Programmed Excel Spreadsheet for August

	Velocity (m/s)	**Route (m)**	**Distance between Reach (m)**	**Velocity (km/day)**	**Average velocity for the Reach (km/day)**	**Distance (km)**	**Time of travel (day)**
S1	0.177	1300	480	15.264	22.37	0.48	0.0215
S2	0.317	1150		27.360			
S3	0.276	1000		23.846			
S4	0.261	900		22.550			
S5	0.294	830		25.430			
S6	0.229	820		19.757			
S7	0.367	800	180	31.680	26.55	0.18	0.0068
S8	0.153	750		13.248			
S9	0.450	700		38.880			
S10	0.338	640		29.174			
S11	0.210	630	590	18.144	21.11	0.59	0.0279
S12	0.281	520		24.278			
S13	0.201	420		17.338			
S14	0.288	320		24.854			
S15	0.115	220		9.936			
S16	0.278	120		23.990			
S17	0.245	50		21.197			
S18	0.250	0		21.600		0	0

Table 4.18: Computation of time of travel on Programmed Excel Spreadsheet for September

	Velocity (m/s)	**Route (m)**	**Distance between Reach (m)**	**Velocity (km/day)**	**Average velocity for the Reach (km/day)**	**Distance (km)**	**Time of travel (day)**
S1	0.171	1300	480	14.746	26.11	0.48	0.0184
S2	0.317	1150		27.360			
S3	0.304	1000		26.294			
S4	0.357	900		30.816			
S5	0.333	830		28.800			
S6	0.332	820		28.656			
S7	0.393	800	180	33.984	28.27	0.18	0.0064
S8	0.250	750		21.600			
S9	0.360	700		31.104			
S10	0.301	640		26.006			
S11	0.251	630	590	21.686	25.78	0.59	0.0229
S12	0.281	520		24.278			
S13	0.217	420		18.720			
S14	0.321	320		27.734			
S15	0.329	220		28.426			
S16	0.377	120		32.544			
S17	0.311	50		26.870			
S18	0.269	0		23.213		0	0

Table 4.19: Computation of k_1 and k_2 on Programmed Excel Spreadsheet for January 2010

	DO (mg/L)	**BOD=L (mg/L)**	**(L_o/L)**	**$\log_{10}(L_o/L)$**	**k_1= 1/t*log(L_o/L) Per day**	**D_{sat} (mg/L)**	**D_u = U/stream deficit (mg/L)**	**D_d = d/stream deficit (mg/L)**	**k_2= 1/t*[log(D_u/D_d)] (per day)**
S1	7.8	24	1.122	0.050	1.603	At reach 3(25°C)= 8.35	1.67	0.55	15.479
S2	6.8	10						1.55	1.039
S3	7.4	8						0.95	7.862
S4	7.2	12						1.15	5.199
S5	8.2	16						0.15	33.586
S6	7.6	14						0.75	11.156
S7	6.8	10	0.920	-0.036	-4.213	At reach 2(24.9°C)= 8.37	2.14	1.57	15.651
S8	7.4	18						0.97	39.983
S9	6.8	6						1.57	15.651
S10	7.2	14						1.17	30.511
S11	6.6	10	0.215	-0.668	-22.953	At reach 1(25°C)= 8.35	2.15	1.75	3.074
S12	6.4	6						1.95	1.458
S13	8.0	24						0.15	39.759
S14	7.4	10						0.95	12.196
S15	6.0	6						2.35	-1.328
S16	6.4	8						1.95	1.458
S17	7.2	8						1.15	9.343
S18	7.0	12							

	L_o for reach 1=	2.58	D_{mix} for reach 1=	6.20
	L_o for reach 2=	9.20	D_{mix} for reach 2=	6.23
	L_o for reach3=	17.95	D_{mix} for reach 3=	6.68

Table 4.20: Computation of k_1 and k_2 on Programmed Excel Spreadsheet for February 2010

	DO (mg/L)	BOD=L (mg/L)	(L_o/L)	$\log_{10}(L_o/L)$	k_1= $1/t*\log_{10}(L_o/L)$ Per day	D_{sat} (mg/L)	D_u = U/stream deficit (mg/L)	D_d = d/stream deficit (mg/L)	k_2= $1/t*[\log(D_u/D_d)]$ (per day)
S1	5.8	4	1.384	0.141	6.903	At reach 3(27.1°C)= 8.09	2.39	2.55	-1.377
S2	7.4	10						0.95	19.597
S3	6.2	4						2.15	2.248
S4	6.4	2						1.95	4.322
S5	5.7	5						2.65	-2.194
S6	5.6	2						2.75	-2.980
S7	6.4	2	1.393	0.144	14.099	At reach 2(26.9°C)= 8.11	0.51	1.97	-57.480
S8	6.4	14						1.97	-57.480
S9	6.4	6						1.97	-57.480
S10	7.6	12						0.77	-17.523
S11	7.6	10	1.393	0.144	4.626	At reach 1(27°C)= 8.10	2.30	0.75	15.657
S12	6.0	6						2.35	-0.301
S13	6.4	2						1.95	2.307
S14	6.8	4						1.55	5.514
S15	6.4	2						1.95	2.307
S16	6.6	8						1.75	3.819
S17	6.2	10						2.15	0.942

S18	5.8	4		
	L_o for reach 1=	5.57	Dmix for reach 1=	5.8
	L_o for reach 2=	13.93	Dmix for reach 2=	7.6
	L_o for reach3=	6.92	Dmix for reach3=	5.7

Table 4.21: Computation of k_1 and k_2 on Programmed Excel Spreadsheet for March 2009

	DO (mg/L)	BOD=L (mg/L)	(L_o/L)	$\log_{10}(L_o/L)$	$k_1= 1/t*\log_{10}(L_o/L)$ Per day	D_{sat} (mg/L)	D_u = U/stream deficit (mg/L)	D_d = d/stream deficit (mg/L)	$k_2= 1/t*[\log(D_u/D_d)]$ (per day)
S1	7.9	60	1.229	0.0895	5.978	At reach 3(26.6°C)= 8.14	1.86	0.24	66.679
S2	6.5	26						1.64	10.925
S3	6.1	30						2.04	4.594
S4	3.7	6						4.44	-17.968
S5	6.3	34						1.84	7.587
S6	6.3	30						1.84	7.587
S7	6.9	26	1.566	0.1947	30.963	At reach 2(26.7°C)= 8.13	1.63	1.23	-60.807
S8	5.1	38						3.03	-123.077
S9	6.3	42						1.83	-88.248
S10	6.7	36						1.43	-71.213
S11	5.9	32	1.393	0.1439	5.232	At reach 1(26.9°C)= 8.11	0.81	2.21	0.630
S12	8.1	42						0.01	85.887
S13	4.3	14						3.81	-7.971
S14	7.7	40						0.41	27.236
S15	6.7	44						1.41	7.728
S16	5.3	42						2.81	-3.163
S17	5.9	34						2.21	0.630
S18	7.3	40							

L_o for reach 1=	55.71	Dmix for reach 1=	7.3
L_o for reach 2=	50.1	Dmix for reach 2=	6.5
L_o for reach3=	41.78	Dmix for reach3=	6.28

Table 4.22: Computation of k_1 and k_2 on Programmed Excel Spreadsheet for July 2009

	DO (mg/L)	**BOD=L (mg/L)**	**(L_o/L)**	**$\log_{10}(L_o/L)$**	**k_1= 1/t*$\log_{10}(L_o/L)$ Per day**	**D_{sat} (mg/L)**	**D_u = U/stream deficit (mg/L)**	**D_d = d/stream deficit (mg/L)**	**k_2= 1/t*[$\log(D_u/D_d)$] (per day)**
S1	5.2	2	1.500	0.176	20.867	Dsat at reach 3 (25.1°C)= 8.34	3.46	3.14	-10.913
S2	5.6	2						2.74	-3.901
S3	6.4	6						1.94	13.868
S4	5.4	2						2.94	-7.526
S5	4.8	2						3.54	-17.084
S6	7.2	2						1.14	41.230
S7	6.8	10	1.800	0.255	28.591	Dsat at reach 3 (25.1°C)= 8.34	2.54	1.54	24.339
S8	6.8	4						1.54	24.339
S9	7.2	8						1.14	38.968
S10	6.2	8						2.14	8.335
S11	5.8	2	3.866	0.587	0.0309	Dsat at reach 3 (24.78°C)= 8.43	1.63	2.63	-7.442
S12	6.6	2						1.83	-1.800
S13	7.0	6						1.43	2.036
S14	5.8	12						2.63	-7.442
S15	6.4	2						2.03	-3.414
S16	7.8	10						0.63	14.787
S17	8.2	6						0.23	30.461
S18	6.8	4							

L_o for reach 1=	7.73	$D_{mix}$for reach 1=	6.8
L_o for reach 2=	3.6	D_{mix} for reach 2=	5.8
L_o for reach3=	3	D_{mix} for reach3=	4.88

Table 4.23: Computation of k_1 and k_2 on Programmed Excel Spreadsheet for August 2009

	DO (mg/L)	BOD=L (mg/L)	(L_o/L)	$\log_{10}$(L_o/L)	k_1= 1/t*$\log_{10}$(L_o/L) Per day	D_{sat} (mg/L)	D_u = U/stream deficit (mg/L)	D_d = d/stream deficit (mg/L)	k_2= 1/t*[log(D_u/D_d)] (per day)
S1	7.6	7.6	1.095	0.039	1.832	At reach 3(24.5°C)=8.43	1.65	0.83	13.906
S2	5.8	26						2.63	-9.435
S3	7.4	20						1.03	9.537
S4	7.2	10						1.23	5.945
S5	6.8	6						1.63	0.247
S6	6.8	32						1.63	0.247
S7	8.2	14	1.342	0.128	18.826	At reach 2(24.5°C)=8.43	1.06	0.23	97.870
S8	6.2	8						2.23	-47.639
S9	7.6	20						0.83	15.667
S10	6.0	2						2.43	-53.140
S11	8.4	6	2.685	0.429	15.350	At reach 1(24.4°C)=8.44	1.44	0.04	55.695
S12	3.6	8						4.84	-18.841
S13	7.8	4						0.64	12.603
S14	7.4	6						1.04	5.057
S15	7.8	10						0.64	12.603
S16	8.4	6						0.04	55.695
S17	6.8	4						1.64	-2.021
S18	7.0	12							

L_o for reach 1=	16.11	$D_{mix}$for reach 1=	7.00
L_o for reach 2=	8.05	D_{mix} for reach 2=	7.37
L_o for reach3=	8.32	D_{mix} for reach3=	6.78

Table 4.24: Computation of k_1 and k_2 on Programmed Excel Spreadsheet for September 2009

	DO (mg/L)	**BOD=L (mg/L)**	**(L_o/L)**	**$\log_{10}(L_o/L)$**	**k_1= $1/t*\log_{10}(L_o/L)$ Per day**	**D_{sat} (mg/L)**	**D_u = U/stream deficit (mg/L)**	**D_d = d/stream deficit (mg/L)**	**k_2= $1/t*[\log(D_u/D_d)]$ (per day)**
S1	6.8	12	1.282	0.108	5.872	At reach 3(25°C)=8.35	1.67	1.55	1.762
S2	5.8	8						2.55	-10.000
S3	5.8	6						2.55	-10.000
S4	6.5	7						1.85	-2.418
S5	6.8	14						1.55	1.762
S6	6.4	6						1.95	-3.662
S7	5.2	2	1.533	0.186	29.155	At reach 2(24.9°C)=8.37	2.14	3.17	-26.801
S8	5.8	14						2.57	-12.489
S9	6.0	12						2.37	-6.963
S10	6.0	4						2.37	-6.963
S11	6.0	6	1.290	0.111	4.833	At reach 1(25°C)=8.35	2.15	2.35	-1.688
S12	6.2	6						2.14	0.089
S13	6.0	4						2.35	-1.688
S14	6.6	14						1.75	3.907
S15	7.0	12						1.35	8.832
S16	6.8	10						1.55	6.210
S17	6.2	6						2.14	0.089
S18	6.2	2							

L_o for reach 1=	2.58	$D_{mix}$for reach 1=	6.2
L_o for reach 2=	9.2	D_{mix} for reach 2=	6.23
L_o for reach3=	17.95	D_{mix} for reach3=	6.68

4.3.2 Hydraulic Radius

The hydraulic radius, whose relationship is defined by equation 4.1, was determined using the principles and assumptions described in section 4.1.1.

4.3.3 Ultimate BOD and De-oxygenation rate k_1

The ultimate BOD, L_o, was computed for each reach of each of the six model months. Its values were then inserted in the programmed excel sheet for the determination of k_1 (Tables 4.19 - 4.24).

4.3.4 Saturation DO and the Upstream and Downstream DO deficits

At each mixing point, the mix temperature is used to read off the saturation DO (Table 2.2). These values were inserted in the programmed excel sheet (Tables 4.19 - 4.24). They were further used in the determination of the upstream and downstream DO deficits as given in section 3.5 and Tables 4.19 - 4.24.

4.3.5 Determination of k_2

The k_2 values were determined using equation 3.5 and are as presented in Tables 4.19 – 4.24.

4.3.6 Model Parameters

The experimental parameters that are needed for the model are re-aeration coefficient, k_2, velocity, V, 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).

$$k_2 = \beta 1 \frac{V^{\beta 2}}{H^{\beta 3}} \tag{4.3}$$

The model parameters $\beta 1$, $\beta 2$ and $\beta 3$ are the unknown values of the function that must be determined. Since $\beta 2$ and $\beta 3$ 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 4.25 – 4.26.

Table 4.25: Model fit and goodness of fit Summary for Dry Season

		MODEL OUTPUT			INITIAL ESTIMATE				GOODNESS OF FIT				
s/n	Month	β_1	β_2	β_3	β_1	β_2	β_3	Fit Type	SSE	R^2	ADJ. R^2	RMSE	COMMENT
1	January 2010	58.2584	0.8906	-0.0135	11	1	0.005	NON REPRESENTATIVE MODEL OUTPUT. DOES NOT PROCEED.					16 data pts
2	February 2010	46.2679	1.5463	0.0128	11	1	0.005	4th Polynomial	9.343	0.9524	0.9048	1.528	9 data pts
								5th Polynomial	8.93	0.9545	0.8786	1.725	
								6th polynomial	8.895	0.9547	0.8186	2.109	
								7th Polynomial	6.163	0.9686	0.7487	2.483	
3	March 2009	1.0e+003	-0.0013	-0.0130				AMBIGUOUS MODEL OUTPUT. DOES NOT PROCEED.					10 data points

Table 4.26: Model fit and goodness of fit Summary for Rainy Season

		MODEL OUTPUT			INITIAL ESTIMATE				GOODNESS OF FIT				
s/n	Month	β_1	β_2	β_3	β_1	β_2	β_3	Fit Type	SSE	R^2	ADJ. R^2	RMSE	COMMENT
1	July 2009	96.2548	0.9614	2.8911	11	1	0.05	4th Polynomial	490.8	0.5394	0.0788	11.08	9 data pts
								5th Polynomial	471.2	0.5578	-0.1792	12.53	
								6th polynomial	375.2	0.6479	-0.4085	13.70	
								7th Polynomial	248.0	0.7672	-0.8622	15.75	
2.	August 2009	38.2995	0.7222	1.1290	11	1	0.05	4th Polynomial	554.4	0.4096	0.0722	8.899	12 data pts
								5th Polynomial	350.7	0.6265	0.3152	7.645	
								6th polynomial	318.5	0.6607	0.2536	7.982	
								7th Polynomial	278.7	0.7032	0.1838	8.347	
								8TH Polynomial	147.7	0.8427	0.4233	7.016	
3.	Sept 2009	301	4.1216	0.3359	11	1	0.05	EXTREME MODEL OUTPUT. DOES NOT PROCEED.					7 data pts

4.3.7 The Model

Following the model output (Appendices 1-3) model validation was done based on the use of graphic aid and the statistic parameters discussed in section 2.6.4. The model selected (equation 4.4) was based on the output with the least error (Table 4.25).

$$k_2 = 46.2679 \frac{U^{1.5463}}{H^{0.0128}} \tag{4.4}$$

This model passed with a 4th polynomial fit to the response values, SSE = 9.343; R^2 = 0.9524; Adjusted R^2 = 0.9048 and a standard error of regression, RMSE = 1.528 (Table 4.25).

4.3.7.1 Assumptions on the model

In the course of modelling, assumptions are required for simplification and simulation purposes. For this model, the following assumptions were made:

i. The stream channel is semi-circular in shape.
ii. There were no oxygen sinks in the system
iii. The stream is uniformly mixed

4.3.8 Comparison with other Selected Models

The data for January, March and July were selected for the test of performance. January data represented dry weather flow. It had straight forward characteristics because it had only one oxygen sink across the three reaches. Also in this particular month, Sona Breweries discharged very strong wastewater that overshadowed every other source of pollution. July 2009 data represented the rainy season with high water discharge and velocity while March 2009 data has the peculiarity of having very unstable and difficult to predict data. This is because there were many sinks of oxygen along the river segment for this month. The performance of equation 4.4, here after referred to as Atuwara re-aeration model after the name of the river, was tested by comparing it with ten well known and carefully selected models that were developed in the past and from different parts of the world. The selected models as well as their properties are detailed in Table 4.27.

Table 4.27: Selected Models for Model Validation (Test of performance)

s/n	Model	Authors	Background	Country
1	$k_2 = 46.2679\frac{U^{1.5463}}{H^{0.0128}}$	Atuwara	Based on data gathered from River Atuwara in Southwest Nigeria. Range: (0.01m/s<U<1.15m/s: 0.1m<H<3.56m) where U is velocity and H is hydraulic radius.	Nigeria
2	$k_2 = 12.9\frac{U^{0.5}}{H^{1.5}}$	O'Connor And Dobbins (1958)	For moderately deep to deep channels. Range: (0.305m<H<9.14m; 0.15m/s<U<0.49m/s; $0.5 \le k_2 \le 12.2$ d^{-1})	USA
3	$k_2 = 11.632\frac{U^{1.0954}}{H^{0.0016}}$	Agunwamba et al. (2007)	Based on data gathered from creeks in the south-south part of Nigeria. Where U is velocity and H is hydraulic radius.	Nigeria
4	$k_2 = 5.792\frac{U^{0.5}}{H^{0.25}}$	Jha et al., (2001)	Based on data obtained from River Kali in India.	India
5.	$k_2 = 5.026\frac{U^{0.969}}{H^{1.673}}$	Streeter and Phelps	Based on data gathered from River Ohio, USA	USA
6	$k_2 = 10.046\frac{U^{2.696}}{H^{3.902}}$	Baecheler and Lazo (1999)	For slight slope rivers in a mountainous environment.	Chile
7	$k_2 = 21.7\frac{U^{0.67}}{H^{1.5}}$	Owens et al., (1964)	Oxygen recovery monitored for six streams in England following de-oxygenation with sodium sulfite. Range: (0.12m<H<3.35m; 0.55m/s<U<1.52m/s	England
8	$k_2 = 4.67\frac{U^{0.6}}{H^{1.4}}$	Bansal (1973)	Based on re-analysis of re-aeration data of numerous data	USA
9	$k_2 = 20.2\frac{U^{0.607}}{H^{1.689}}$	Bennet and Rathburn (1972)	Based on re-analysis of historical data	USA
10	$k_2 = 1.923\frac{U^{0.273}}{H^{0.584}}$	Long (1984)	Based on data collected from streams in Texas. Equation also known as Texas equation.	USA
11	$k_2 = 7.6\frac{U}{H^{1.33}}$	Langbein and Dururn (1967)	Based on synthesis of data from O'Connor and Dobbins (1958), Churchill *et al.*, (1962), Krenkel and Orlob (1963), Streeter *et al.*, (1936) aka USGS equation.	USA

Procedure for the composite goodness of fit

The performance measurement was done using the composite goodness of fit. The term 'composite goodness of fit' was coined from the combination of the merits of statistical goodness of fit and graphical (trend lines and scatter diagrams) goodness of fit. In order to compare the predictive capacity of two or more k_2 models, the process begins with the regression (linear or non-linear) of observed data and predicted data. Then the statistical goodness of fit of each model is determined using the procedure described in the flowchart (Figure 4.6). The process illustrated in the flowchart is repeated for each of the models listed in Table 4.27 to generate an output which serve as the input data in the algorithm of the composite-goodness-of-fit.

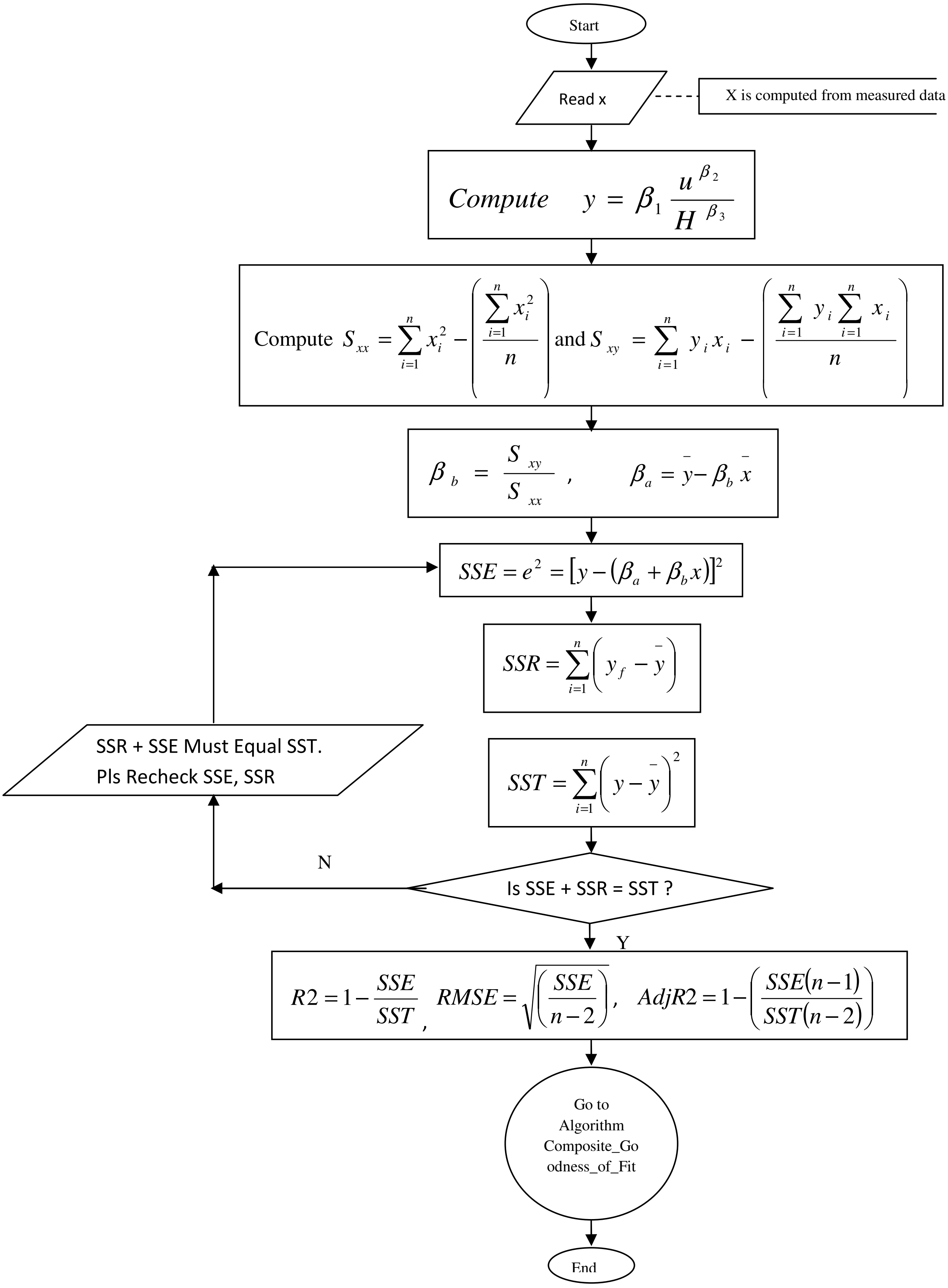


Fig 4.6.: Flowchart showing the progression of the statistical analysis

Data Structure

1. Stat: array of records: Each record has 14 fields

   Fields in a record: Type, SSE, SSR, RMSE, R2, SSEW, SSRW, RMSEW, R2W, ADJR2 ADJR2W, SUMOFALL, Wsfactor, Wgfactor

2. Graph: array of records: Each record has 3 fields

   Fields in a record: Type, Weight, Wgfactor

3. Merge: array of of records: Each record has 2 fields

   Fields in a record: Type, Overallweight

ALGORITHM OF COMPOSITE_GOODNESS_OF_FIT

```
STEP 1:     Initialize Stat, Graph, Merge

STEP 2:         For i = 1 to 11

            Begin

              Stat[i].Type = i; //model name 1,2,3,…11

              Compute

              Stat[i].SSE;

              Stat[i].SSR;

              Stat[i].RMSE;

              Stat[i].R2;

              Stat[i].ADJR2;

            End

STEP 3:         Sort Stat in ascending order of Stat.SSE

STEP 4:         For i = 1 to 11

            Begin

              Assign weight to Stat[i].SSEW;

              //highest weight to least value of SSE

            End

STEP 5:     Sort Stat in ascending order of Stat.SSR

STEP 6:         For i = 1 to 11

            Begin

              Assign weight to Stat[i].SSRW;

              //highest weight to least value of SSR

            End
```

```
STEP 7:     Sort Stat in ascending order of Stat.RMSE
STEP 8:             For i = 1 to 11
            Begin
              Assign weight to Stat[i].RMSEW;
              //highest weight to least value of SSE
            End
STEP 9:             Sort Stat in ascending order of Stat.R2
STEP 10:    For i = 1 to 11
            Begin
              Assign weight to Stat[i].R2W;
              //highest weight to highest value of R2
            End
STEP 11:    Sort Stat in ascending order of Stat.AdjR2
STEP 12:    For i = 1 to 11
            Begin
              Assign weight to Stat[i].AdjR2W;
              //highest weight to highest value of AdjR2
            End
STEP 13:    For i = 1 to 11
            Begin

        Stat[i].SUMOFALL=Stat[i].SSEW+Stat[i].SSRW+Stat[i].RMSEW+Stat[i].R2W+Stat[i].AdjR2W;
            End
STEP 14:    Sort Stat in descending order of Stat.SUMOFALL
            //the model in Stat[1].Type is the best model
STEP 15:    For i = 1 to 11
            Begin
              Graph[i].Type = i;       //model name
              Print ‘‘Enter graphical weight for model %d: ’’ i;
              Input Graph[i].Weight;
            End
STEP 16:    Print ‘‘Enter Graphical Percentage: ’’
STEP 17:    Input N1
```

```
STEP 18:    Print ‘‘Enter Statistical Percentage: ’’
STEP 19:    Input N2
STEP 20:    Print ‘‘Caution: N1+N2 should be equal to 100’’
STEP 21:    gfactor = $\frac{N1}{100}$
STEP 22:    sfactor = $\frac{N2}{100}$
STEP 23:    For i = 1 to 11
            Begin
               Graph[i].Wgfactor = gfactor * Graph[i].Weight;
               Stat[i].Wsfactor = sfactor * Stat[i].SUMOFALL;
            End
STEP 24:    Sort Stat in ascending order of Stat.Type
STEP 25:    For i = 1 to 11
            Begin
               Merge[i].Type = i;        //model name
               Merge[i].Overallweight = Stat[i].Wsfactor+Graph[i].Wgfactor;
            End
STEP 26:    Sort Merge in descending order of Merge.Overallweight
//the first i.e. Merge[1].Type is the best overall model having combine Stat & Graph
```

The statistical values and graphs are the input data for the composite goodness of fit procedure described in steps by the algorithm stated below (Lines 1-3 of data structure). The procedure operates by adapting the Likert scale system of weight allocation (Page-Buchi, 2003; Uebersax, 2006; Longe *et al.*, 2009) to statistical and graphical input data (Steps 4, 6, 8, 10, 12 and 15). For the statistical input data, the error term for the best model is expected to be the least. Therefore, the model with the minimum error is allocated the highest weight, *n*. The highest weight, *n* = the number of models being considered. Likewise, the best model is expected to have the highest value of coefficient of determination. Therefore, the highest weight is allocated to the model with the highest R^2 or Adjusted R^2. For the graphical input data, the weights are allocated by inspection. The response trend line that best imitates the measured data trend line is allocated the highest weight. If two models display the same statistical value or trend line, the same values are allocated to them. However, the value of weight that may be allocated to the next model will be *m-j*, where *m* = the weight value shared by two or more models and *j* = the number of models that share the value. Another sensitive part of the composite goodness of fit is the allocation of importance to the statistical and graphical components of the composite goodness of fit (Steps 16-22 of the algorithm). For this study, equal importance was given to them therefore each carried a 50% cumulative weight in the final analysis (Steps 25-26).

Statistical Analysis

The results of the statistical analysis using the procedure in Figure 4.6 are presented in Tables 4.28 – 4.31. The model with the best statistical output was Texas equation (Long, 1984). Agunwamba re-aeration model was in the fourth position and Atuwara re-aeration model was in the sixth position.

Table 4.28: Goodness of fit using January Data

	Atuwara	w	O'Connor	w	Agunwamba	w	Jha	w	Streeter	w	Baecheler	w	Owens	W	Bansal	w	Bennet	w	Long	w	Langbein	w
SSE=	129.29	8	6785.58	4	16.573	10	17.99	9	759.2331	5	169141	1	43299.1	2	536.633	7	25186.9	3	8.432	11	545.872	6
SSR=	22.2823	8	391.431	4	2.1175	9	1.167	10	70.90248	5	24793.2	1	3231.22	2	34.516	7	1714.05	3	0.2908	11	52.1983	6
R2 =	0.14701	11	0.05454	2	0.1133	9	0.061	4	0.085411	7	0.12784	10	0.06944	6	0.06043	3	0.06372	5	0.0333	1	0.08728	8
RMSE=	2.93587	8	21.269	4	1.0511	10	1.095	9	7.11446	5	106.189	1	53.7271	2	5.98127	7	40.9772	3	0.7498	11	6.03253	6
Adj. R2=	0.09014	11	-0.00849	2	0.0542	9	-0	4	0.024438	7	0.0697	10	0.00741	6	-0.0022	3	0.0013	5	-0.0311	1	0.02643	8
TOTAL SCORE		**46**		**16**		**47**		**36**		**29**		**23**		**18**		**27**		**19**		**35**		**34**

NB: w = weighting system based on Likertscale (Page-Buchi, 2003; Uebersax, 2006; Longe *et al.*, 2009)

Table 4.29: Goodness of fit using March Data

	Atuwara	w	O'Connor	w	Agunwamba	w	Jha	w	Streeter	w	Baecheler	w	Owens	w	Bansal	w	Bennet	w	Long	w	Langbein	w
SSE=	1201.37	5	1320.76	4	91.114	9	28.01	10	174.5671	7	3794.77	3	6178.08	1	129.361	8	4221.66	2	3.818	11	229.133	6
SSR=	27.3381	5	85.2295	4	1.2952	9	0.168	11	6.101995	8	107.48	3	343.823	1	6.13083	7	241.447	2	0.1718	10	6.55914	6
R2 =	0.02225	3	0.06062	11	0.014	2	0.006	1	0.033774	6	0.02754	4	0.05272	9	0.04525	8	0.0541	10	0.0431	7	0.02783	5
RMSE=	8.94937	5	9.38354	4	2.4646	9	1.367	10	3.411423	7	15.9055	3	20.2946	1	2.93667	8	16.7763	2	0.5045	11	3.90839	6
Adj. R2=	-0.04293	3	-0.00201	11	-0.0517	2	-0.06	1	-0.03064	6	-0.0373	4	-0.01043	9	-0.0184	8	-0.009	10	-0.0207	7	-0.037	5
TOTAL SCORE		**21**		**34**		**31**		**33**		**34**		**17**		**21**		**39**		**26**		**46**		**28**

NB: w = weighting system based on Likertscale (Page-Buchi, 2003; Uebersax, 2006; Longe *et al.*, 2009)

Table 4.30: Goodness of fit using July Data

	Atuwara	w	O'Connor	w	Agunwamba	w	Jha	w	Streeter	w	Baecheler	w	Owens	w	Bansal	w	Bennet	w	Long	w	Langbein	w
SSE=	4843.94	1	50.254	5	249.58	2	21.45	7	11.21727	9	20.0913	8	151.538	3	7.46274	10	130.324	4	0.7124	11	32.8521	6
SSR=	4.05001	1	0.55222	4	0.3763	5	0.088	7	0.087571	8	0.00136	11	1.6657	2	0.08055	9	1.45062	3	0.0065	10	0.21255	6
R2 =	0.00084	2	0.01087	10	0.0015	3	0.004	4	0.007746	6	6.8E-05	1	0.01087	10	0.01068	8	0.01101	11	0.009	7	0.00643	5
RMSE=	17.9702	1	1.83037	5	4.079	2	1.196	7	0.864765	9	1.15733	8	3.17844	3	0.70535	10	2.94758	4	0.2179	11	1.47991	6
Adj. R2=	-0.06578	2	-0.05507	10	-0.0651	3	-0.06	4	-0.0584	6	-0.0666	1	-0.05507	10	-0.0553	8	-0.0549	11	-0.0571	7	-0.0598	5
TOTAL SCORE =		**7**		**34**		**15**		**29**		**38**		**29**		**28**		**45**		**33**		**46**		**28**
AVERAGE SCORE FOR 3 MONTHS=		**25**		**28**		**31**		**22**		**34**		**23**		**22**		**37**		**26**		**42**		**30**
AVERAGE SCORE FOR 3 MONTHS (%) =		**7.8**		**8.8**		**9.7**		**6.9**		**10.6**		**7.2**		**6.9**		**11.6**		**8.1**		**13.1**		**9.4**
RATING		**8**		**6**		**4**		**10**		**3**		**9**		**10**		**2**		**7**		**1**		**5**

NB: w = weighting system based on Likertscale (Page-Buchi, 2003; Uebersax, 2006; Longe *et al.*, 2009)

Graphical Analysis

By simple observation, some models appear to describe the measured data more than others. Some of these graphics are presented in Figures 4.7 – 4.12. The ten models (Table 4.27) were all plotted together for January, March and July data (Figures 4.7, 4.9 and 4.11).

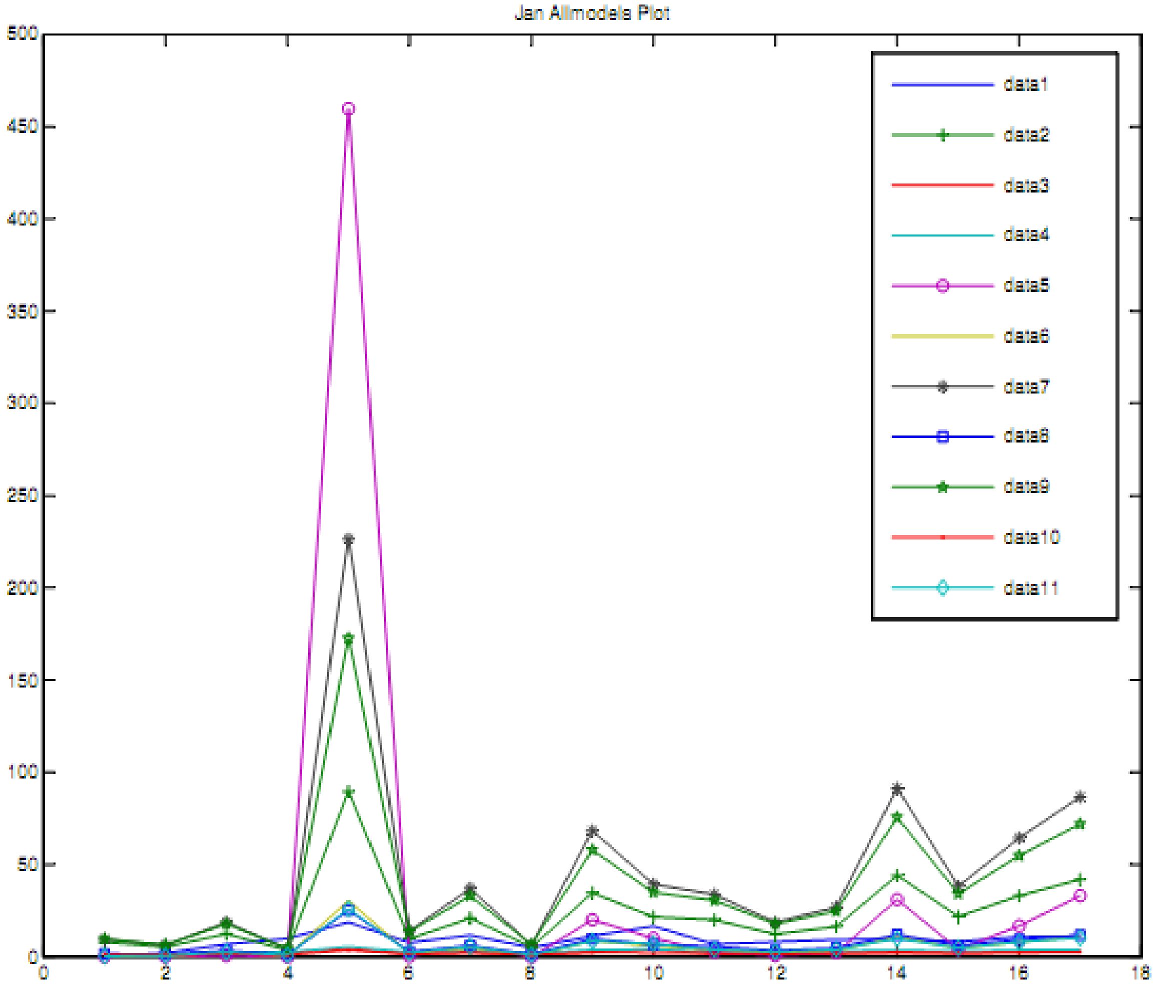


Figure 4.7: Plot of 11 models using January data

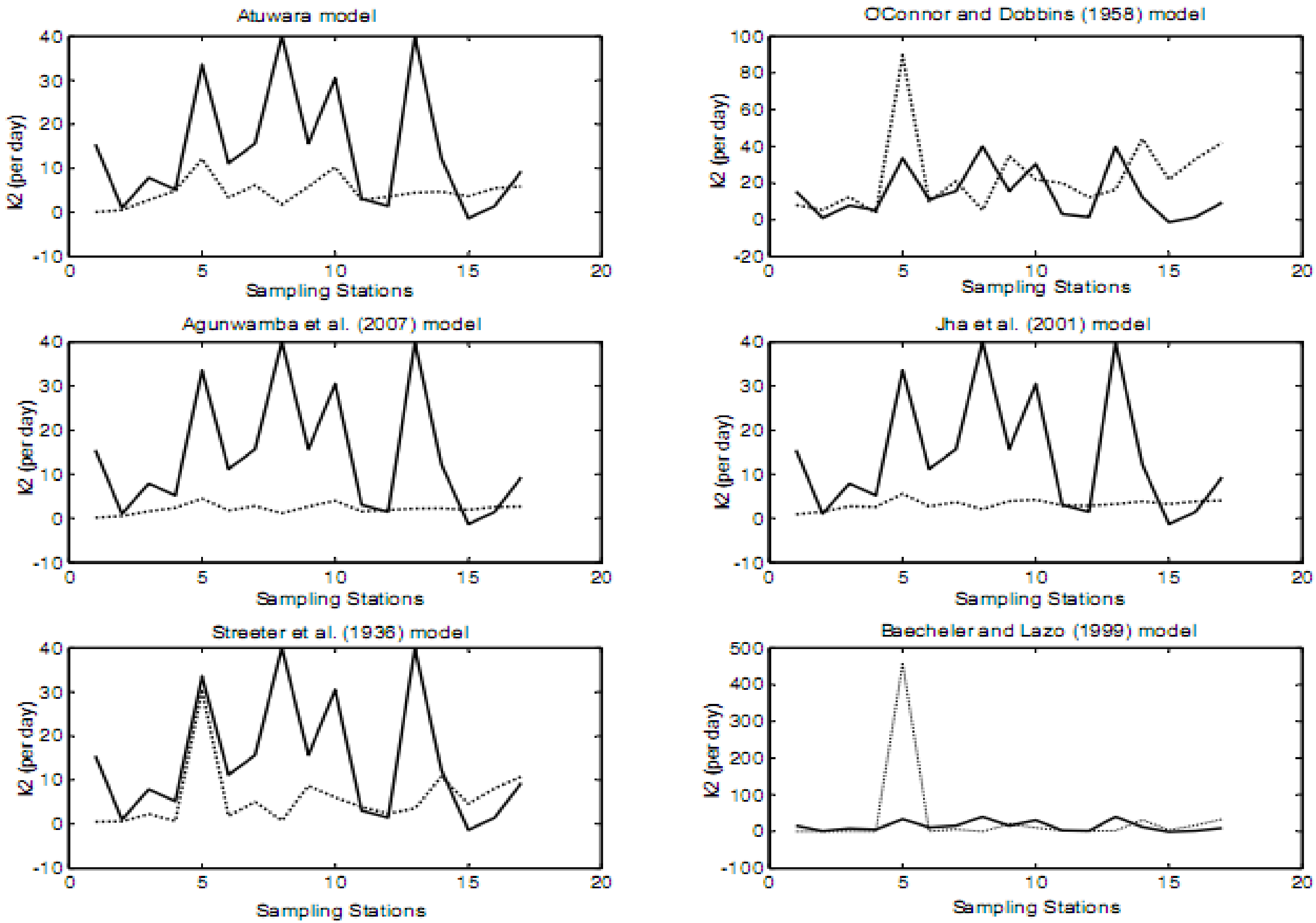


Figure 4.8: Plot of measured k_2 against computed k_2 using January data

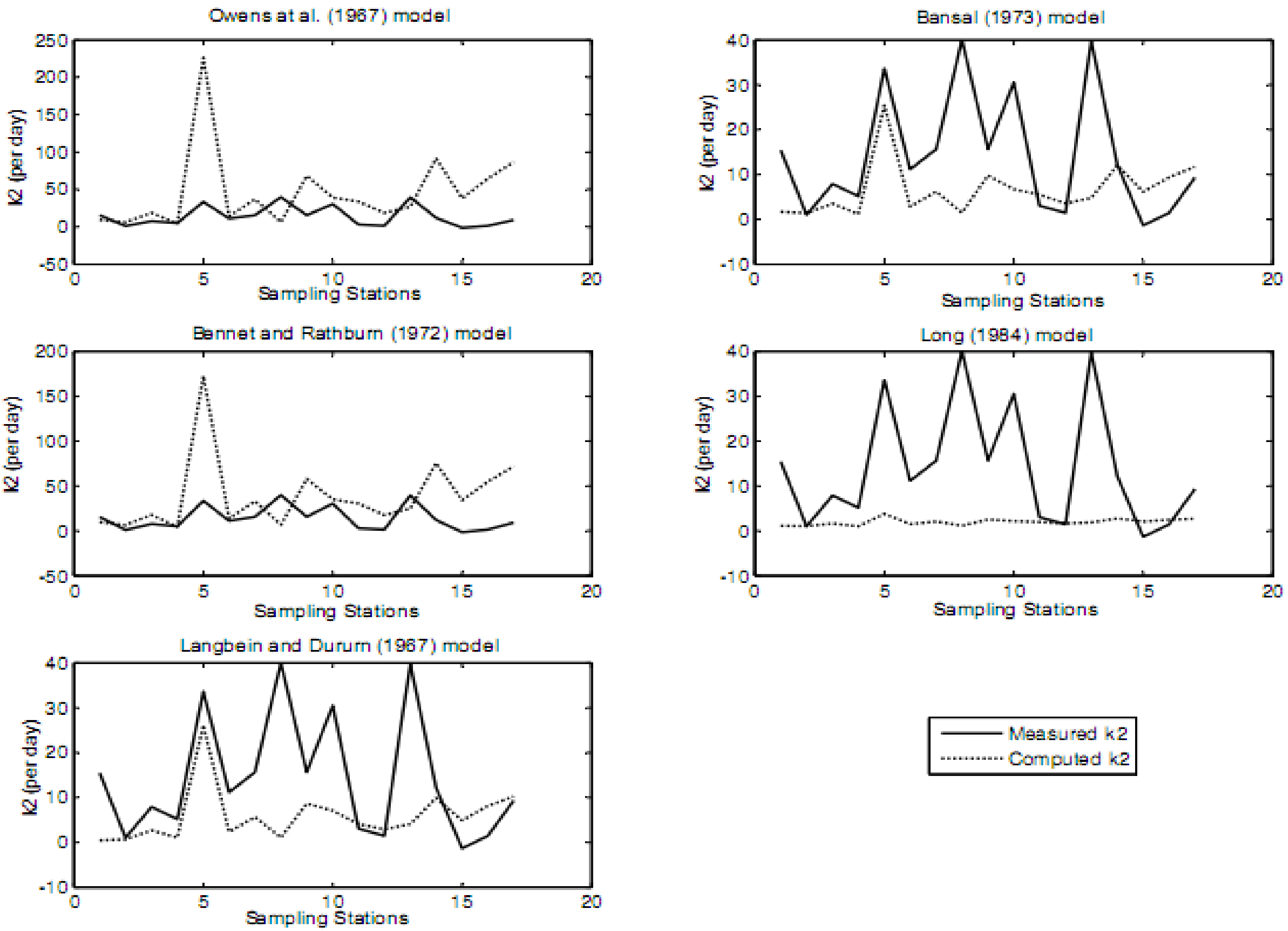


Figure 4.8 continued: Plot of measured k_2 against computed k_2 using January data

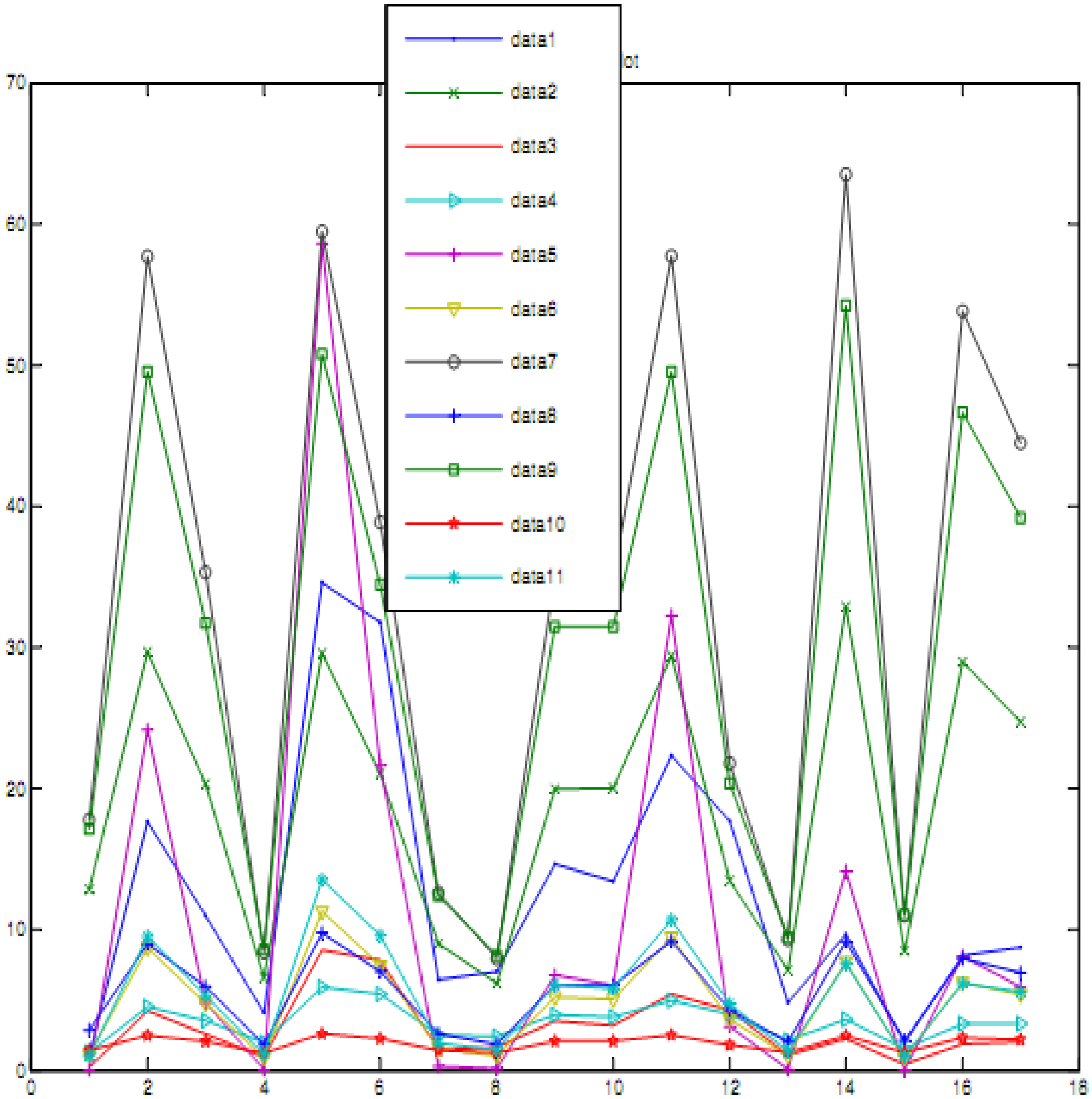


Figure 4.9: Plot of 11 models using March data

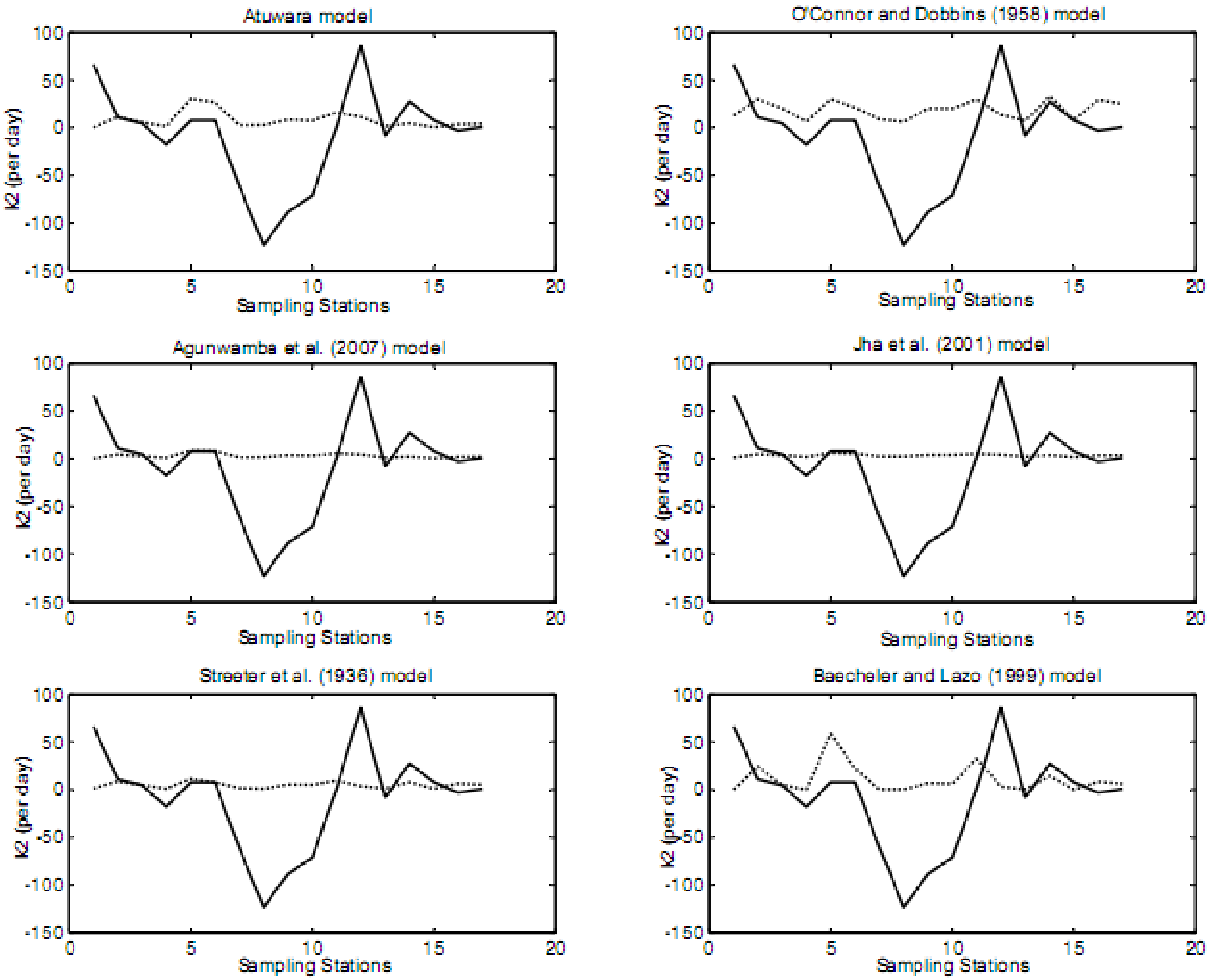


Figure 4.10: Plot of measured k_2 against computed k_2 using March data

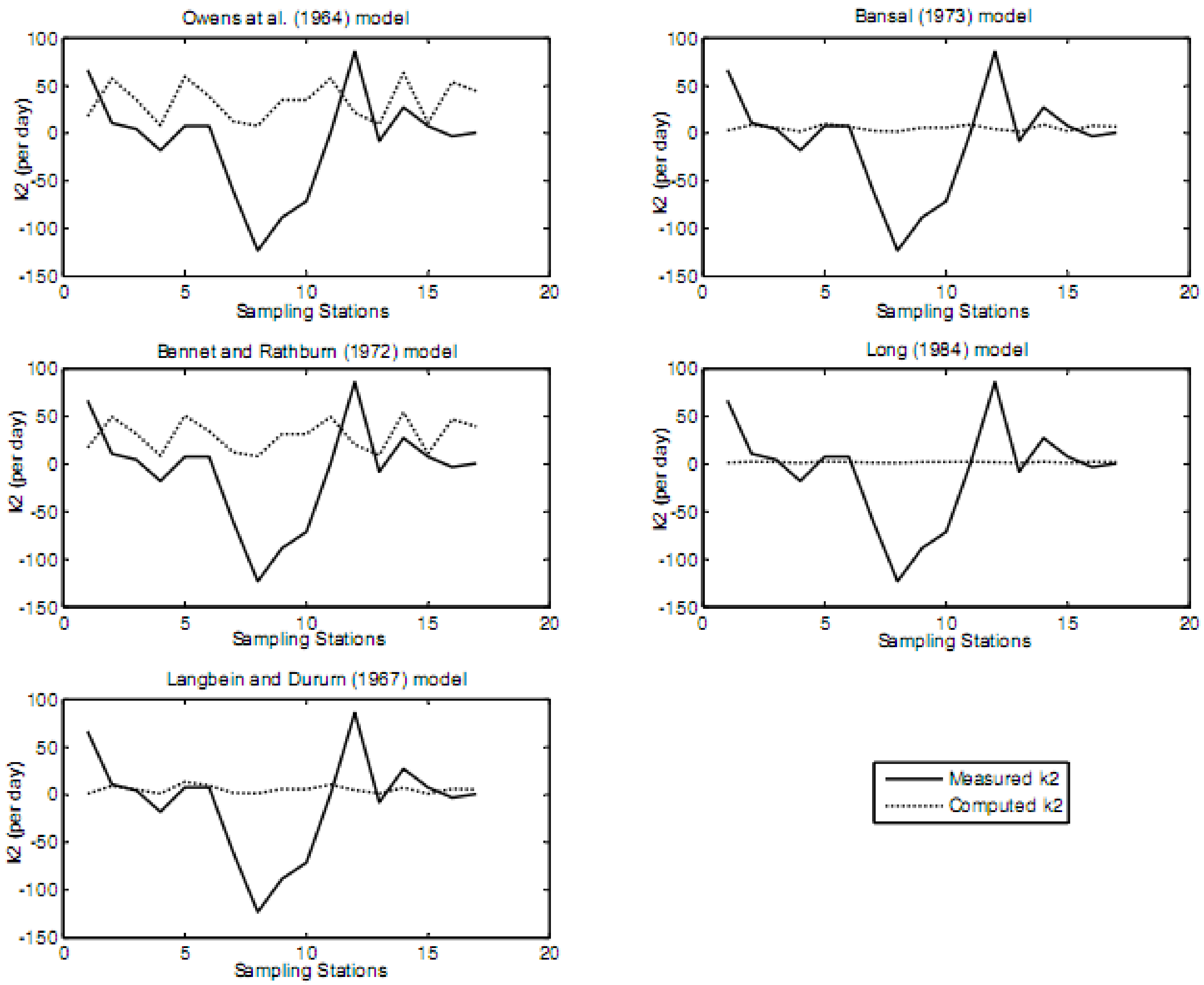


Figure 4.10 continued: Plot of measured k_2 against computed k_2 using March data

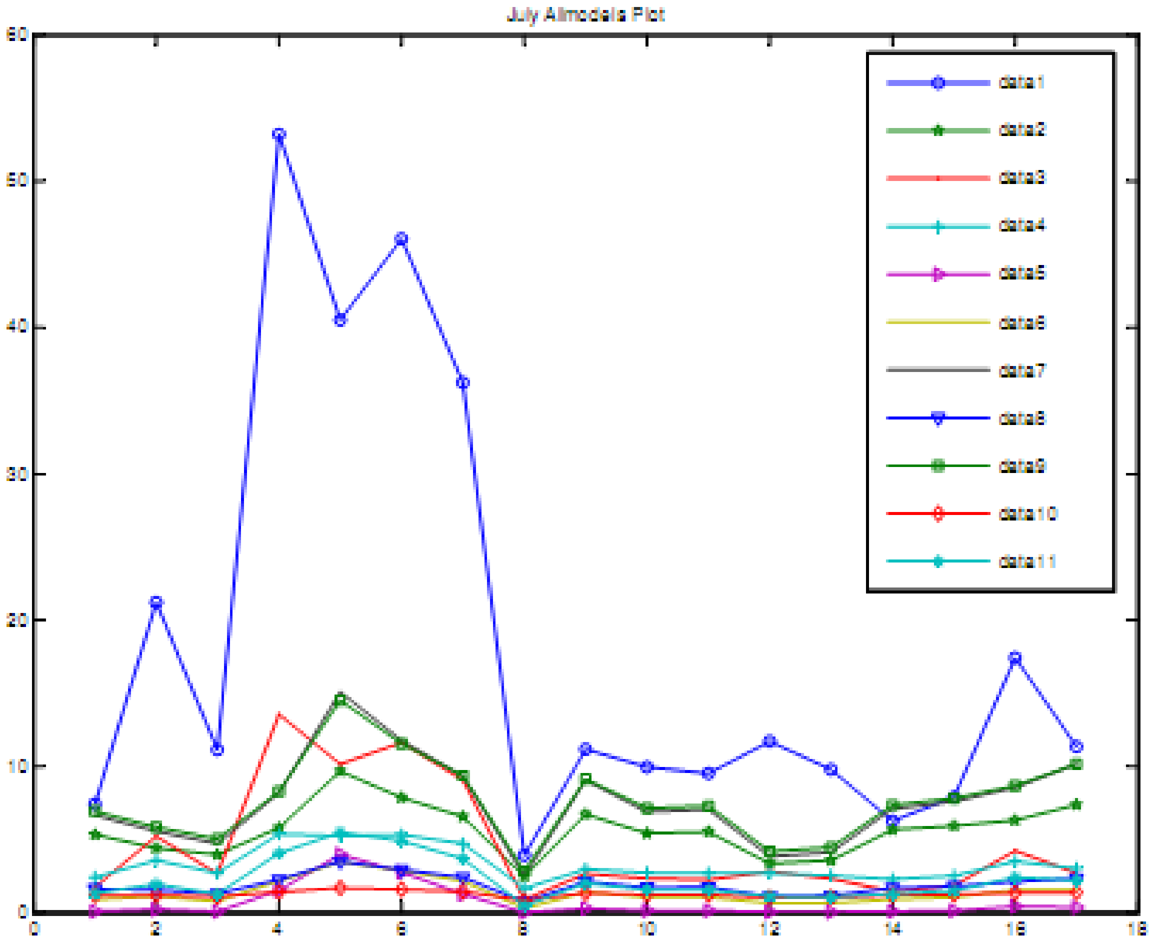


Figure 4.11: Plot of 11 models using July data

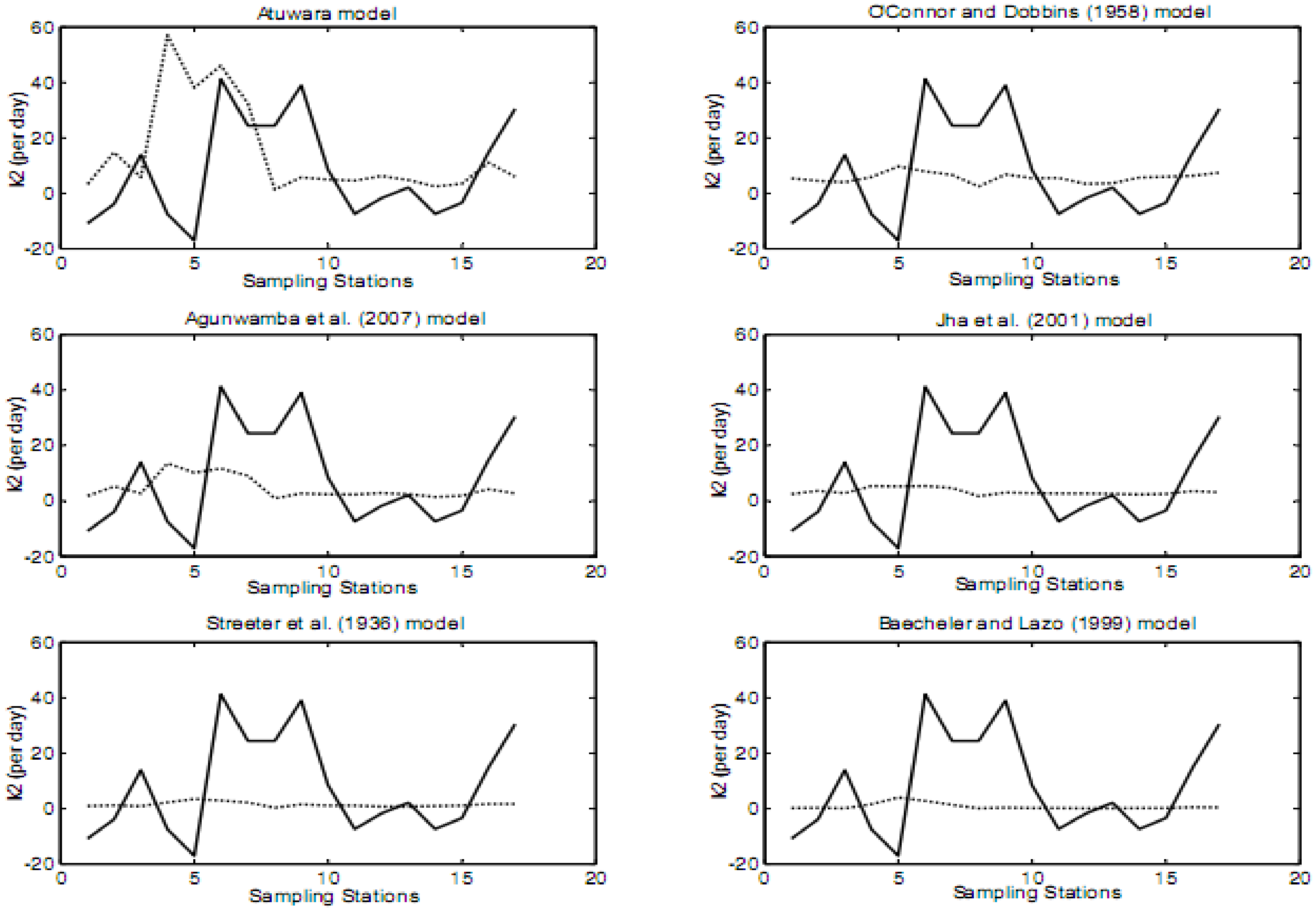


Figure 4.12: Plot of measured k_2 against computed k_2 using July data

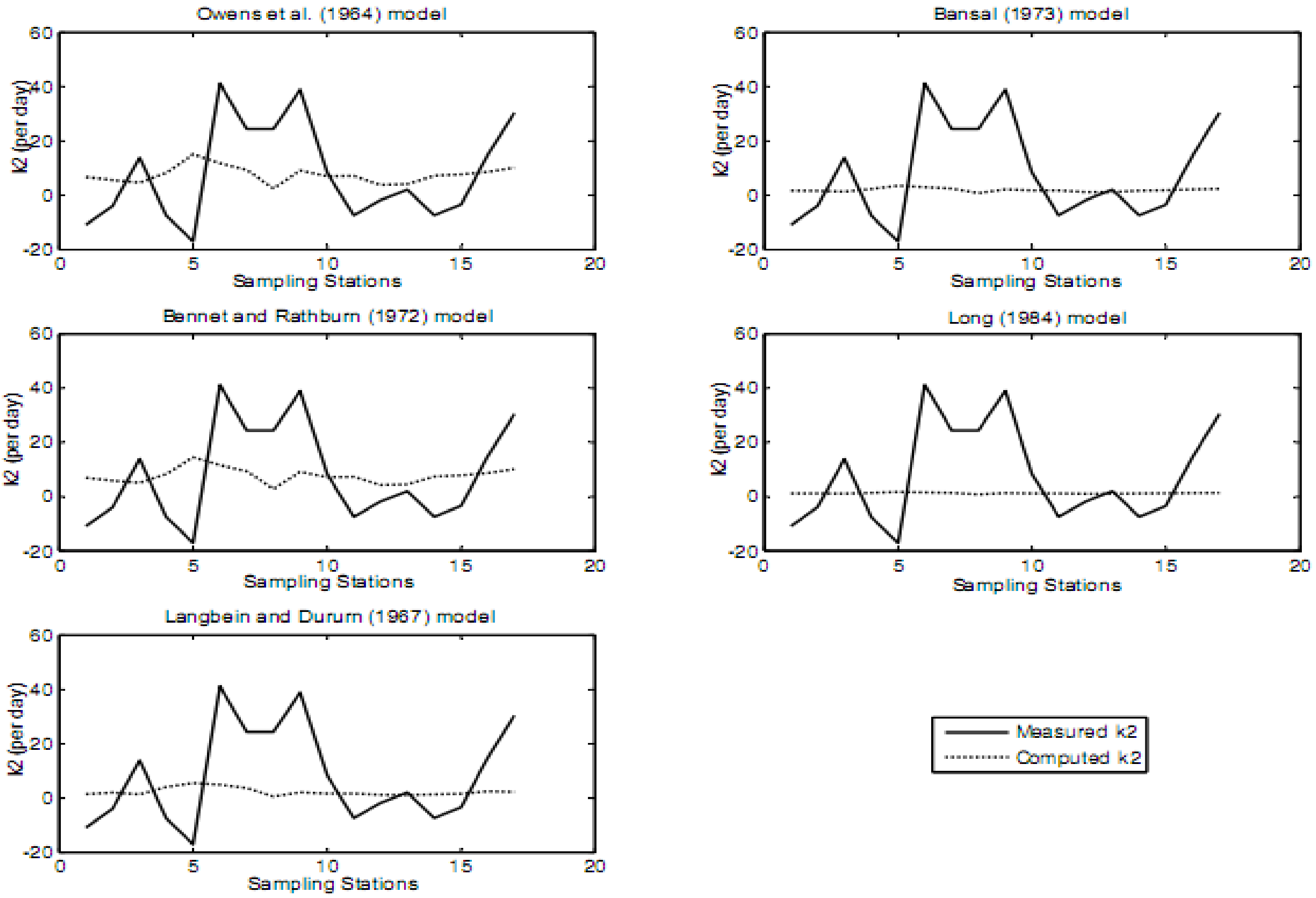


Figure 4.12 continued: Plot of measured k_2 against computed k_2 using July data

The score from the observation of the graphs and its combination with the summary of the statistics (Table 4.30) is shown in Table 4.31. Bennet and Rathburn model had the best graphical representation of measured data while Atuwara re-aeration model was fourth. Although Texas equation had the best statistical output, it was very poor in graphical display as it became a flat line in nearly all the data tested.

Table 4.31: Graphical Goodness of fit using January, March and July Data

s/n		**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**	**Model 9**	**Model 10**	**Model 11**
1	**JANUARY**	5	11	4	4	8	1	10	7	10	2	7
2	**MARCH**	8	9	3	3	5	7	11	6	11	1	7
3	**JULY**	11	8	10	9	4	2	8	4	8	1	5
4	**AVERAGE SCORE FOR 3 MONTHS**	8.0	9.3	5.7	5.3	5.7	3.3	9.7	5.7	9.7	1.3	6.3
5	**AVERAGE SCORE FOR 3 MONTHS (%)**	11.4	13.3	8.1	7.6	8.1	4.7	13.9	8.1	13.9	1.9	9
6	**AVERAGE SCORE FOR STAT. & GRAPH (%)**	**9.6**	**11.1**	**8.9**	**7.3**	**9.4**	**6.0**	**10.4**	**9.9**	**11.0**	**7.5**	**9.2**

NB: w = weighting system based on Likertscale (Page-Buchi, 2003; Uebersax, 2006)

The order of performance of the models from the composite goodness of fit analysis is presented in Table 4.32. This revealed that the model with the best fit and best interpretation of the conditions of River Atuwara is O'Connor and Dobbins (1958) equation. The Atuwara re-aeration model came in the fifth position and the Agunwamba model came in the eighth position. With the exception of O'Connor and Dobbins model, the other three models that displayed better composite goodness of fit than Atuwara re-aeration model were developed either by using re-analysis of multiple existing data or multiple rivers (Table 4.27). This suggests that replication in the process of model formulation has a direct impact on the model output.

Table 4.32 – Order of Composite Goodness of Fit

s/n	MODEL	AVERAGE SCOREFOR STAT & GRAPH (%)
1	O'Connor and Dobbins (1958) model	11.1
2	Bennett and Rathburn (1972) model	11.0
3	Owens et al., (1964) model	10.4
4	Bansal (1973) model	9.9
5	Atuwara model	9.6
6	Streeter et al., (1936) model	9.4
7	Langbein and Dururn (1967) model	9.2
8	Agunwamba et al., (2007) model	8.9
9	Long (1984) model	7.5
10	Jha et al., (2001) model	7.3
11	Baecheler and Lazo (1999) model	6.0

The observed differences in these models are expected. While some of the models are theoretical relationships, others are empirical based on field measurements which are influenced by the local conditions. The theoretical models need verification against observed conditions while the empirical models are valid for given conditions.

Both the Atuwara re-aeration model and the Agunwamba re-aeration model are applicable to the Nigerian rivers. The differences in their formation are probably due to locations of data collection. While the Atuwara model was based on data collected from a running river located in the mainland of South-West Nigeria, the Agunwamba model was developed from data collected from creeks in the South-South part of Nigeria with proximity to the Atlantic Ocean.

4.4 Water Use Practices

During the preliminary field survey in Ota in 2009, it was estimated at 95% confidence level that between 11% and 24.4% of the 526, 565 residents (NBS, 2006) have no access whatsoever to safe water sources. These are the people who depend completely on surface water sources for their livelihood including bathing, cooking, drinking, recreation and farming. Unfortunately for this underprivileged category of people, some other users employ the use of surface water bodies as an avenue for waste disposal. This includes hazardous industrial effluents, pig farm and slaughterhouse effluents, sewage dumping and outright dumping of carcasses (Plate 4.3).

Plate 4.3 – Human skeleton found in the River

Apart from domestic and waste disposal uses, Ota residents also use the river water to economic advantages. Some of these purposes include sand dredging (Plate 4.1), farm irrigation, fish farming, animal husbandry, poultry farming and bamboo tree logging for building construction. Unfortunately, all these activities come along with pollution and channel blockage (Plates 4.4 and 4.5). The water from River Atuwara is drawn by the State Water Corporation for treatment and further distribution to some residents (Plate 4.6). Other uses for which the river is put include recreation activities. People often go to the river for swimming and fishing activities (Plate 4.7).

Plate 4.4: Pollution along the river channel

Plate 4.5: The research team could not proceed because of blockage of the river channel

Plate 4.6: Water intake station for Ogun State Water Corporation

Plate 4.7: Man swimming after the day’s work

4.5 Pollutants and Public Health Implications

Three water samples were obtained for detailed analysis in February 2010. Sample A was obtained at the upstream part, near the effluent mixing zone. Sample B was obtained from the downstream end of the reach. This is the water quality downstream of the effluent discharge point and is the point where Iju villagers draw water for their domestic use. Sample C is the raw effluent itself. On a closer look, it can be seen that the water from River Atuwara which is being consumed by residents of Iju for domestic purposes exceeded the limits for nitrite, lead, nickel and Total Coliform. Many colonies of coliform bacteria were isolated as indicated in the result in Table 4.33 due to faecal contaminations and some chemical deposits. Sample C is an acidic mixture, thus the low BOD. The acidic nature of the effluent destroys the bacteria that would ordinarily have broken down the waste loads in the water system. However, due to the high dilution factor attributable to the low effluent discharge and high river discharge and velocity, the impact of Chelsea alcoholic effluent discharge is significantly attenuated.

Table 4.33: Comprehensive River water and Industrial Effluent Analysis

S/N	**PARAMETERS**	**RESULTS**			**NSDWQ**	**METHOD OF DETERM-INATION**	**REMARK**
	Physical, Chemical &Microbiological	SAMPLE A	SAMPLE B	SAMPLE C			
1	Temperature (0°C)	28.8	28.6	NT	22-30	Jenway PH meter	
2	PH	6.792	6.821	5.689	6.8-8.5	Jenway meter	Sample C is acidic
3	Colour	Colourless	Colourless	NT	Clear/Colourless		
4	Taste	Unobjectionable	Unobjectionable	NT	Unobjectionable		
5	Odour	Odourless	Odourless	NT	Unobjectionable		
6	Turbidity (NTU)	0.05	0.01	NT	5	Hannah kit	
7	Conductivity (μS/cm)	85	76	218.5	1,500 × 10^{-6}	Electrochemistry analyszer	All samples NC
8	Total Solids (mg/l)	0.178	0.200		1,200	Gravimetric	
9	Total Suspended Solids (mg/l)	0.118	0.030	0.012	15	Gravimetric	
10	Total Dissolved Solids (mg/l)	0.060	0.170	0.180	500 (FMEnv)	Gravimetric	
11	Total Hardness (mg/l)	22	24	NT	400	Titrimetry	
12	Total Alkalinity (mg/l)	250	140	210	100 (W.H.O)	Titrimetry	All samples NC
13	Total Acidity (mg/l)	4	5	151	5	Titrimetry	Sample C is NC
14	Calcium (mg/l)	8.82	9.6192	74.55	50 (W.H.O)	Titrimetry	Sample C is NC
15	Magnesium (mg/l)	13.18	3.4945	111.45	50 (W.H.O)	Titrimetry	Sample C is NC
16	Biochemical Oxygen Demand (BOD) (mg/l)	15	18	0.4	-	Titrimetry	
17	Dissolved Oxygen (mg/l)	3.4	2.4	0.7	-	Electrochemistry analyzer	
18	COD (mg/l)	2.8	3.4	0.4	-	Refluxing	
19	Chloride (mg/l)	56.72	49.63	35.45	250	Titrimetric method	
20	Nitrate (mg/l)	3.4	22.5	15.8	50	Hach	
21	Nitrite (mg/l)	16.0	17.0	NT	5	Hach	Samples A snd B NC
22	Sulphate (mg/)	30.0	32.0	52.0	200	Hach	
23	Copper (mg/l)	0.18	0.30	NT	2	AAS	
24	Manganese (mg/l)	0.024	ND	0.129	0.5	AAS	
25	Iron (mg/l)	0.014	0.008	0.046	0.3(FMEnv.)	AAS	
26	Zinc (mg/l)	1.396	1.462	1.471	5 (FMEnv.)	AAS	
27	Lead (mg/l)	0.090	0.101	0.114	0.01 (FMEnv.)	AAS	All samples

							NC
28	Cadmium (mg/l)	ND	ND	ND	0.003	AAS	
29	Nickel (mg/l)	1.382	1.181	1.702	0.07 (WHO)	AAS	All samples NC
30	Chromium (mg/l)	0.014	ND	0.020	0.05	AAS	
31	Total Bacterial Count (cfu/100ml)	2.240×10^6	2.20×10^6	NT	-	Spread plate Techniques	
32	Total Coliform (cfu/100ml)	1.600×10^2	1.0×10^3	NT	0-10	Spread plate Techniques	Samples A snd B NC
33	Total Fungi/Yeast Counts	2.000×10^1	1.00×10^2	NT	-	Spread plate Techniques	

Notes: ND - Not detected, NT- Not Tested; NC – Not Compliant with standards; cfu - colony forming unit; WHO - World Health Organization; NSDWQ (2007) - Nigerian Standard for Drinking Water Quality; FMEnv – Federal Ministry of Environment.

The high total coliform count, although not a health threat in itself, is indicative of whether other potentially harmful bacteria such as Fecal Coliform and E.Coli are present (EPA, 2003; Hammer, 1986). When they are present, the public is at risk of contracting gastrointestinal illnesses such as diarrhoea, vomiting, cramps. This concern cannot be ruled out judging from the point raised in section 3.1 and plates 3.5 and 4.3. The high level of lead in the water being consumed by the villagers also poses a risk to infants and children. It causes delays in physical or mental development (WHO, 2006). Children could show slight deficits in attention span and learning abilities. When it bio-accumulates in the body, it could also lead to kidney problems and high blood pressure in adulthood (WHO, 2006). The high lead content in the Chelsea effluent could be regarded as the cause of the lead content in River Atuwara, even though other unidentified sources may be equally responsible for this problem. From the foregoing, it can be concluded that drinking the water from River Atuwara by Ota residents is highly unsafe for public health. It is therefore, strongly recommended that the water be treated before human consumption. The presence of nitrite in River Atuwara is also a public health risk. Nitrates originate from runoff from fertilizer use, leaching from septic tanks, sewage and erosion of natural deposits (EPA, 2003). Infants below the age of six months that drink water containing nitrate in excess of the maximum contaminant level could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome (WHO, 2006). Nickel was found to exceed the limits in the river. Nickel, like lead, causes peripheral neuropathy and brain damage (Clausen and Rastogi, 1977; Tolonen, 1972).

One of the primary aims of water quality modelling is to monitor the constituents of the natural resource. Monitoring is necessary in order to preserve the quality of natural national water resources and to protect them from indiscriminate abuse by users. This is the very reason why the Nigerian authorities need to wake up to this onerous task because much more than any western citizens, our own people depend more on these resources in the naturally occurring state for survival (section 4.5). This study focused more on BOD and DO in the modelling effort. However, BOD is only an indicator of the measure of pollution and so does not out rightly identify the pollutants. An attempt was made, however, to make a comprehensive test of water samples from some of the sampling stations of interest. The results and implications are alarming and ought to be re-visited by researchers in the nearest future. One would have been tempted to conclude that the effluent discharge from Intercontinental Distilleries is harmless and has been attenuated due to the high dilution factor but the lead content demonstrated otherwise (Table 4.32). The conclusion of this addendum to the study is that all the persons currently using the water for domestic purposes are exposed to long and short term health risks (Section 4.5). River Atuwara is also unsafe for fishing since the chemical pollutants in the river can bio-accumulate in the fish and get transferred to humans. Safe water sources such as boreholes have been sunk in Iju village. However, some of the villagers, especially those living close to River Atuwara, feel the borehole is too far from their homes and thus still visit the stream. The village chief in particular reported that though his children fetch water from the borehole, his body system has not been able to re-adjust to borehole water. He reported frequent stooling whenever he ingests borehole water, thus his preference for the stream water which according to him, he is accustomed to.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

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

i. An empirical expression has been developed for re-aeration coefficient model (otherwise known as Atuwara re-aeration model) based on an extensive field data obtained from River Atuwara in Ota, Ogun State, Nigeria. The model was statistically validated and compared with 10 models reported in literature.

ii. Based on its physical, chemical and bacteriological characteristics River Atuwara is highly polluted. It is unsafe, without treatment, for human and animal consumption and unfit for fish and poultry farming.

The limitations to the study include:

i. Insufficient funds. Water quality modelling is a very expensive, detailed, meticulous and rigorous exercise. Most of the western researches had superb research grants and sponsorships that aided them in getting their desired output.

ii. This research could have been more robust had there been sufficient funds to investigate more rivers in different locations in the country. The research coverage of many of these foreign studies is broad. From Table 4.27, it can be seen that some of the models originated from studies on 6 different rivers. Some covered up to 50 kilometres along the same river. O'Connor and Dobbins studied rivers with a wider range of stream depth and velocity than those studied here in Nigeria, thus the high level of citation of the model.

iii. Researches in the western countries are often based on the interest of the government of those countries to monitor their aquatic environment. For instance in the United States of America, the USGS and USEPA put in a lot of resources to monitor, document and secure their surface water resources. Thus it is easier to secure financial support for such research when the national authorities are interested in the subject.

5.2 Contributions to Knowledge

At present, little work has been carried out on water quality modelling in Nigeria. The research work reported here is an attempt to bridge the gap.

1. The study has been able to gather extensive data from River Atuwara for further analysis by future researchers. Cited models such Bansal (1973), Bennet and Rathburn (1972), and Langbein and Dururn (1967) were built based on re-analysis of existing data.

2. The study has developed a model with minimum design error that can be of use to future researchers in the area of water quality modelling in Nigeria.

3. This study has also provided the reliability of the recommended models through data validation which was carried out statistically and graphically.

4. The study has also pointed out multi-disciplinary research areas for future postgraduate students or career researchers by pointing out the problem of oxygen sinks in River Atuwara and the heavy pollution caused by industries as a result of untreated wastes.

5. The study applied a new method (composite goodness of fit) for comparing different models.

5.3 Recommendations

From the foregoing, the following recommendations are made:

i. The Atuwara and Agunwamba re-aeration coefficient may be adopted for the Nigerian environment. Graphically, Atuwara model showed a better rating than Agunwamba model. Statistically, however, Agunwamba *et al.,*

(2007) model gave a better rating. However, further investigations are needed on Nigerian rivers in order to verify the wide applicability of the two models.

ii. O'Connor and Dobbins (1958) model, which is perhaps one of the most cited models ever, is also an alternative model that gave good graphical and statistical proofs of suitability to the Nigerian environment.

iii. All models on re-aeration coefficient should be checked and measured graphically and statistically against several international models.

iv. For all water quality field surveys, boats fitted with a mobile laboratory should be acquired to reduce fatigue and errors introduced through the time lapse between sampling and laboratory work.

v. Since the cost of water quality survey is enormous, individuals, non-governmental and governmental agencies should be sensitized on the need for sponsorship. 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, leaving these vast natural surface water resources to the whims and caprices of polluters may not be in the best interest of the citizenry, the environment or the nation as a whole.

vi. The cause of the oxygen sinks in River Atuwara and other Nigerian rivers should be considered in future investigations.

vii. Surface water polluters should be strictly censored and held accountable for their actions and inactions.

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

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APPENDIX 1

MATLAB CODE FOR OBTAINING BETA

Function File for January Model

```
functionyhat = gbengamodeljan(beta,x)
%A model for computing reaeration coefficient.
%yhat = gbengamodeljan(beta,x) gives the predicted values of reaeration
%coefficient for january, yhat, as a function of the vector of parameters,
%BETA,and the matrix of data,x.
%BETA must have three elements while x must have 2 columns.
%the model form is:
%y=(b1*(x1.^b2))./(x2.^b3)
%where x1 is velocity(m/s) and x2 is
%hydraulic radius = [(stream depth)/2](m)
% All negative values removed
%k2 value is in per day i.e. actual computation value
b1=beta(1);
b2=beta(2);
b3=beta(3);
x1=x(:,1);
x2=x(:,2);
yhat = (b1*(x1.^b2))./(x2.^b3);
```

Script file for nonlinear fit

```
beta=[11;1;0.05];
k2 = [15.479;1.0392;7.8618;5.1992;33.586;11.156;15.651;39.983;...
    15.651;30.511;3.0739;1.458;39.759;12.196;1.458;...
    9.3433];
x = [0.013333  0.325;0.057333 0.69167;0.16233       0.55833;...
    0.23667    1.4483;0.41667 0.205;0.18333  0.68333;...
    0.27       0.46667;0.122  0.9;0.26       0.33;0.37667   0.50833;...
    0.16167    0.40667;0.19   0.594;0.22     0.51333;0.22667       0.2685;...
    0.25       0.336;0.26     0.29033];
b1=beta(1);
b2=beta(2);
```

```
b3=beta(3);
betahat=nlinfit(x,k2,'gbengamodeljan',beta)
```

Script file for computation of confidence level

```
beta=[11;1;0.05];
k2 = [15.479;1.0392;7.8618;5.1992;33.586;11.156;15.651;39.983;...
    15.651;30.511;3.0739;1.458;39.759;12.196;1.458;...
    9.3433];
x = [0.013333  0.325;0.057333 0.69167;0.16233       0.55833;...
    0.23667    1.4483;0.41667 0.205;0.18333  0.68333;...
    0.27       0.46667;0.122  0.9;0.26       0.33;0.37667   0.50833;...
    0.16167    0.40667;0.19   0.594;0.22     0.51333;0.22667       0.2685;...
    0.25       0.336;0.26     0.29033];
b1=beta(1);
b2=beta(2);
b3=beta(3);
[betahat,resid,J] = nlinfit(x,k2,'gbengamodeljan',beta);
betaci = nlparci(betahat,resid,J)
```

Script file for computation of opd

```
beta=[11;1;0.05];
k2 = [15.479;1.0392;7.8618;5.1992;33.586;11.156;15.651;39.983;...
    15.651;30.511;3.0739;1.458;39.759;12.196;1.458;...
    9.3433];
x = [0.013333  0.325;0.057333 0.69167;0.16233       0.55833;...
    0.23667    1.4483;0.41667 0.205;0.18333  0.68333;...
    0.27       0.46667;0.122  0.9;0.26       0.33;0.37667   0.50833;...
    0.16167    0.40667;0.19   0.594;0.22     0.51333;0.22667       0.2685;...
    0.25       0.336;0.26     0.29033];
b1=beta(1);
b2=beta(2);
b3=beta(3);
[yhat,delta] = nlpredci('gbengamodeljan',x,betahat,resid,J);
opd = [k2 yhat delta]
```

Function File for February Model

```
functionyhat = gbengamodelfeb(beta,x)
%A model for computing reaeration coefficient.
%yhat = gbengamodelfeb(beta,x) gives the predicted values of reaeration
%coefficient for february, yhat, as a function of the vector of parameters,
%BETA,and the matrix of data,x.
%BETA must have three elements while x must have 2 columns.
%the model form is:
%y=(b1*(x1.^b2))./(x2.^b3)
%where x1 is velocity(m/s) and x2 is
%hydraulic radius = [(stream depth)/2](m)
% All negative values removed
%k2 value is in per day i.e. actual computation value
b1=beta(1);
b2=beta(2);
b3=beta(3);
x1=x(:,1);
x2=x(:,2);
yhat = (b1*(x1.^b2))./(x2.^b3);
```

Script file for nonlinear fit

```
beta=[11;1;0.05];
k2 = [19.597;2.2479;4.3219;15.657;2.3065;5.514;2.3065;3.8184;0.94227];
x = [0.56222   0.57404;0.18333        0.29972;0.21741       1.1989;0.22333 0.37084;...
    0.2975     0.41148;0.23333        0.25908;0.19333       0.6096;0.21    0.36576;...
    0.22333    0.32004];
b1=beta(1);
b2=beta(2);
b3=beta(3);
betahat=nlinfit(x,k2,'gbengamodelfeb',beta)
```

Script file for computation of confidence level

```
beta=[11;1;0.005];
```

```
k2 = [19.597;2.2479;4.3219;15.657;2.3065;5.514;2.3065;3.8184;0.94227];
x = [0.56222   0.57404;0.18333       0.29972;0.21741       1.1989;0.22333 0.37084;...
    0.2975     0.41148;0.23333       0.25908;0.19333       0.6096;0.21    0.36576;...
    0.22333    0.32004];
b1=beta(1);
b2=beta(2);
b3=beta(3);
[betahat,resid,J] = nlinfit(x,k2,'gbengamodelfeb',beta);
betaci = nlparci(betahat,resid,J)
```

Script file for computation of opd

```
beta=[11;0.5;5];
k2 = [19.597;2.2479;4.3219;15.657;2.3065;5.514;2.3065;3.8184;0.94227];
x = [0.56222   0.57404;0.18333       0.29972;0.21741       1.1989;0.22333 0.37084;...
    0.2975     0.41148;0.23333       0.25908;0.19333       0.6096;0.21    0.36576;...
    0.22333    0.32004];
b1=beta(1);
b2=beta(2);
b3=beta(3);
[yhat,delta] = nlpredci('gbengamodelfeb',x,betahat,resid,J);
opd = [k2 yhat delta]
```

Function File for July Model

```
functionyhat = gbengamodeljul(beta,x)
%A model for computing reaeration coefficient.
%yhat = gbengamodelfeb(beta,x) gives the predicted values of reaeration
%coefficient for July, yhat, as a function of the vector of parameters,
%BETA,and the matrix of data,x.
%BETA must have three elements while x must have 2 columns.
%the model form is:
%y=(b1*(x1.^b2))./(x2.^b3)
%where x1 is velocity(m/s) and x2 is
%hydraulic radius = [(stream depth)/2](m)
% All negative values removed
%k2 value is in per day i.e. actual computation value
```

```
b1=beta(1);
b2=beta(2);
b3=beta(3);
x1=x(:,1);
x2=x(:,2);
yhat = (b1*(x1.^b2))./(x2.^b3);
```

Script file for nonlinear fit

```
beta=[11;1;0.05];
k2 = [13.868;41.23;24.339;24.339;38.968;8.335;2.0362;14.787;30.461];
x = [0.26      1.4021;1       1.3919;0.79667 1.4529;0.096667       1.3818;...
    0.26      0.98552;0.23333       1.0973;0.23    1.4427;0.39667 1.1836;...
    0.26333   0.92964];
b1=beta(1);
b2=beta(2);
b3=beta(3);
betahat=nlinfit(x,k2,'gbengamodeljul',beta)
```

Script file for computation of confidence level

```
beta=[11;1;0.005];
k2 = [13.868;41.23;24.339;24.339;38.968;8.335;2.0362;14.787;30.461];
x = [0.26      1.4021;1       1.3919;0.79667 1.4529;0.096667       1.3818;...
    0.26      0.98552;0.23333       1.0973;0.23    1.4427;0.39667 1.1836;...
    0.26333   0.92964];
b1=beta(1);
b2=beta(2);
b3=beta(3);
[betahat,resid,J] = nlinfit(x,k2,'gbengamodeljul',beta);
betaci = nlparci(betahat,resid,J)
```

Script file for computation of opd

```
beta=[11;1.5;0.5];
k2 = [13.868;41.23;24.339;24.339;38.968;8.335;2.0362;14.787;30.461];
```

```
x = [0.26      1.4021;1       1.3919;0.79667 1.4529;0.096667       1.3818;...
    0.26      0.98552;0.23333       1.0973;0.23    1.4427;0.39667 1.1836;...
    0.26333   0.92964];
b1=beta(1);
b2=beta(2);
b3=beta(3);
[yhat,delta] = nlpredci('gbengamodeljul',x,betahat,resid,J);
opd = [k2 yhat delta]
```

Function File for August Model

```
beta=[11;1.5;0.5];
k2 = [13.868;41.23;24.339;24.339;38.968;8.335;2.0362;14.787;30.461];
x = [0.26      1.4021;1       1.3919;0.79667 1.4529;0.096667       1.3818;...
    0.26      0.98552;0.23333       1.0973;0.23    1.4427;0.39667 1.1836;...
    0.26333   0.92964];
b1=beta(1);
b2=beta(2);
b3=beta(3);
[yhat,delta] = nlpredci('gbengamodeljul',x,betahat,resid,J);
opd = [k2 yhat delta]
```

Script file for nonlinear fit

```
beta=[11;1;0.05];
k2 = [13.906;9.5365;5.9452;0.24681;0.24681;97.87;15.667;55.695;...
    12.603;5.0577;12.603;55.695];
x = [0.17667   0.46228;0.276  0.64516;0.261  1.0566;...
    0.29433   0.67056;0.22867       1.2954;0.36667 0.82296;...
    0.45      0.58928;0.21   0.37592;0.20067       0.69088;...
    0.28767   0.59436;0.115  0.65024;0.27767       0.5334];
b1=beta(1);
b2=beta(2);
b3=beta(3);
betahat=nlinfit(x,k2,'gbengamodelaug',beta)
```

Script file for computation of confidence level

```
beta=[11;1;0.005];

k2 = [13.906;9.5365;5.9452;0.24681;0.24681;97.87;15.667;55.695;...

    12.603;5.0577;12.603;55.695];

x = [0.17667   0.46228;0.276  0.64516;0.261  1.0566;...

    0.29433    0.67056;0.22867        1.2954;0.36667 0.82296;...

    0.45       0.58928;0.21   0.37592;0.20067        0.69088;...

    0.28767    0.59436;0.115  0.65024;0.27767        0.5334];

b1=beta(1);

b2=beta(2);

b3=beta(3);

[betahat,resid,J] = nlinfit(x,k2,'gbengamodelaug',beta);

betaci = nlparci(betahat,resid,J)
```

Script file for computation of opd

```
beta=[11;0.5;5];

k2 = [13.906;9.5365;5.9452;0.24681;0.24681;97.87;15.667;55.695;...

    12.603;5.0577;12.603;55.695];

x = [0.17667   0.46228;0.276  0.64516;0.261  1.0566;...

    0.29433    0.67056;0.22867        1.2954;0.36667 0.82296;...

    0.45       0.58928;0.21   0.37592;0.20067        0.69088;...

    0.28767    0.59436;0.115  0.65024;0.27767        0.5334];

b1=beta(1);

b2=beta(2);

b3=beta(3);

[yhat,delta] = nlpredci('gbengamodelaug',x,betahat,resid,J);

opd = [k2 yhat delta]
```

APPENDIX 2

MODEL OUTPUT FROM MATLAB

Model Output for January

```
>>gbengafilejan


betahat =


   58.2584

    0.8906

   -0.0135

>> gbengajanci4b


>>gbengacijan


betaci =


 -105.1395  221.6563

   -0.7526    2.5338

   -1.0940    1.0669


>>gbengaopdjan


opd =


   15.4790    1.2271    6.2379

    1.0392    4.5444   10.7342

    7.8618   11.4483    9.9548

    5.1992   16.2247   22.0817

   33.5860   26.1478   23.3047

   11.1560   12.7933    9.8221

   15.6510   17.9668    9.0712

   39.9830    8.9349   11.1304

   15.6510   17.2916    9.5633

   30.5110   24.1961   20.5961

    3.0739   11.3580   10.9816
```

```
    1.4580   13.1820    9.2450

   39.7590   14.9907    8.4930

   12.1960   15.2602   12.2815

    1.4580   16.7021    9.4535

    9.3433   17.2616   10.8880
```

Model Output for February

```
>>gbengafilefeb


betahat =


   46.2679

    1.5463

    0.0128


>>gbengacifeb


betaci =


  -22.4158  114.9516

    0.0301    3.0625

   -2.1946    2.2201


>>gbengaopdfeb


opd =

   19.5970   19.1266   12.6616

    2.2479    3.4096    4.5586

    4.3219    4.3604   11.2834

   15.6570    4.6138    4.7125

    2.3065    7.1789    5.3600

    5.5140    4.9598    7.0483

    2.3065    3.6681    5.5458

    3.8184    4.1957    4.5490

    0.9423    4.6225    5.2731
```

Model Output for July

```
>>gbengafilejul

betahat =

   96.2548
    0.9614
    2.8911

>>gbengacijul

betaci =

  -64.0838  256.5935
   -0.2917    2.2144
   -1.3942    7.1764

>>gbengaopdjul

opd =

   13.8680    9.9230   14.4894
   41.2300   37.0027   24.5275
   24.3390   26.2707   16.4426
   24.3390    3.9982   10.3587
   38.9680   27.4988   15.6427
    8.3350   18.1646   13.2513
    2.0362    8.1211   13.9435
   14.7870   24.3065   10.9262
   30.4610   32.9548   22.5873
```

Model Output for August

```
>>gbengafileaug

betahat =

   38.2995
    0.7222
    1.1290

>>gbengaciaug

betaci =

  -88.9645  165.5637
   -1.9426    3.3870
   -2.1912    4.4491

>> gbengaaugopd4

>>gbengaopdaug

opd =

   13.9060   26.1697   36.0191
    9.5365   24.7910   22.4490
    5.9452   13.6426   31.0523
    0.2468   24.8616   23.6308
    0.2468    9.8518   30.3383
   97.8700   23.1231   32.9597
   15.6670   39.0876   58.1180
   55.6950   37.4452   56.3036
   12.6030   18.2285   27.1549
    5.0577   28.0216   22.6976
   12.6030   13.0574   34.8108
   55.6950   30.8641   25.3262
```

APPENDIX3

MATLAB CODE THAT COMPUTES OUTPUT FOR 11 DIFFERENT MODELS USING ONE DATA SET

JULY ALLMODELS CODE

Allmodels Function File

```
function yjul = julallmodels(ip,par)

%The function computes the values for atuwaramodel and 10 other models

%for the purpose of comparing their output.

%y = allmodels(ip,par) gives the computed values of

%reaeration coefficient for July, yjul, as a function of the

%vector of parameters,BETA,and the matrix of data,x.

%BETA has three elements while x has 2 columns.

%the model form is:

%y=(b1*(x1.^b2))./(x2.^b3)

%where x1 is velocity(m/s) and x2 is hydraulic radius(m)

% Hydraulic Radius=Depth/2

b1=par(1);b2=par(2);b3=par(3);

x1=ip(:,1);

x2=ip(:,2);

yjul = (b1*(x1.^b2))./(x2.^b3);
```

Allmodels Script File

```
bpar=[46.2679 1.5463 0.0128;12.9 0.5 1.5;11.632 1.0954 0.0016;...
    5.792 0.5 0.25;5.026 0.969 1.673;10.046 2.696 3.902;...
    21.7 0.67 1.85;4.67 0.6 1.4;20.2 0.607 1.689;1.923 0.273 0.584;...
    7.6 1 1.33]';
x = [0.17667    1.0109;0.48 1.6002;0.26 1.4021;1.15 1.7831;...
    0.88333 1.1633;1    1.3919;0.79667  1.4529;0.096667 1.3818;...
    0.26    0.98552;0.23333 1.0973;0.22333  1.0668;0.27333  1.5951;...
    0.23    1.4427;0.15 0.91948;0.18667 0.96012;0.39667 1.1836;...
    0.26333 0.92964];
for k=1:11
    mpar=bpar(:,k);
    yjul(:,k)=julallmodels(x,mpar)
end
```

```
plot(yjul)
```

MARCH ALLMODELS CODE

Allmodels Function File

```
function ymar = marallmodels(ip,par)
%The function computes the values for atuwaramodel and 10 other models
%for the purpose of comparing their output.
%y = allmodels(ip,par) gives the computed values of
%reaeration coefficient for March, ymar, as a function of the
%vector of parameters,BETA,and the matrix of data,x.
%BETA has three elements while x has 2 columns.
%the model form is:
%y=(b1*(x1.^b2))./(x2.^b3)
%where x1 is velocity(m/s) and x2 is hydraulic radius(m)
% Hydraulic Radius=Depth/2
b1=par(1);b2=par(2);b3=par(3);
x1=ip(:,1);
x2=ip(:,2);
ymar = (b1*(x1.^b2))./(x2.^b3);
```

Allmodels Script File

```
bpar=[46.2679 1.5463 0.0128;12.9 0.5 1.5;11.632 1.0954 0.0016;...
    5.792 0.5 0.25;5.026 0.969 1.673;10.046 2.696 3.902;...
    21.7 0.67 1.85;4.67 0.6 1.4;20.2 0.607 1.689;1.923 0.273 0.584;...
    7.6 1 1.33]';
x = [0.026667   0.29972;0.39667 0.42164;0.25333 0.46736;...
    0.1 0.72644;0.75333 0.52324;0.69667 0.64008;0.15333 0.68072;...
    0.16667 0.89916;0.33333 0.51816;0.30667 0.50292;0.49667 0.4572;...
    0.4 0.71628;0.11667 0.72644;0.22333 0.32512;0.05    0.48768;...
    0.19    0.33528;0.20333 0.381];
for k=1:11
    mpar=bpar(:,k);
    ymar(:,k)=marallmodels(x,mpar)
end
plot(ymar)
```

JANUARY ALLMODELS CODE

Allmodels Function File

```
function yjan = janallmodels(ip,par)
%The function computes the values for atuwaramodel and 10 other models
%for the purpose of comparing their output.
%y = allmodels(ip,par) gives the computed values of
%reaeration coefficient for january, yjan, as a function of the
%vector of parameters,BETA,and the matrix of data,x.
%BETA has three elements while x has 2 columns.
%the model form is:
%y=(b1*(x1.^b2))./(x2.^b3)
%where x1 is velocity(m/s) and x2 is hydraulic radius(m)
% Hydraulic Radius=Depth/2
b1=par(1);b2=par(2);b3=par(3);
x1=ip(:,1);
x2=ip(:,2);
yjan = (b1*(x1.^b2))./(x2.^b3);
```

Allmodels Script File

```
bpar=[46.2679 1.5463 0.0128;12.9 0.5 1.5;11.632 1.0954 0.0016;...
    5.792 0.5 0.25;5.026 0.969 1.673;10.046 2.696 3.902;...
    21.7 0.67 1.85;4.67 0.6 1.4;20.2 0.607 1.689;1.923 0.273 0.584;...
    7.6 1 1.33]';
x = [0.013333   0.325;0.057333  0.69167;0.16233 0.55833;...
    0.23667 1.4483;0.41667  0.205;0.18333   0.68333;0.27    0.46667;...
    0.122   0.9;0.26    0.33;0.37667    0.50833;0.16167 0.40667;...
    0.19    0.594;0.22  0.51333;0.22667 0.2685;0.19333  0.406;...
    0.25    0.336;0.26  0.29033];
for k=1:11
    mpar=bpar(:,k);
    yjan(:,k)=janallmodels(x,mpar)
end
plot(yjan)
```

OUTPUT

B1 = 46.2679, B2 = 1.5463, B3 = 0.0128; FOR JANUARY

```
>>janallmodelsfile
yjan =

  Columns 1 through 7

    0.0592    8.0395    0.1029    0.8858    0.5022    0.0071    9.6200
    0.5590    5.3696    0.5080    1.5207    0.5834    0.0190    6.3209
    2.8026   12.4581    1.5890    2.6996    2.2885    0.7259   18.8659
    4.9597    3.6006    2.3979    2.5685    0.6693    0.0486    4.1644
   12.1948   89.7129    4.4697    5.5563   30.4956  459.7158  226.4519
    3.3739    9.7782    1.8150    2.7276    1.8364    0.4581   14.0851
    6.1693   21.0260    2.7752    3.6413    5.0578    5.7607   36.9662
    1.7910    5.2772    1.1613    2.0771    0.7807    0.0522    6.4413
    5.8454   34.6981    2.6643    3.8966    8.7068   20.1150   68.4291
   10.3122   21.8450    3.9961    4.2099    6.0527   10.1252   39.4443
    2.7963   20.0005    1.5827    2.9163    3.8737    2.4728   33.8177
    3.5720   12.2825    1.8878    2.8758    2.4032    0.8714   18.6948
    4.4893   16.4515    2.2172    3.2095    3.5362    2.2866   27.0177
    4.7406   44.1439    2.2933    3.8308   10.7640   31.0738   91.4170
    3.6872   21.9255    1.9253    3.1904    4.6194    4.0308   38.2390
    5.5002   33.1170    2.5522    3.8038    8.1332   16.8680   64.4691
    5.8550   42.0473    2.6649    4.0234   10.7873   33.1556   86.7245
```

```
Columns 8 through 11


    1.6890    9.8087    1.1406    0.4518

    1.4077    6.6392    1.0928    0.7115

    3.5474   17.9294    1.6453    2.6782

    1.1711    4.5057    1.0452    1.0990

    25.3943 172.5889    3.8205   26.0599

    2.8759   13.7228    1.5115    2.3120

    6.1876   33.0546    2.0991    5.6545

    1.5318    6.7306    1.1515    1.0667

    9.8261   58.0056    2.5436    8.6330

    6.7033   35.0171    2.1869    7.0405

    5.5151   30.5478    1.9776    4.0658

    3.5749   17.7676    1.6565    2.8869

    4.7887   24.8509    1.8775    4.0589

   12.0790   75.6116    2.7637    9.9017

    6.1540   34.1456    2.0785    4.8727

    9.3585   54.9432    2.4902    8.1044

   11.7558   72.0138    2.7412   10.2362
```

B1 = 46.2679, B2=1.5463, B3= 0.0128; FOR MARCH

```
>>marallmodelsfile
ymar =


ymar =


  Columns 1 through 7


    0.1730   12.8382    0.2199    1.2783    1.1258    0.0631   17.7803

   11.1978   29.6751    4.2303    4.5270    8.7011   24.1455   57.7119
```

```
    5.5902   20.3215    2.5881    3.5258    4.7432    4.8234   35.3244
    1.3206    6.5886    0.9343    1.9839    0.9214    0.0704    8.3799
   30.1067   29.5822    8.5380    5.9108   11.2885   58.6104   59.4899
   26.6093   21.0258    7.8346    5.4048    7.4694   21.6206   38.8825
    2.5595    8.9940    1.4923    2.4969    1.5543    0.2872   12.5846
    2.9015    6.1768    1.6344    2.4283    1.0579    0.1214    7.9525
    8.5341   19.9678    3.4952    3.9414    5.2070    6.7581   35.0774
    7.5048   20.0298    3.1903    3.8088    5.0489    6.0647   35.0555
   15.8365   29.4079    5.4109    4.9640    9.4483   32.2744   57.7602
   11.2668   13.4585    4.2656    3.9819    3.6146    3.1233   21.7739
    1.6761    7.1166    1.1062    2.1429    1.0698    0.1067    9.2919
    4.6217   32.8850    2.2557    3.6249    7.7038   14.1501   63.5292
    0.4545    8.4698    0.4375    1.5498    0.9168    0.0514   11.0083
    3.5982   28.9638    1.8896    3.3178    6.2564    8.1166   53.8543
    3.9895   24.7345    2.0348    3.3243    5.3949    5.9175   44.4881

  Columns 8 through 11

    2.8675   17.1295    1.4450    1.0064
    8.9837   49.5532    2.4739    9.5076
    5.9432   31.7211    2.0611    5.2950
    1.8350    8.5661    1.2361    1.1626
    9.7572   50.7920    2.5982   13.5496
    7.0211   34.4619    2.2609    9.5841
    2.5974   12.3921    1.4428    1.9435
    1.8495    8.1468    1.2546    1.4590
    6.0645   31.4780    2.0916    6.0737
    6.0148   31.4724    2.0805    5.8142
    9.1793   49.5388    2.5090   10.6891
    4.2997   20.3501    1.8196    4.7382
    2.0129    9.4065    1.2892    1.3564
    9.1585   54.2401    2.4615    7.5638
```

```
    2.1150   11.0247    1.2910    0.9876
    7.9616   46.6811    2.3133    6.1770
    6.9333   39.1965    2.1870    5.5768
```

<u>B1 = 46.2679, B2=1.5463, B3= 0.0128; FOR JULY</u>

```
>>julallmodelsfile



yjul =

  Columns 1 through 7

    3.1704    5.3347    1.7418    2.4279    0.9201    0.0899    6.6581
   14.7832    4.4152    5.2019    3.5678    1.1240    0.2218    5.5612
    5.7382    3.9619    2.6582    2.7141    0.7741    0.0711    4.7092
   57.0062    5.8100   13.5438    5.3751    2.1869    1.5330    8.1743
   38.1179    9.6630   10.1516    5.2416    3.4603    3.9848   15.0950
   46.0725    7.8556   11.6258    5.3324    2.8905    2.7646   11.7702
   32.4004    6.5747    9.0627    4.7088    2.1584    1.2671    9.3364
    1.2428    2.4692    0.8993    1.6609    0.3041    0.0052    2.4933
    5.7641    6.7232    2.6597    2.9641    1.3961    0.2815    9.0409
    4.8692    5.4211    2.3619    2.7336    1.0503    0.1383    6.8928
    4.5519    5.5327    2.2514    2.6933    1.0553    0.1371    7.0518
    6.1892    3.3477    2.8072    2.6945    0.6548    0.0492    3.8360
    4.7455    3.5702    2.3240    2.5345    0.6553    0.0457    4.1147
    2.4645    5.6666    1.4561    2.2908    0.9201    0.0838    7.1103
    3.4544    5.9243    1.8502    2.5280    1.0579    0.1276    7.5994
   11.0508    6.3095    4.2233    3.4974    1.5475    0.4302    8.5502
    5.8831    7.3853    2.6972    3.0269    1.5585    0.3658   10.1581
```

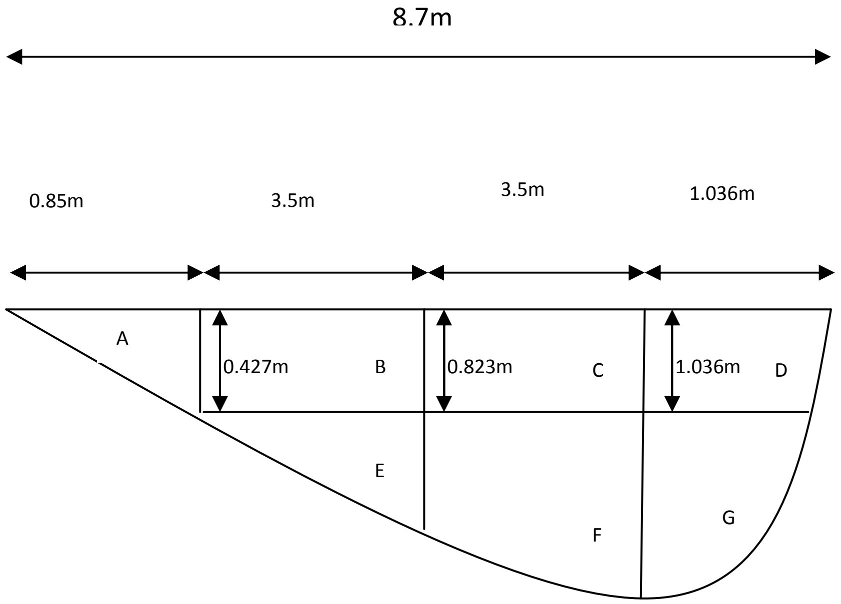
```
Columns 8 through 11

    1.6256    6.9251    1.1904    1.3235
    1.5567    5.8481    1.1960    1.9521
    1.2966    5.0388    1.0928    1.2606
    2.2599    8.2786    1.4252    4.0499
    3.5077   14.5109    1.7018    5.4899
    2.9394   11.5557    1.5853    4.8957
    2.4152    9.3629    1.4531    3.6840
    0.7309    2.8327    0.8413    0.4779
    2.1241    9.1399    1.3427    2.0147
    1.7126    7.1384    1.2243    1.5673
    1.7353    7.2900    1.2298    1.5574
    1.1154    4.1775    1.0275    1.1163
    1.1575    4.4573    1.0394    1.0736
    1.6827    7.3589    1.2032    1.2747
    1.8060    7.8117    1.2454    1.4976
    2.1178    8.6687    1.3539    2.4092
    2.3226   10.1651    1.3941    2.2052
```

APPENDIX 4

SAMPLE CALCULATION FOR DILUTION EFFECTS AT THE MIXING ZONES OF CONFLUENCES USING THE MONTH OF MARCH

REACH 1

Main River



BOD_1 = 40mg/L, DO_1 = 7.3mg/L, T_1 = 26.9°C

Calculate area of shapes

$$A = \frac{1}{2}bh = \frac{1}{2}(0.85 \times 0.427) = 0.182\ \text{m}^2$$

B = C = length x breadth = 2(0.427 x 3.5) = 2.99m^2

D = length x breadth = 1.036 x 0.85 = 0.88m^2

$$E = \frac{1}{2}bh = \frac{1}{2}(3.5 \times 0.396) = 0.693\ \text{m}^2$$

$$F = \frac{1}{2}(a+b)h = \frac{1}{2}(0.396 + 0.609)3.5 = 1.759\ \text{m}^2$$

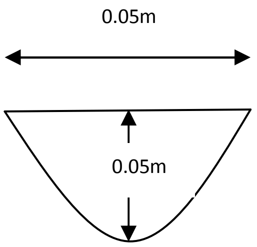
G = $\pi ab = [\pi(0.609)(0.9)] = 0.431\text{m}^2$

TOTAL CROSS-SECTIONAL AREA, A_1 = 7.038m^2

Discharge is given by,

$Q_1 = A_1V_1$ = 7.038 X 0.203 = 1.429m^3/s

Effluent Discharge



BOD_2 = 1 mg/L, DO_2 = 0.1mg/L, T_2 = 31.3^{o}C

Calculating area of cross-sectional shape

$$A_2 = \frac{\frac{\pi d^2}{4}}{2} = \frac{\pi(0.05)^2}{8} = 0.00098\text{m}^2$$

$Q_2 = A_2V_2$ = 0.00098 X 0.25 = 0.00025m^3/s

$Q_1 + Q_2$ = 1.429 + 0.00025 = 1.429m^3/s

Mix parameters

$$BOD = \frac{(40\times 1.429)+(1\times 0.00025)}{1.429} = \frac{57.16+0.00025}{1.429} = 40mg/L$$

$$DO = \frac{(7.3\times 1.429)+(0.1\times 0.00025)}{1.429} = \frac{10.43+0.00003}{1.429} = 7.3mg/L$$

$$T = \frac{(26.9\times 1.429)+(31.3\times 0.00025)}{1.429} = \frac{38.44+0.0078}{1.429} = 26.9mg/L$$

k_1 at 26.9°C = 0.1 x $1.047^{6.9}$ = 0.14 d^{-1}

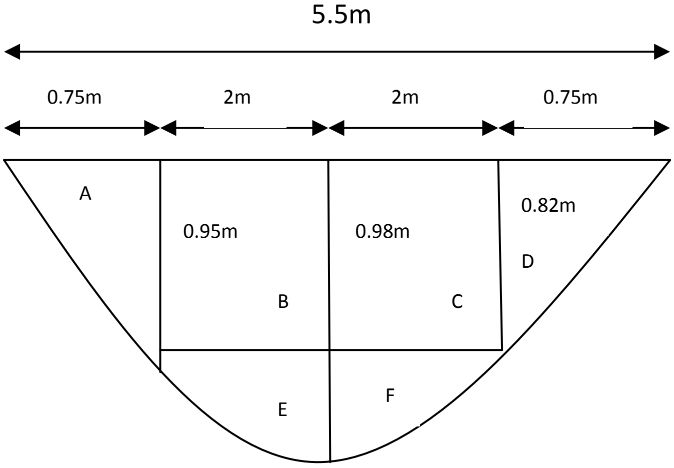
Therefore,

$$L_o = \frac{40}{\left[1-10^{-5(0.14)}\right]} = \frac{40}{0.718} = 55.71 mg/L$$

$D_o = D_{sat} - D = 8.11 - 7.3 = 0.81 mg/L$

REACH 2

Main River



BOD_1 = 32mg/L, DO_1 = 5.9mg/L, T_1 = 26.8°C

Calculating area of cross-sectional shape

$A = \pi ab = [\pi(0.75)(0.95)] \div 4 = 0.56 \, m^2$

B = C = length x breadth = 2(0.82 x 2) = 3.28m^2

$D = \pi ab = [\pi(0.75)(0.82)] \div 4 = 0.48 \, m^2$

$$E = \frac{1}{2}(a+b)h = \frac{1}{2}(0.13+0.16)2 = 0.29 \, m^2$$

$F = \pi ab = [\pi(0.16)(2)] \div 4 = 0.25 \, m^2$

TOTAL CROSS-SECTIONAL AREA, A_1 = 4.86m^2

Discharge is given by,

$Q_1 = A_1V_1 = 4.86 \text{ X } 0.203 = 0.987m^3/s$

River Balogun

BOD_2 = 40 mg/L, DO_2 = 7.1mg/L, T_2 = 26.5°C

A = $\pi ab = [\pi(0.7)(0.55)] \div 4 = 0.302\,\text{m}^2$

B = C = length x breadth = 2(0.49 x 1.5) = 1.47m^2

D = $\pi ab = [\pi(0.49)(0.7)] \div 4 = 0.269\,\text{m}^2$

E = $\frac{1}{2}(a+b)h = \frac{1}{2}(0.06+0.21)1.5 = 0.203\,\text{m}^2$

F = $\pi ab = [\pi(0.15)(0.21)] \div 4 = 0.247\,\text{m}^2$

TOTAL CROSS-SECTIONAL AREA, A_1 = 2.49m^2

$Q_2 = A_2V_2 = 2.49 \text{ x } 0.38 = 0.95m^3/s$

$Q_1 + Q_2 = 0.987 + 0.946 = 1.93m^3/s$

Mix parameters

BOD = $\frac{(32\times 0.987)+(40\times 0.946)}{1.93} = \frac{31.584+37.84}{1.93} = 35.97mg/L$

DO = $\frac{(5.9\times 0.987)+(7.1\times 0.946)}{1.93} = \frac{5.82+6.71}{1.93} = 6.5mg/L$

T = $\frac{(26.8\times 0.987)+(26.5\times 0.946)}{1.93} = \frac{26.45+25.07}{1.93} = 26.7^o C$

k_1 at 26.7°C = 0.1 x 1.047 = 0.14 d^{-1}

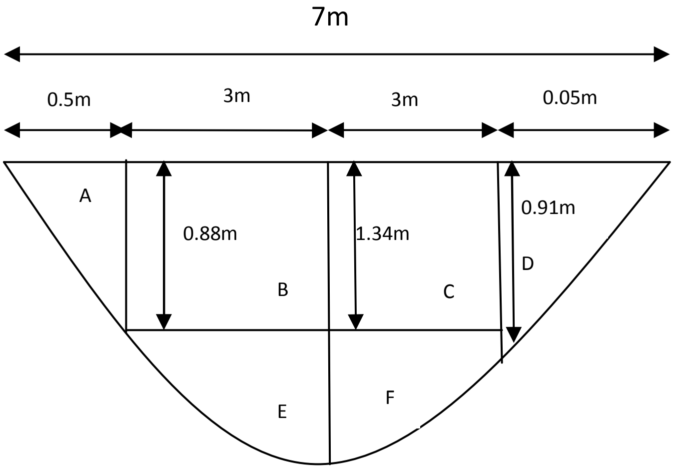
Therefore,

$L_o = \frac{35.97}{0.718} = 50.1 mg/L$

$D_o = 8.13 - 6.5 = 1.63$ mg/L

REACH 3

Main River



$BOD_1 = 30mg/L$, $DO_1 = 6.3mg/L$, $T_1 = 26.6^oC$

Calculating area of cross-sectional shape

$A = \pi ab = [\pi(0.5)(0.88)] \div 4 = 0.346 m^2$

B = C = length x breadth = 2(3 x 0.88) = 5.28m^2

$D = \pi ab = [\pi(0.91)(0.5)] \div 4 = 0.357 m^2$

$E = \pi ab = [\pi(3)(0.46)] \div 4 = 1.084 m^2$

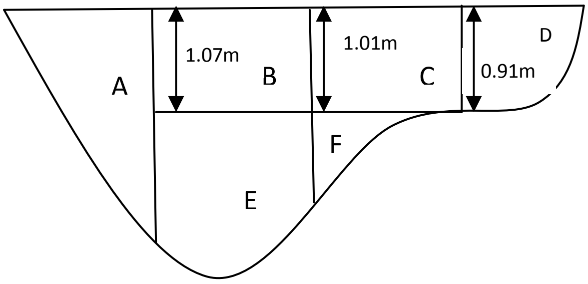
F = $\frac{1}{2}(a+b)h = \frac{1}{2}(0.46+0.03)3 = 0.735\,\text{m}^2$

TOTAL CROSS-SECTIONAL AREA, $A_1 = 7.8\text{m}^2$

Discharge is given by,

$Q_1 = A_1V_1 = 7.81 \text{ X } 0.753 = 5.88\text{m}^3/\text{s}$

Unknown River



$BOD_2 = 30$ mg/L, $DO_2 = 3.3$mg/L, $T_2 = 26.9^{o}C$

Calculating area of cross-sectional shape

A = $\pi ab = [\pi(0.7)(1.07)] \div 4 = 0.588\,\text{m}^2$

B = C = length x breadth = 2(0.91 x 2) = 3.64m^2

D = $\pi ab = [\pi(0.91)(0.7)] \div 4 = 0.5\,\text{m}^2$

E = $\frac{1}{2}(a+b)h = \frac{1}{2}(0.16+0.1)2 = 0.26\,\text{m}^2$

F = $\frac{1}{2}bh = \frac{1}{2}(2 \times 0.1) = 0.10\,\text{m}^2$

TOTAL CROSS-SECTIONAL AREA, $A_1 = 5.09\text{m}^2$

$Q_2 = A_2V_2 = 5.09 \text{ x } 0.01 = 0.051 m^3/s$

$Q_1 + Q_2 = 5.88 + 0.051 = 5.93 m^3/s$

$$\text{BOD} = \frac{(30\times5.88)+(30\times0.051)}{5.93} = \frac{176.4+1.53}{5.93} = 30mg/L$$

$$\text{DO} = \frac{(6.3\times5.88)+(3.3\times0.051)}{5.93} = \frac{37.04+0.168}{5.93} = 6.28mg/L$$

$$T = \frac{(26.6\times5.88)+(26.9\times0.051)}{5.93} = \frac{156.41+1.37}{5.93} = 26.6mg/L$$

k_1 at $26.6^oC = 0.1 \text{ x } 1.047 = 0.14 \text{ d}^{-1}$

Therefore,

$$L_o = \frac{30}{0.718} = 41.78mg/L$$

$D_o = 8.14 – 6.28 = 1.86$ mg/L

APPENDIX 5

LABORATORY REPORTS

APPENDIX 6

PROCEDURE FOR DATA ANALYSIS