POLLUTION PROBLEMS AND AN ENGINEERING APPROACH TO THE MANAGEMENT AND CONTROL OF INDUSTRIAL EFFLUENTS IN OTTA, NIGERIA

BY

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DECLARATION

I, Ogbiye Adebanji Samuel, declare that this thesis was done entirely by me under the supervision of Dr. I.K.Adewumi (Major Supervisor) of The Department of Civil Engineering, Obafemi Awolowo University, Ile – Ife, Osun State and Dr. E.O.Longe (Co – Supervisor) of The Department of Civil and Environmental Engineering University of Lagos, Akoka Yaba, Lagos 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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Ogbiye .a.s

CERTIFICATION

This thesis titled **Pollution Problems and an Engineering Approach to the Management and Control of Industrial Effluents in Ota Nigeria** written by OGBIYE Adebanji Samuel under our supervision meets the regulations governing the award of the degree of Doctor of Philosophy (Ph.D) in Civil Engineering of Covenant University, Otta, and 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.

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DEDICATION

This work is absolutely dedicated to the Worthy Lamb that was slain to receive power and riches, and wisdom and strength and honour and glory and blessing, JESUS CHRIST THE BEGOTTEN SON OF THE LIVING GOD

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LIST OF ACRONYMS

BOD	Biochemical Oxygen Demand
CBOD	Carbonaceous Biochemical Oxygen Demand
CE-QUAL-ICM	Three-Dimensional Eutrophication Model
CE –QUAL-W2	Two – Dimensional, Laterally-Averaged Hydrodynamic and Water Quality Model
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DYNHYD	Link Node Tidal Hydrodynamic Model
EFDC	Environmental Fluid Dynamics Code
FEPA	Federal Environmental Protection Agency
GIS	Geographic Information Systems
GPS	Global Positioning System
HEM-3D	Three-Dimensional Hydrodynamic-Eutrophication Model
HM	Heavy Metals
HSPF	Hydrologic Simulation Program – FORTRAN
IPP	Integrated Product Policy.
MAN	Manufacturers Association of Nigeria
MEDLI	Model for Effluent Disposal using Land Irrigation
MEPP	Ministry of Environment and Physical Planning

NBOD	Nitrogenous Biochemical Oxygen Demand
NH_3-N	Ammonia-nitrogen
NMS	National Minimum Standards
NPES	National Pollutant Discharge Elimination System
OGEPA	Ogun State Environmental Protection Agency
OPO_4	Ortho-Phosphorus or Inorganic Phosphorus
QUAL2E	Enhanced Stream Water Quality Model
QUAL2K	Enhanced Stream Water Quality Model (Improved)
RIVMOD-H	River Hydrodynamics Model and
SBR	Sequencing Batch Reactors
SOD	Sediment Oxygen Demand
TBOD	Total Biochemical Oxygen Demand
TDS	Total Dissolved Solids
TMDL	Total Maximum Daily Load
TOC	Total Organic Carbon
TPWQM	Tidal Prism Water Quality Model
TSS	Total Suspended Solids
TVA	Tennessee Valley Authority
UNESCO	United Nations Educational, Scientific and Cultural Organization

USEPA	United States Environmental Protection Agency
USGS	United State Geological Survey
WASP	Water Quality Analysis Simulation Programme Water Quality Model Developed by USEPA
WES	World Environmental Systems
WHO	World Health Organization
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant

ABSTRACT

This study examined the effects of effluent discharges from various point-loads on a purposively selected receiving river, the self-recovery ability of the river and the treatability of both the discharges and the receiving stream in a heavily industrialized community.

The work involved field survey of industries producing and discharging effluents in the study area (Ado Odo/ Otta industrial zone of Ogun State, Nigeria); determination of the effluents' physico – chemical, biological and microbial characteristics, and the impact of the discharged effluents on the receiving surface water using standard methods. Primary data were also collected for analysis using structured questionnaires and oral interviews to elicit the contribution of the industries to water pollution.

To advance analytical process various scenarios of improving water quality along the river under study were examined. An array of computer based hydrogeometric and water quality models were investigated. QUAL2K was operated as a one-dimensional steady state and completely mixed system for hydrogeometric and water quality analysis on the Atuwara River. The 10.81 km long stretch from upstream at Owode – Ijako to Iju Water Works was mapped with geographical positioning systems (GPS) and divided into 7 reaches with further segmentation of 0.3 km each from where grab samples were collected routinely throughout the study period.

The research analyzed the effluent discharges from all industries along the river for priority pollutants such as BOD, COD, TDS, TSS, and Heavy metals using standard methods. The effluent samples were obtained and compared with river water samples before and after receiving waste loads in the dry and wet seasons. Model result was interfaced with geographical information systems (GIS) for clear display of model outcome to demarcate polluted zones, limnographic points and wetlands of the Atuwara watershed. The worst scenario of the effluent samples were obtained for laboratory-scale treatability studies by applying electro – Fenton alone or with further treatment by Granulated Activated Carbon (GAC) type BBC 945 to properly remove traces of heavy metals.

The result showed that the effluents were acidic in both seasons with range between pH 5.4 - 6.7. The BOD and COD concentration were also very high especially at immediate downstream of points of discharge. The level of dissolved oxygen (DO) attained at points of discharge remain anoxic with the DO gradually increasing at short distances downstream to each discharge point but much higher where tributaries discharge into the river under study. The assimilative capacity of the river is very high because of the contribution from the tributaries. Calculated worst scenario of BOD discharge was about 12 metric tonnes per day. The heavy metals (cadmium, lead and iron) were slightly above the FEPA standard at all sections of the river. All these indicated that the river is impaired and should be declared polluted and not good for human consumption without adequate treatment.

The study showed that the Atuwara River was grossly polluted. Treatment of the worst scenario effluent collected from an industry showed that COD removal of more than 66% was achieved with electro-Fenton treatment at a molar ratio of H_2O_2/Fe^{2+} between 150-250, using 0.3M H_2O_2 and 0.002M Fe^{2+} and when further treated with the GAC 945 sample, the COD removal was 86%.

To achieve river water quality specified by regulatory authorities, it is therefore recommended that substantial load curtailment from the firms discharging the effluents be enforced by the government through mandatory provision of in-house adequate treatment and at regulated flow rate to meet the National standards.

CHAPTER ONE

1. INTRODUCTION

1.1 Background to the Study

Water is life and the quality and adequacy of water is an essential measure of the quality of life or rather the existence of life. Consequently water quality management is (or should be) one of the most important activities of mankind, so as to protect and save human life. The management of water quality, or the protection of the aquatic ecosystem in a broader sense, means the control of pollution. Water pollution originates from point and non-point (diffuse) sources and is mostly anthropogenic activities.

A crucial aspect in the series of complex activities of planning and implementing water pollution control actions is the quantitative determination and description of the relationship between human activities and the state of the aquatic system. These activities are essential for the modelling of aquatic systems (hydrological, hydrodynamics, hydraulic, and water quality modelling) (Jolankai, 1997).

Planning and management activities require the assessment of hydraulic and water quality conditions often beyond the range of observed field data. In this context, both hydraulic and water quality models need be made that are general enough to (1) describe observed conditions and (2) predict planning scenarios that may be substantially different from observed conditions. In stream water pollution control the main objective is to assess if the system complies with the maximum pollutant release allowed from point and non-point source pollution, so that pollutant levels in the receiving streams meet water quality standards. Water quality models for in - stream water pollution control have been calibrated and verified with data collected prior to model development during surveys designed to check basin wide water quality for regulatory compliance (Radwan *et al*, 2003).

1.2 Statement of the Problem

A lot of environmental degradation is generated during the planning, developmental stage including construction and final occupation of engineering projects.

The problems include deforestation, land and water pollution, and contamination of ground water, poor environmental sanitation, poorly planned road network, air and noise pollution, destruction of natural food chain, toxicity and radioactivity within the eco-system, etc. Others are:

- Rapidly increasing generation of industrial effluents and discharge into the available water courses
- Increasing difficulty of industries to comply and meet regional and national water quality standards and limits
- Increasing occurrence of water- borne diseases as a result of pollutions from indiscriminate industrial effluents discharge into water courses
- Deterioration of water quality standards and its effects on water supply, aquatic ecosystems and public health due to river pollution in populated areas
- Service delivery standards**:** Many existing national environmental standards and environmental management practices are based on those developed in industrialized countries, under conditions totally different from those existing in developing countries.

These standards are often inappropriate, even where they are in theory appropriate they often cannot be applied due to high cost.

1.3 Aims of the Research

The aims of this research include the:

i. Determination of the dilution power and self- recovery ability of a purposively selected river in Ado-Odo/Otta District after receiving industrial effluents, *and*
ii. Assessment of the industrial waste management capability of the treatment facilities of selected industries.

1.4 Specific Objectives of the Study

The specific objectives of this study are to:

1. Characterize selected industrial effluents and determine their impacts on a purposively selected receiving water courses;
2. Use an existing model to determine the ability of the selected receiving stream to recover from the environmental impacts of the industrial activities, *and*
3. Determine the treatability of the effluents and recommend an engineering solution to the impacts.

1.5 Justification for the Research

Existing literature showed that there has been no detailed scientific and engineering study of industrial impact on the rivers in Ado-Odo/Otta Industrial Zones. Presently there exists a global focus on sustainable consumption and production activities by industries. There is the need therefore to determine conformity by the industries with the Federal Environmental Protection Agency (FEPA) of Nigeria other national and international regulations.

The findings of this work will be useful to Engineers in the design and management of industrial wastes.

1.6 Scope of the Study

i. The scope of this study was limited to a field survey of selected industries which discharges industrial effluents into River Atuwara.
ii. Laboratory scale modelling of the pollution impacts, using QUAL2K developed by the United States Environmental Protection Agency (USEPA), to determine the hydrodynamics and water quality of the receiving river; and
iii. Laboratory bench - scale treatability study and analysis of the identified pollutants of concerns in the effluents from the selected industries

1.7 Delimitation of the Study

The study covered River Atuwara in Otta Municipal Districts. The major polluting industries in the industrial layouts will be determined in the three major industrial areas in Otta viz: Idiroko road, Ijoko road and Lagos-Abeokuta expressway. A model to simulate one-dimensional hydrodynamic and water quality parameters of the receiving streams will be examined.

1.8 Operational Definition of Terms

Industrial pollution*:* is a very broad category of pollution resulting from manufacturing activities. Industrial pollution can be in the form of air pollution, water pollution or solid and hazardous wastes.

Industrial wastes*:* industrial and radioactive waste from chemical plants and nuclear power plants includes potentially dangerous substances such as petro-chloro-benzene (PCBs), tributylin (TBT), organo-chlorides, heavy metals (HMs), acidic wastes, radioactive caesium and plutonium 239,(Falconer ,1990).

Industrial effluent*:* These are partially treated or untreated wastewater discharges from industries. It is normally unacceptable to discharge untreated industrial wastewater direct to rivers, land or disposal down mineshafts wells etc. Gaseous discharges from stacks are also part of industrial effluent.

Industrial wastewater management*:* This is the process that ensures the minimization of wastewater production for recovery and reuse. The recovery and reuse of wastewater in an economic way enable the cost of wastewater treatment to be minimized. The options for the industrialist are: (1) to treat or partially treat at source within the site;(2) treat at a centralized works effluents plant within the industrial complex or (3) discharge the wastewater to a sewer and pay for off site treatment.

Water quality: a term used to describe the chemical, physical and biological characteristics of water, usually in respect to its suitability for a particular purpose.

Mathematical model*:* Mathematical models are useful instruments in the survey of computer systems. It is not possible to survey the many components and their reactions in an ecological system without the use of mathematical models as synthesis tool. Mathematical models can be used to reveal dynamic system properties. They revealed gaps in knowledge on ecological systems and can therefore be used to set up research priorities as an idealized formulation that represents the response of a physical system to external stimuli.

Transport processes*:* this is the movement of matter through the volume along with water flow. Mass is gained or lost by transformations or reactions of substances within the volume. Based on Fick’s first and second law, which are widely used in models of aquatic ecosystems and transport of pollutants in air and soil, the transport process of evaporation is mainly used in models of soil pollution and crop pollution.

Residence time*:* The residence time T_e of a substance represents the mean amount of time that a molecule or particle of E would stay or 'reside' in a system. It is defined for a steady state, constant-volume system as

$$\mathrm{T}_E = \frac{E}{\left(\pm {}^{dE}\!/_{dt}\right)} \qquad (1.1)$$

Where E = quality of E in the volume and $\left(\pm {}^{dE}\!/_{dt}\right)$ = absolute value of either the sources or the sinks, e.g. pollutant residence time

Water pollution*:* Water pollution affects the rivers, the lakes, ponds, the oceans and even the rainfall. Some industries particularly power plants have been identified as contributors to acid rain. Water is needed for man’s survival. Hazardous wastes cause toxic chemicals to enter water and soil and can be eaten by various grazing animals and also filter to groundwater, which is a source of drinking water for many people

The critical velocity*:* is that at which erosion of the bed of a river and or bank material begins.

$$V = \left({}^{1}\!/_{n}\right) R^{2/3} S^{1/2} \qquad (1.2)$$

Where v = velocity (m\s), n = Manning's roughness coefficient, R = hydraulic radius (m) and s = slope of the river bed.

Critical shear stress*:* T_C is a measure of the stability of the bed and banks of a river against erosion. T_C is the stress at which erosion of the bed and\or bank material begins.

$T_C = \gamma RS$ In which to = the bottom shear stress (N\m^2), γ = specific weight of water (N\m^3), R = hydraulic radius (m) and S = slope of the river bed.

For wide channels, i.e. those with a top width T > 10R, the flow depth h is substituted for R. $T_O = \gamma hS$.

Estuary: This is a mixing region between river and ocean water, a place where fresh and salt water mix, such as a bay, salt marsh, or where a river enters an ocean.

Response time: is a parameter group that represents the time it takes for the lake or stream to complete a fixed percentage of its recovery.

$$t_\Phi = \frac{1}{\lambda}\ln\frac{100}{100-\Phi} \qquad (1.3)$$

And

$$C = C_O e^{-\lambda t} \qquad (1.4)$$

Where λ is called the Eigen - values = the response time C_o = initial concentration and $t_o = \frac{0.693}{\lambda}$

Diffusion*:* Diffusion is one of the most basic processes in nature and accounts at the molecular level for most of the transport that takes place. The diffusing phase can be a gas, a solid, or a liquid. The basic relationship governing diffusion is called Fick's First Law .This refers to the movement of mass due to random water motion or mixing. Such transport causes the dye path to spread out and dilute over time with negligible net movement of its centre of mass. Molecular diffusion results on a microscopic scale from the random Brownian motion of water molecules while turbulent diffusion occurs on a larger scale due to creation of eddies. Both diffusion types have a tendency to minimize gradients by moving mass from regions of high to low concentration.

Advection: This result from flow that is unidirectional and does not change the identity of the substance is transported. Advection moves matter from one position in space to another.

Dispersion is a term used for the combined effects of molecular diffusion and turbulent diffusion and both processes are caused by pulsating motion i.e. Brownian (wave) and flow velocity around its mean value caused by turbulence .This is the result of velocity differences in space. It is the process by which pollutants do spread in the water bodies in which they are discharged.

Conduction/convection generally refers to the motions in a fluid that result in the transport and mixing of the fluid property. It takes two forms the free and forced convention. The free convention refers to vertical atmospheric motions due to the buoyancy of heated or cooled fluid while the forced convention is due to external forces.

Point source pollution is water pollution or discharge or sources of pollution that can be located to an individual point of an effluent outfall. It also occurs when harmful substances are emitted directly into a body of water. One way in which this occurs is when someone throws a coke can into a body of water. An example is water pollution coming from a single point such as a sewage-outflow pipe.

Non-point or dispersed source is water pollution when pollutants are delivered indirectly through environmental changes. This occurs majorly through runoff. They are forms of diffuse pollution caused by sediment, nutrients, and organic and toxic substances originating from land-use activities, which are carried to lakes and streams by surface run off. This is contamination that occurs when rainwater, snowmelt or irrigation washes off ploughed fields, City Street, etc. it prices up soil particles and pollutants such as nutrients and pesticides.

Water-quality modelling originally focused on river and streams pollution, because they provided drinking water and navigation. Rivers were sites of many large cities and their associated waste discharge. Rivers and streams bear the brunt of urban point sources pollution and provide water for other uses such as agriculture, industry and power supply. Each of these uses can potentially affect water quality.

1.9 Expected Result and Contribution to Knowledge

1.9.1 Expected Results

Inventories of the industries currently located along River Atuwara were generated. The industrial effluents discharged by each industry were determined. This was in terms of the quantity and quality. The flow rate and seasonal variability of the volume of water and the contribution of the effluents being discharged were also determined.

The treatability study established appropriate treatment method and conditions for the major polluting industrial effluents. The data generated will be valuable to regulatory bodies, engineers and in particular the industries. Modellers will also benefit from the study etc.

1.9.2 Expected Contributions to Knowledge

a. The database to be generated will be useful to Scientists and Engineers working on similar study area;
b. The findings and the bench-scale treatment process will be useful to engineers in designing treatment plants for industrial effluents in similar study area;

c. The QUAL2E and its variant that may be developed will be useful in hydrodynamic studies of streams and rivers by hydrologists and engineers. The research findings will also find application in the following areas:

   i. Information from the model can be used to develop an action plan for water resources management for (Ogun/ Oshun) River Basin and help prioritize the management action to obtain the optimum achievement of the river water quality.
   ii. The application of the prototype models will provide a useful tool to support the rehabilitation planning and assist the decision-makers and other stakeholders.
   iii. The prototype models will demonstrate a practical tool in integrated management of the water resources for sustainable development in River Basins across the country.
   iv. To promote transfer of cleaner production techniques and technologies including energy efficiency and sound environmental management practice.
   v. To explore the application of appropriate technology for solving problems of environmentally unsustainable industrial development in Nigeria.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Water Quality and Pollution Problems

2.1.1 Water Quality

Water quality is a term used to describe the chemical, physical and biological characteristics of water, usually in respect to its suitability for a particular purpose. Scientific measurements are used to define water quality; it is the quality of natural water suitable for aquatic plants and animals. Water quality is closely linked to water use and to the state of economic development.

Pure water is colourless, odourless and tasteless is vital for all life on earth. Water is a universal solvent because it dissolves more substances than any other liquid. Pure water has a neutral pH of 7, which is neither acidic nor basic. Water is unique in that it is the only natural substance that is found in all three states—liquid, solid (ice) and gas, (steam). Earth's water is constantly interacting changing and in movement. The occurrence of chemical that can harm water quality such as nutrients and pesticides exist in water resources. The vulnerability of surface water and ground water to degradation depends on a combination of natural landscape features, such as geology, topography and soil type. Climate and others are atmospheric contributors to pollution while human activities related to different contributors and land-management practices (USGS, 2007).

In Nigeria, the rapid growth of the urban population has outpaced the ability of governments to expand sewage and water infrastructures. While water borne diseases has been eliminated in the developed world, outbreaks of cholera and other similar diseases still occur with high frequency in the developing countries, since World War II and the birth of the chemical age. Water quality has been heavily impacted world wide by industrial and agricultural chemicals (Terry, 1996).

2.1.2 Pollution Problems

According to the World Health Organization (WHO, 1996), the environment is considered polluted when it is altered in composition or condition directly as a result of activities of man so that it becomes less suitable for some or all of the uses for which it would be suitable in its natural state. The Federal Environmental Protection Agency (FEPA) Act Section 38 of Cap 131 LFN (1990) also defines pollution to mean man-made or man-aided alteration of chemical, physical, or biological quality of the environment to the extent that it is detrimental to that environment or beyond acceptable limits.

Pollution is caused by washing into surface water of sewage and fertilizers, which contain nutrients such as nitrate and phosphates. If these nutrients, are present in excess they stimulate the growth of aquatic plants and algae that consequently clog watercourses and use up dissolved oxygen as they decompose (Adenuga *et al*, 2003).

Water pollution occurred when a body of water is adversely affected by the addition of large amounts of materials to the water. When it is unfit for its intended use, water is considered polluted. Two types of water pollution exist, point source and non-point source. Point source pollution occurs when harmful substances are discharged directly into a body of water. A non-point source delivers pollutants indirectly through environmental discharges. An example of this type of pollution is when fertilizer from a field is carried into a stream by rain in the form of run off which in turn affects aquatic life. There are various technologies in existence to monitor and control point sources. Pollution arising from non-point sources is much more difficult to control.

2.1.3 Causes of Water Pollution

Water pollution has many causes and characteristics where increases in nutrients loading may lead to eutrophication. Organic wastes such as sewage impose high oxygen demand on the receiving water leading to oxygen depletion with potentially severe impacts on the whole ecosystem (Krantz and Kifferstein, 2001). Industries discharge a variety of pollutants in their wastewater. Such pollutants include heavy metals, organic toxins, oil nutrients and solids. Discharge can also have thermal effects especially those from power stations and these too reduce the available oxygen. Silt-bearing runoff from many activities including construction sites, deforestation and agriculture can inhibit the penetration of sunlight through the water column .This restricts photosynthesis and causes blanketing of the lake or river bed thereby damaging ecological systems. Pollutants in water include a wide spectrum of chemicals, pathogens and physico-chemical or sensory changes. Many of the chemical substances are toxic. Pathogens can obviously produce water borne diseases in either human or animal hosts (West, 2006 and Pink, 2006).

Alteration of water’s physical chemistry includes acidity, conductivity, temperature and eutrophication. Eutrophication is the fertilization of surface water by nutrients that were previously scarce... It has been suggested that it is the leading worldwide cause of deaths and diseases and that it accounts for the deaths of more than 14000 people daily (West, 2006). Water pollution is also caused when silt and other suspended solids such as soil and wastes are washed off ploughed fields. Construction and logging sites, urban areas and eroded river banks into surface waters. Naturally lakes, rivers and other water bodies undergo eutrophication, an aging process that slows fills in the water body with sediments and organic matter. Pollution in the form of organic matters enters water ways in many different forms as sewage, as leaves and grass chippings or as runoff from livestock feedlots and pastress chippings or protozoan and bacteria or in the water break down this organic material used up the dissolved oxygen.

Many types of fish and aquatic animals and life cannot survive when level of dissolved oxygen drop below 2—5 mg/l, hence and die off in large number leading to disruption in the food chain. Pathogens constitute another type of pollution that is harmful. They can cause many illnesses that range from typhoid and dysentery to minor respiratory and skin diseases. Pathogens include such organisms as bacteria, viruses and protozoan. These pollutants enter waterways through untreated sewage, storm drains, septic tanks, runoff from farm and particularly boats that dump sewage. These pollutants have a tremendous effect evidenced by their ability to cause sickness. Water pollution can also be as a result of discharge from petroleum, radioactive substances and heat.

Petroleum often pollutes water bodies in the form of oil spills. These large-scale accidental discharges are an important cause of pollution along shorelines. An estimated one-ton of oil is spilled for every million tons of oil transported; this is about 0.0001 percent of the production. Radioactive substances are produced in the form of waste from nuclear power plants and from industrial, medical and scientific use of radioactive materials. Specific forms of radioactive pollutants in waters are uranium and thorium from mining and refining.

The last form of water pollution is heat. Heat is a pollutant because increased temperature of water bodies results in the death of many aquatic organisms. Decrease in temperature due to discharge of cooling water by factories and power plants also occur and can affect aquatic organism (Krantz and Kifferstien, 2001).

2.1.4 Sources and Effects of Water Pollution

The fresh water available in rivers, lakes and underground all put together constitute only 0.34% of the total water available on earth. The main source of fresh water pollution can be attributed to discharge of untreated waste dumping of industrial effluent and runoff from agricultural fields. Industrial growth, urbanization and the increased use of synthetic organic substances have serious and adverse impacts on fresh water bodies. It is a generally accepted fact that the developed countries suffer from problems of chemical discharge into the water sources mainly groundwater while developing countries face problems of agricultural run off in surface water sources (West,2006).

Some of the principal sources of water pollution are:

i. Industrial discharge of chemicals into waterways;
ii. Discharge of poorly treated and untreated sewage;
iii. Surface runoff containing pesticides and fertilizers;

iv. Slash and burn farming practice, which is often an element within shifting cultivation agricultural system;
v. Surface runoff containing spilled petroleum products;
vi. Surface runoff from construction sites, farms or paved and other impervious surfaces e.g. sill;
vii. Discharge of contaminated and or heated water used for industrial processes;
viii. Acid rain caused by industrial discharges of sulphur dioxide from the burning of fossil fuels with high sulphur concentration;
ix. Excess nutrients added by runoff containing detergents or fertilizers; *and*
x. Underground storage tank leakage, leading to soil contamination and ultimately aquifer contamination.

2.2 Receiving Environment Characteristics

The physical and chemical characteristics of the receiving waters are important factors influencing the impacts of industrial effluents on aquatic environments. These characteristics include water hardness, temperature, acidity or alkalinity, background concentrations of nutrients and metals, and the physical nature of the receiving water body (e.g., whether it is a stream, lake, or estuary; whether it contains fresh water or salt water). The toxic effects of ammonia, for example, are related to the pH and temperature of the receiving waters. Un-ionized ammonia, which is highly toxic to fish, exists in equilibrium in water with its non-toxic counterpart, ammonium (or ionized ammonia). When the water becomes warmer and more alkaline, however, more ammonium is converted back to unionized ammonia, and the concentrations of un-ionized ammonia rise. Thus, quite significant amounts of ammonia can form merely as the result of a change in water temperature and pH as indicated in the equation that follows:

$$[NH_3]T = [NH_4^+] + [NH_3]$$

$$HN_4^+ = NH_3^+ + H^+$$

The toxicity of many substances tends to be affected by elevated temperatures, such as are common near industrial wastewater outfalls. For most chemicals acute toxicity increases by an average of 3.1 times for every 10°C rise in temperature (Mayer and Ellersieck 1988). The effects of water hardness and pH, on the other hand, tend to vary with the type of substance involved. Water hardness, for instance, affects the toxicity of most inorganic chemicals, such as chlorides, but has little effect on the toxicity of organic chemicals (Pickering and Henderson, 1964; Inglis and Davis, 1972). The relative acidity or alkalinity of the water can also alter the toxicity of metals and weak organic and inorganic acids and bases (Mayer *et al*. 1994). As the water becomes more alkaline, the toxicity of bases, such as ammonia, increases, and the toxicity of acids, such as sulphuric acid decreases.

In addition, in the case of organic chemicals, their bioavailability (i.e., the portion of the total amount of chemical that is available for uptake by an organism) can be reduced by the presence of particles of organic matter. This is because organic chemicals tend to form complexes with particulate matter, and these complexes are too large to pass through gill membranes of fishes, for example (Gobas and Zhang 1994). Since the amount of particulate matter can differ between aquatic ecosystems, the bioavailability, hence the toxicity of a given concentration of a contaminant can differ substantially from one ecosystem to another. Similarly, the bioavailability and toxicity of a substance can be different in marine and freshwater ecosystems, although these differences have not been deeply studied.

2.2.1 Assimilative Capacity of the Receiving Water

The volume and flow of a receiving water will determine its ability to dilute or assimilate effluent discharges and hence, the extent of toxic by the discharge. Although a concentrated effluent may be highly lethal in laboratory tests, receiving systems with a large assimilative capacity may dilute the effluent to the point where it is no longer deadly. However, in small watercourses, intertidal areas, or receiving waters that are subject to periodically low seasonal flows, the water volume may be insufficient to dilute the effluent to non-toxic levels (OMOE 1990). In addition, a high assimilative capacity may have little effect on the long-term impact of persistent chemicals that tend to accumulate in sediments or the tissues of aquatic organisms over long periods of time (Adelegan, 2002; Ritu and Prateek, 2004).

The dilution capacity of a receiving water body also varies with time and depends on the volume of the discharge and the flow of the receiving water at the point of discharge. Receiving water flow is determined by precipitation, surface runoff, groundwater discharge, and the area, slope, soils, and vegetation of the drainage basin. Tidal patterns can also influence the dilution capacity of estuarine and marine receiving waters (Ritu and Prateek, 2004).

2.2.2 Views on Global Water Quality

Environmental problems (such as global climate change; ozone layer depletion; rise in ocean, water, land and air pollution and resource degradation- compounded by an expanding World population) respect no border but threatens the health and prosperity of nations. There is a recent focus on the environmental performance of specific products (IPP, 2003), EU Integrated product policy. New demands on an organization’s knowledge of its own processes and products and on cooperation throughout the product’s value chain. This demand can be met by companies improving environmental performance and handling of environmental data more efficiently and effectively. This study contributes to this effort by empirically mapping a production site’s existing and needed systems.

The UN Third World Water Forum in Japan March 2003 reported that the world water crisis would reach unprecedented level by the year 2050, when up to 7 billion people in 60 countries could face acute water shortage, 1.2 billion people do not have access to safe drinking water, more than two million die each year from diseases contaminated water (Wito, 2004), 2.4 billion people do not have access to proper sanitation, 50% of all solid waste is uncollected and 3 billion people have to survive on less than US$ 2/day (Truong *et al* , 2003).

UNESCO also reported that average supply of water available per person will drop by one third within 20 years, climatic change will account for 20% of the decline in water supply through erratic rainfall and a rise in sea level. While pollution continues to increase unabated, with 2 million tonnes of waste dumped daily into surface waters (Truong, 2003). Fresh water scarcity is predicted to become the greatest single threat to international stability, human health and global food supply.

Current practice involves the discharge of industrial effluents to surface water bodies, after some preliminary treatment. According to the World Resources Institute, within the next 25 years, more than half of world population will be suffering from severe fresh water shortages. The goal of the international fresh water conference held in Bonn Germany in December 2001 was to articulate solutions to global water problems. One-fifth of the world population does not have access to sufficient clean drinking water.

The stress on water resources is continuously increasing in developing countries and managing water resources in a sustainable approach is a challenging mission; the problem include water quality degradation, toxic waste dumping and sanitation intrusion leading to conflicts and confrontations among various water users (Sukanda et al, 2004).

The Minnesota Pollution Control Agency (MPCA, 1999) posited that underground disposal of commercial and industrial wastewater can cause serious soil and groundwater contamination if not carefully controlled .On site sewage treatment systems designed to treat domestic waste water do not provide adequate treatment for the types of contaminants found in commercial and industrial facilities. Due to the potential for wastewater to contaminate soil and groundwater, the policies and regulations regarding underground disposal in most developing countries are strict. These facts provide an overview of the regulations and restriction concerning the management, treatment and disposal of industrial effluent in underground sewerage systems.

From the health perspective, improving access to safe water supply and sanitation services is a preventive intervention whose main outcome is a reduction in the number of episodes of diarrhoea and a proportionate reduction in the number of deaths. Increased access to water is essential to reduce the burden of water-related diseases and to improve the well being of a large part of the world's population. This is also a vital input into economic development and poverty alleviation. Countries sharing common resources share a common future and are downstream and upwind, not just north and south, or east and west of each other. Threats to a shared forest, a common river, or a seamless coastline are forcing countries to expand their existing bilateral relationships to include environmental issues and to create new regional framework to confront and combat shared environmental challenges.

2.3 Water Quality in Nigeria

Nigeria lies between latitudes 4^0 10' and 13^0 32' N, longitudes 2^0 24' and 14^0 19'E. She is bordered by the Republic of Benin to the West, the Republic of Niger to the North and the Republic of Cameroon and Chad to the East and the Atlantic Ocean (Gulf of Guinea) to the South on an 835km long coastline (Iwugo *et al*, 2003). It has a total land area of 923,768 square kilometres (92 million hectares) of which one third is arable and another third is Forest and Woodland .The climate is tropical, but while the South has ill defined seasons and a mean annual rainfall in excess of 150cm the North has more clearly defined wet and dry seasons and much less rain. Daily temperatures range between 21^0C and 32^0C in the South and 15^0C and 35^0C in the North.

The country's population as per the 2006 census was 140.1 million with a population growth rate of 3.3% and a population density of 152 persons per square kilometre of which the urban population stands at 42.1 millions,peri-urban population of 55.83 million and rural population of about 42 millions (Adeniji, 2006). Nigeria's water resources statistics (Adeniji, 2006) stands as listed below:

- Total water resources = 433billion m^3
- Surface water resources = 226 billion m^3
- Ground water resources = 208 billion m^3
- Shallow aquifers = 122billion m^3
- Deep aquifers = 87 billion m^3

In the year 2000, the country's water use (World Bank, 2004) is as follows:

- Agricultural water use = 69.0%
- Domestic water use = 21%
- Industrial water use = 10%

Between 1970 and 1990, per capita water supply decreases worldwide by a third. As developing countries on average use 30% to 50% less water than developed countries, this looming crisis will affect developing countries most, where more water for both agricultural and industrial development as well as for health improvement is required. The developing countries cannot afford chemically treated polluted and contaminated water, which are energy sapping and very costly.

The United Nations’ Conferences on Environmental Development, which adopted agenda 21 of 1992, proclaimed that human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature (UN, 1993).

Environmental insecurity is defined as the vulnerability of people to the effects of environmental degradation (Bernett, 2001). The five key environmental challenges that affect most, if not all areas of the world are:

- Water resources;
- Air quality;
- Energy resources;
- Land use and urban development; *and*
- Industrial growth.

Hazardous wastes and industrial effluents represent a far more insidious and pernicious substances in rapidly developing municipal communities. Unlike for the highly putrescible mountains of municipal solid wastes, research revealed that Nigeria has no environmentally secured industrial waste disposal site. Effluents are discharged into water bodies or find their ways into the underground water resulting in heavy pollution loads in the form of colour, turbidity, odour, heat, suspended solids, dissolved solids, Biochemical oxygen demand (BOD), various inorganic elements, volatile organic compounds, toxic chemicals and general public health nuisance.

In Nigeria it is estimated that 80% of industrial effluents and emissions are discharged without any form of treatment. Major coastal towns and cities such as Lagos, Warri and Port-Harcourt have large human populations but invariably lack sewage treatment plants except in a few relatively new and isolated residential or industrial estates. Most residents use septic tanks whose contents when dislodged are discharged into coastal rivers, lagoons and near shore waters without further treatment. The associated problems includes increases in BOD and the introduction of pathogenic micro-organisms and intestinal parasites which pose risks to swimmers and fishermen as well as the general public (Aka *et al*, 2002).

2.4 Historical Development of Hydrodynamic Systems

Hydrodynamics models of rivers and estuaries have been in existence for more than a century. In 1875, a French engineer named Louis Fargue developed a physical model of the Garonne River near Bordeaux. France Fargue used his model to perform 21 simulations runs during the course of 2 years. This research led to the publication of an article entitled *"Experiences relatives a laction de l'eau courante sur un fond de bable"* or experiments relating to the action of running water on a sand bottom. Two major goals were achieved through the research *viz*: he verified the results of his 1868 research concerning the correlation between the configuration of the bed and the depth of water in the rivers. Second he became the first engineer/scientist to use a hydraulic model in the discipline of river engineering (Hager, 2003). After Fargue, Osborne Reynolds constructed a physical model of the Mersery Estuary located near Liverpool, England.

Computer-based hydrodynamic models have been in existence for more than 30years. During the 1960s the United State Geological Survey (USGS) developed an implicit finite-difference model that solved the 1-dimensional equations of motion or Saint Venant equations. The USGS achieved fairly accurate results with their implicit finite-difference model and the development of other computer-based numerical models soon followed by Miller and Cunge in 1975. One Hydrodynamic model developed and refined shortly after is USEPA's Dynamic Estuary Model (DYNHYD). In 1970, Feigner and Harris released the Dynamic Estuary Model. This model was updated (Roesch *et al*, 1979) and became known as the Potomac Estuary Hydrodynamic Model or DYNHYD2.

Since 1979 DYHYD2 has been enhanced and updated (Ambrose *et al*, 1988). The current release is DYNHYD5 (Ambrose *et al*, 1993) which is distributed with USEPA's Water Quality Analysis Simulation Program (WASP) modelling software.

2.5 Historical Development of Water Quality Models

Water Quality Modelling is a complex computer programme for the analysis and simulation of river systems that are available. The Modelling packages may be used for flood prediction or the analysis of quality aspects in the river (e.g. dissolved oxygen and BOD distribution). The input of these models includes hydrological and hydraulic data together with a range of quality parameters. The models may be dynamic with variable inputs and coefficients, giving a time variable output from the model. Water quality modelling evolved at its innovation in the early years of the twentieth century. The innovation can be broken down into four major phases. These phases relate both to societal concerns and the computational capabilities that were available during each periods (Chapra, 1997).

2.5.1 Early Modelling Works

Phase I — Early modelling work focused on the urban waste load allocation problem. The research work at this stage was the model developed by Streeter and Phelps (1925) on the Ohio River, A sample model is as shown in *Figure 2.1*. A Water Treatment Plant (WTP) purifies water for human consumption. A Wastewater Treatment Plant (WWTP) removes pollutants from sewage to protect the receiving water.

Their investigation provided a means to evaluate dissolved oxygen levels in streams and estuaries. Others such as Velz (1938, 1947); O’Connor (1960, 1967) equally dealt with the same scope of water quality modelling. Bacterial models were developed by O'Connor in 1962. Due to non-availability of computers then, model solution were closed forms, i.e. applications were usually limited to linear kinetics, simple geometrics and steady-state receiving waters.

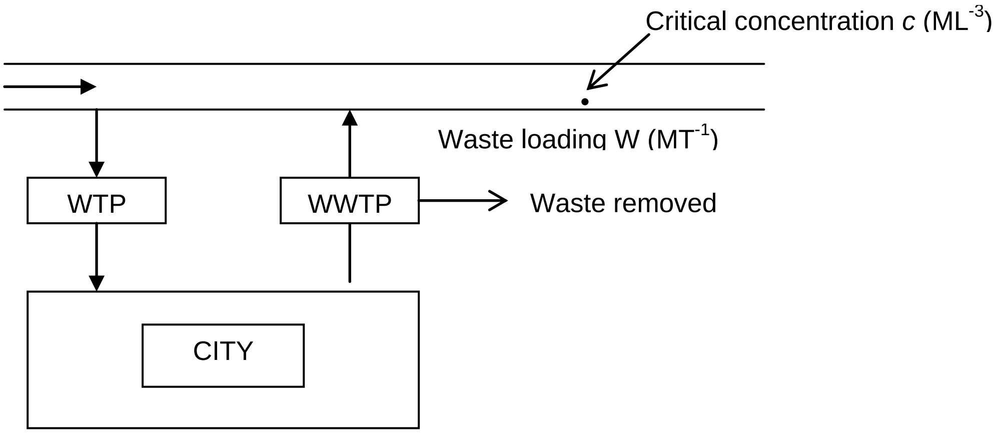


Fig. 2.1 An urban water—wastewater system

The availability of digital computers in 1960 led to major advances in both the models and the mode of application.

The modelling advances then involved numerical experiences of the analytical frameworks as stated by Thomann in 1963 with oxygen still as the focus. But the computer allowed analysts to address more complicated systems geometrics, kinetic and time variable simulations. Particularly the models were extended to two-dimensional systems such as wide estuaries and bays. This period also brought changes to model application in that model no longer focused only on local effects of single point sources; drainage basins as a system were covered. Tools developed in the field of operation research were coupled with the models to generate cost-effective treatment alternatives (e.g. Thomann and Sobal, 1964; Deiningner, 1965; Ravelle *et al*, 1967) focus, hence was still on point sources.

In 1970, societal awareness began to move beyond dissolved oxygen and urban point sources to an ecological movement peeking at environmental remediation. Thus the principal water-quality problem addressed was eutrophication. More mechanistic representation of biological processes were included such as oceanographic phenomenon (Steele, 1962). Environmental engineers developed elaborate models capable of simulating nutrient/food chain models (Di Toro *et al*, 1971; Canale *et al*, 1974, 1976). Also computational advancement feedback and non-linear kinetics could be employed in the frameworks. It was also a period when attention was shifted towards non-point sources of oxygen-demanding wastes and installations of secondary treatments plants for municipal treatment of effluents.

Still in the 1970s, the environmental awareness had focused on:

- System analysis method to optimize dynamic problems of eutrophication than urban point-source control, because they are much more complicated and computationally intensive than for the linear, steady -state, point-source problem;
- The environmental movement considered a matter of urgency regarding cleanup and a remediation “at any cost” which led to the concepts of “zero-discharge articulated as a national goal, *and*
- Legality supplanted sound engineering due to economic boom as the basis for most pollution control strategies.

The most recent stage of model development evolved as a result of energy crisis of the mid-seventies and increased deficit budgets, forcing pollution control back to economic reality. The major advancement in modelling involved the prominent role of solid matter in the transport and fate of toxicants (Thomann and Di Toro, 1983; Chapra and Reckhow, 1983 and O’Connor, 1988). In particular, the association of toxicants with settling and re-suspension particles represents a major mechanism controlling their transport and fate in natural waters.

Today, there is a strong recognition that environmental protection is critical to the maintenance of high quality of life. Some of the factors militating against this include:

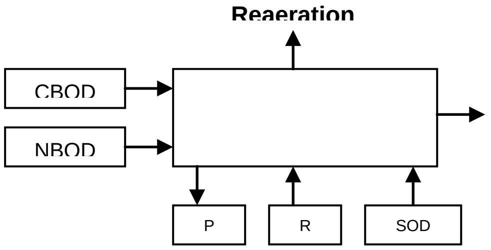
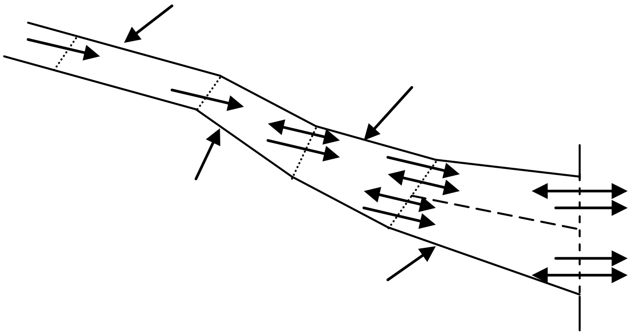
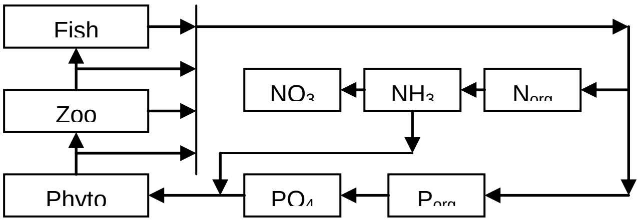
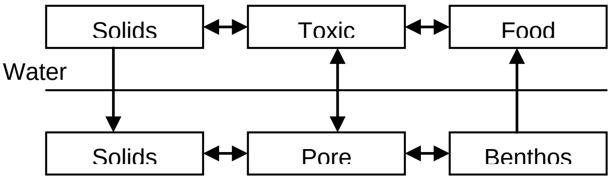
- Developed Countries experiencing economic pressures necessitating incentives for cost-effective solutions and reductions of non-point or diffuse sources, which are typically more expensive than point-source controls. Today better models are needed to avoid the severe economic penalties associated with faulty decisions.

- Developing countries are forced to recognize that environmental protection must be coupled with economic development; hence cost-effective, model-based control strategies could provide a means to control pollution and sustain a high quality of life while maintaining economic growth.
- Computer hardware and software advances are developed thereby enhancing graphical users' interfaces and decision support systems to facilitate the generation and visualization of model output and also removing computational constraints, so that two- and three- dimensional models with highly mechanistic kinetics models can be simulated at a reasonable cost.
- Further advances in computer technology significantly assisted mechanistic characterizations of sediment-water interactions and hydrodynamics that they can effectively apply into water-quality modelling framework.
- The development of computer-based Water Quality Models has closely followed water pollution control in the United States. Before 1970 the focus of water pollution control was directed towards achieving the ambient water quality standards. These standards were extremely hard to administer due to the fact that current Biochemical Oxygen Demand (BOD_5) and Dissolved Oxygen (DO) models were not prepared for the challenge of translating the ambient standards to effluent discharge limits.

In 1970 the USEPA was established and two years later congress passed the Clean Water Act of 1972. Also the National Pollutant Discharge Elimination System (NPES) was developed by USEPA in 1972. Consequently computer- based numerical eutrophication and hydrothermal models were developed. For example Orlob and Selna (1970) developed a mathematical model to simulate temperature distribution in the Fontana Reservoirs, which is operated, and maintained by the Tennessee Valley Authority (TVA). Markotsky and Harleman (1973) developed a mathematical model to predict dissolved oxygen concentrations as well as temperature variations in the same reservoir. In 1977, water quality criteria were established for toxic substances, producing a need for water quality models to simulate toxics. This is illustrated in Table 2.1.

In 1982, USEPA proposed the use of water quality based controls instead of the conventional National Pollutant Discharge Elimination System (NPDES) (technology-based) controls hence waste load allocation (point source) models were developed. In addition USEPA established special fund to initiate the clean up of the nation's hazardous waste sites, this in turn sparked the development of computer based sediment models. Recently USEPA has evolved a more comprehensive approach in cleaning up and protecting the United States water bodies. The total maximum daily load (TMDL) process of the Clean Water Act considers waste loads allocations (point sources) and non-point sources wild life and a margin of safety.

Table 2.1: Development Periods of Water Quality Models (Chapra, 1997)

Development Periods & Treatments	Model
1925—1960 (Streeter-Phelps) *Problems:* Untreated and primary effluents *Pollutants:* BOD/DO	
1960—1970 (Computerization) *Problems:* Primary and secondary effluents *Pollutants:* BOD/DO	
1970—1977 (Biology) *Problems:* Eutrophication *Pollutants:* Nutrients	
1970— Present (Toxics) *Problems:* Toxics *Pollutants:* Organics, metal *Systems:* Sediment-water interactions/	

With the introduction of TMDL process, a significant number of new computer-based water quality models have been developed and implemented (Lung, 1993). One major water quality model developed and refined throughout the process is USEPA's Water Quality Analysis Simulation Programme (WASP).

Di Toro *et al* (1983) developed the first complete version of USEPA's Water Quality Analysis Simulation Programme software. Ambrose *et al* (1988) updated the software once again and it became WASP4. Ambrose *et al* (1993) refined the modelling software and effectively producing WASP 5. The current release is WASP6.1 (Wool *et al*, 2003) and is distributed and maintained by USEPA's watershed and water quality modelling technical support Centre in Athens Georgia.

There are significant numbers of computer-based water quality models that have been developed over the past three decades. Some of these are presented in Table 2.2.

Table 2.2: Abbreviated List of Water Quality Models with Reference

Model	References
Enhanced Stream Water Quality Model (QUAL2E)	Brown and Barnwell (1987) USEPA 1975
Three-Dimensional Hydrodynamic-Eutrophication Model (HEM-3D)	Park et al (1995) Sisso *et al* (1997)
Tidal Prism Water Quality Model (TPWQM)	Kuo and Neilson (1988) Kuo and Park (1994) Kuo *et al* (1999); Shen *et al* (2002)
Two-Dimensional, Laterally-Averaged Hydrodynamic and Water Quality Model (CE–QUAL-W2)	Cole and Wells,2002
Three-Dimensional Eutrophication Model (CE-QUAL-ICM)	Cerco and Cole (1994) Cerco and Cole (1995)

Hammond, A. J. (2004).

2.6 Water Quality Standards

There are many water quality variables that cause water pollution problems, such as BOD, nutrients (nitrogen and phosphorus), toxic substances, bacteria, and solids. There are a total of 28 variables in many National Surface Water Quality Standards. Water quality parameters measured were physico-chemical parameters (pH, turbidity, conductivity, total suspended solids, total phosphorus, total solids, BOD, DO, nitrate-nitrogen, heavy metals), and biological parameters (faecal and total Coliform bacteria) (Simachaya, 2002).

In recent years, water quality models have become an important part of most water quality management and planning process. The need to understand the cause/effect relationship in water pollution, and the desire to develop a tool that can aid decision makers in selecting management procedures or technologies, are two important reasons for water quality model application. Thus, water quality models can be power tools when used to determine acceptable contaminant levels or when testing the alternative strategies for water quality management.

The ambient water quality standards has been established since 1994 and served as guidelines of protecting the receiving waters based on major beneficial uses. The surface water quality standards are classified into 5 classes as follows:

Class 1: Extra clean for conservation purposes

Class 2: Very clean used for (1) consumption, which requires ordinary water treatment processes (2) aquatic organism conservation (3) fisheries, and (4) recreation [DO > 6 mg/L, BOD < 1.5 mg/L, Faecal Bacteria < 1000 MPN/100ml)

Class 3*:* Medium clean used for (1) consumption but passing through an ordinary treatment process and (2) agriculture [DO > 4 mg/L, BOD < 2 mg/L, Faecal Bacteria < 4000 MPN/100ml)

Class 4: Fairly clean used for (1) consumption, but requires special treatment process and (2) industry [DO > 2 mg/L, BOD < 4 mg/L)

Class 5*:* Waters which are not classification in class 1-4 and used for navigation (Simachaya, 2002)

The main pollutants that pose threat to water quality standard are organic wastes, bacteria, nutrients, and solids especially in the lower parts of the central river basins. The water quality has been less than the surface water quality standard and its classification. The major water quality problems are high coliform bacteria (in term of total and faecal coliform bacteria, 34 %), high solids (in terms of turbidity and total solids, 31 %), total phosphorus (TP, 15%), low dissolved oxygen (DO, 12 %), Ammonia-nitrogen (NH_3-N, 6%), and high organic matter (in term of biochemical oxygen demand (BOD, 2 %), as indicated. These problems were perceived to be most serious during the winter season when there is minimal dilution capability in streams (Try and Price, 1995).

Water quality standards are affected by domestic and industrial wastewater discharges, agricultural point and non-point source discharges, deforestation, and other development projects. In industrial cities of many developing countries, surface water quality were severely polluted, which affects aquatic resources, water uses for various purposes as well as human health. Monitoring program of the river water quality indicated deteriorated water quality in the lower parts of the major rivers. Discharges from the urban wastewater have been the major pollution source. Most rivers flowing through the urban areas contained high organic contamination and high Coliform bacteria.

Enforcement of related regulations has to be seriously practiced. To manage water quality in the whole watershed, integrated approaches should be taken into account in future such as basing planning or ecosystem approach which considers both point and non-point source pollution (Simachaya, 2002).

2.7 Hydrodynamics and Hydraulics

Flow of water in a river is described by the continuity and momentum equations. The latter is known as the Navier-Stokes or Reynolds equation. Methods vary from the use of eddy viscosity as known parameters to the application of the k – ε theory (Bedford et al., 1988)

$$V_s = \frac{8.64g}{18\mu}(\rho_s \rho_w)d_p^2 \qquad (2.2)$$

Where:

V_S = Stokes' settling velocity for particle with diameter d and density ρ_s in m/day

g = acceleration due to gravity in cm/s^2

μ = absolute viscosity of water = 0.01 poise (g/cm^3-sec) at 20^{0}C

ρ_s = density of the solid, g/cm^3

ρ_w = density of water, 1.0 g/cm^3

dp = particle diameter in mm

Values of Vs for a range of particle sizes and densities are provided in Table 2.3. Benthic exchange of sediment and particulate chemicals is driven by the net scour and deposition velocities:

$$W_{BS} \bullet A_{ij} (W_R S_1 \bullet W_D S_j) \qquad (2.3)$$

Where:

W_{BS} = net sediment flux rate, g/day

S = sediment concentration, g/m^2

W_D = deposition velocity, m/day

W_R = scour velocity, m/day

A_{ij} = benthic surface area, m^3

i = benthic segment

j = water segment

The deposition velocity can be calculated as the product of the Stokes's settling velocity and the probability of deposition:

$$\mathrm{W_s} \bullet V_S \bullet D$$

Where:

D = probability of deposition upon contact with the bed

Table 2.3: Stokes's Settling Velocities (in m/day) at 20°C

Particle Diameter, mm	**Particle Density/cm^3**			
	1.80	2.00	2.50	2.70
Fine Sand				
0.3	300.00	400.00	710.00	800.00
0.05	94.00	120.00	180.00	200.00
Silt				
0.05	94.00	120.00	180.00	200.00
0.02	15.00	19.00	28.00	32.00
0.01	3.80	4.70	7.10	8.00
0.005	0.94	1.20	1.80	2.00
0.002	0.15	0.19	0.28	0.32
Clay				
0.002	0.15	0.19	0.28	0.32
0.001	0.04	0.05	0.07	0.08

Bedford *et al.*, 1988

Also different forms and approximation of the Saint Venant equations are relevant for a study depending upon whether the flow is steady or unsteady and which simplification are made. Hence for the water quality studies often the equation of steady, gradually variable flow is employed (which further simplified to the Manning's equation.) Unsteady models include the kinematics, diffusive, and dynamic wave approaches, all based on the continuity and momentum equations. The difference stems from simplifications of the latter: dynamic wave models solve for full equation, diffuse one exclude the acceleration terms, while kinematics ones disregard the pressure gradient term that is essential for the description of backwater effects (Routing methods commonly used in hydrology usually correspond to the last approach (Mahmood and Yevjevich, 1975).

The hydrodynamic equations are generally solved by efficient finite difference methods (Mahmood and Yevjevich, 1975). For water quality issues the acceleration terms in the momentum equation rarely play a significant role and the typical time scales are amplified by conversion processes. For these reasons, the diffusive wave approach is often a satisfactory approximation.

2.7.1 Hydraulic Routing Techniques

Many different forms and approximation to the Saint Venant equation are known depending upon whether the flow is steady or unsteady and which simplifications are made The St Venant equations consisting of the continuity equation (Eqn.2.4) and the momentum equation (Eqn. 2.5)

The equation that describe 1-D unsteady flow in open channels the Saint Venant equations consist of the continuity equation (Eqn.2.4) and the momentum equation (Eqn. 2.5) .The solution of these equations defines the propagation of a flood wave with respect to the distance along the channel and time.

$$A\frac{\partial v}{\partial x} + VB\frac{\partial y}{\partial x} + B\frac{\partial y}{\partial t} - q \qquad (2.4)$$

$$S_f = S_o - \frac{\partial y}{\partial x} - \frac{v}{g}\frac{\partial v}{\partial x} - \frac{1}{g}\frac{\partial v}{\partial t} \qquad (2.5)$$

Where:

A = cross –sectional area;

x =distance along channel.

V = average velocity of water;

B = water surface width;

y = depth of water;

t = time;

q = lateral inflow per unit length of channel;

S_f = Friction slope,

S_0 = Channel bed slope

g = gravitational acceleration

Henderson 1996 explains the meaning of the various terms in the dynamic wave equation solved together with the proper boundary conditions Equations 2. 3 and 2. 4 are for the complete dynamic wave.

Thus:

1. Continuity equation

$A\frac{\partial U}{\partial x}$ = Prism Storage

$UB\frac{\partial y}{\partial x}$ = Wedge storage

$B\frac{\partial y}{\partial t}$ = Rate of rise

q_L = Lateral inflow per unit length.

2. Momentum equation

S_f = Friction slope (frictional forces)

$\frac{\partial U}{\partial x}$ = Pressure differential

$\frac{U}{g}\frac{\partial u}{\partial x}$ = Convective acceleration

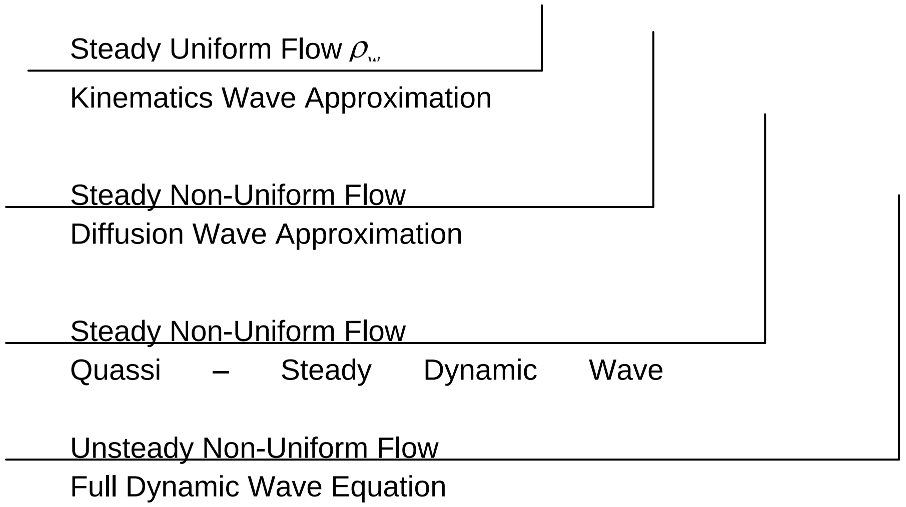
$\frac{1}{g}\frac{\partial u}{\partial t}$ = Local acceleration

Thus for water quality studies after the equation of steady, gradually variable flow is employed (which may be further simplified to the so –called Manning equation as done in QUAL2E) Unsteady models include the kinematics, diffusive and dynamic wave approaches all based on the continuity (e.g. *Eqn. 2.4*) and momentum equations (e.g. *eqn. 2.5*)

The difference stems from simplifications of the latter: dynamic wave models solve the full equation; diffusive ones exclude the acceleration terms while kinematics ones disregard also the pressure gradient term that is essential for the description of backwater effects.

The most common approximations of the momentum equation are:

$$S_f = S_O - \frac{\partial y}{\partial x} - \frac{U}{g}\frac{\partial U}{\partial x} - \frac{1}{g}\frac{\partial U}{\partial t} \qquad (2.6)$$



The use of approximations to the full equations for unsteady flow can be justified when specific terms in the momentum equation are small in comparison to the bed slope. Henderson (1996) computed values for each of the terms on the right hand side of the momentum equation for a steep alluvial stream as indicated on Table 2.4.

The understanding of the equations utilized within the models is required to know the model set up and their implementation, hence the equation for simulating estuary hydrodynamics (velocities, water surface elevations) are briefly presented below:

2.7.2 1-Dimensional Equation of Motion

One-dimensional river models provide engineers and hydrologists the capability of simulating hydrodynamics in the longitudinal direction or along the length of the river. They typically require less time and resources to set up, calibrate, and validate than equivalent 2- or 3-dimensional models. Due to their longitudinal environment, 1-dimensional models are best suited for rivers that are long, narrow, and shallow in nature.

1-dimensional models employ the use of the conservation of mass and momentum equations to determine a number of river hydraulic characteristics, such as flow rates, depths, velocities, top widths, and cross-sectional areas (Hammond, 2004).

Typically it is assumed that the density of water remains constant, therefore, the conservation of mass equation simplifies to the continuity equation. Considering the control volume in the continuity equation (2.7) can be written:

Table 2.4 Shows values of parameters in the Henderson's momentum equation.

Momentum equation	S_O =	$\frac{\partial y}{\partial x}$ -	$\frac{V}{g}\frac{\partial v}{\partial x}$ -	$\frac{1}{g}\frac{\partial v}{\partial t}$
Magnitude (ft /mi)	26	5	12.25	0.5

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_L \qquad (2.7)$$

Where:

$\frac{\partial A}{\partial t}$ is change in wetted channel cross-sectional area per unit time

$\frac{\partial Q}{\partial x}$ is the change in channel inflow or outflow per unit channel length

q_L is the channel lateral inflow or outflow per unit channel length.

Chaudhry in 1993 noted that for a channel with a regular cross-section, the top width (B) is a continuous function of depth (y) and presents a modified version of the continuity equation (2.8)

$$B\frac{\partial y}{\partial t} + \frac{\partial Q}{\partial x} = q_L \qquad (2.8)$$

It is then noted that $Q = AU \square \frac{\partial A}{\partial x} = B\frac{\partial y}{\partial x}$ and the equivalent channel depth (D) can be defined as $D = \frac{A}{B}$, substituting this in equation (7) yield: ρ_w

$$\frac{\partial y}{\partial t} + D\frac{\partial U}{\partial x} + U\frac{\partial y}{\partial x} - \frac{q_L}{B} = 0 \qquad (2.9)$$

Where:

$\frac{\partial y}{\partial t}$ is the change in the depth per unit time

$\frac{\partial U}{\partial x}$ is the change in average cross- sectional velocity per unit channel length

and,

$\frac{\partial y}{\partial x}$ is the change in the depth per unit channel length.

Note that for most 1-dimensional river models, the lateral inflow or outflow per unit channel length is assumed to be negligible when compared to the main channel inflows or outflows. As a result, the q_L term in equation 8 is zeroed out, therefore producing the Saint Venant continuity equation (2.10): ρ_w

$$\frac{\partial y}{\partial t} + U\frac{\partial y}{\partial x} + y\frac{\partial U}{\partial y} = 0 \qquad (2.10)$$

To reproduce the 1-dimensional momentum equation, one must apply Newton's second law, which states that the sum of the forces acting on a control volume is equal to the rate of change of momentum. Considering the control volume as in Chaudhry (1993) the momentum equation (2.6) can be written: ρ_w

$$\sum F = \frac{d}{dt}\int_{x_1}^{x_2} U\rho A dx = U_2\rho A_2 U_2 - U_1\rho A_1 U_1 - V_X \rho q_L \left(X_2 - X_1\right) \qquad (2.11)$$

Where U_x is the velocity of the lateral inflow or outflow per unit channel length in the x-direction after manipulation, the momentum equation (10) simplifies to the following equation: ρ_w

$$\frac{\partial Q}{\partial t} + \frac{\partial (QU)}{\partial x} + gA\frac{\partial y}{\partial x} = V_X q_L + gA\left(S_o - S_f\right) \qquad (2.12)$$

Where S_o is the bed slope of the control volume, and S_f is the energy slope of the control volume. Assuming that the lateral inflow or outflow per unit channel length (q_L) is approximately zero, equation (2.12) produces the well-known dynamic equation:

$$\frac{\partial U}{\partial t} + g\frac{\partial}{\partial x}\left\{\frac{U^2}{2g} + y\right\} = g\left(S_O - S_f\right) \qquad (2.13)$$

The Saint Venant momentum equation (2.14) can be obtained from the dynamic equation (2.13) with further manipulation: ρ_w

$$\frac{1}{g}\frac{\partial U}{\partial t} + \frac{U}{g}\frac{\partial U}{\partial x} + \frac{\partial y}{\partial x} = S_o - S_f \qquad (2.14)$$

Hammond (2004) noted that equations (2.9) to (2.14) are used to describe 1-dimensional open channel flow neglecting lateral inflows or outflows. With given initial and boundary conditions, one can solve the equations simultaneously to obtain velocity (U) and depth (y) at any distance (x) along the estuary at any time (t), (Falconer, 1990).

2.7.3 2-Dimensional Equations of Motion

Two-dimensional estuary models provide users the capability of simulating hydrodynamics in the longitudinal direction as well as the lateral direction or vertical direction. Depth averaged 2-dimensional models (simulation in the longitudinal and lateral directions) are employed when changes in the vertical direction are negligible, such as a completely mixed water body. They are typically applied to rivers, lakes, reservoirs, and estuaries that are long, wide, and relatively shallow. Laterally averaged 2-dimensional models (simulation in the longitudinal and vertical directions) are used when changes in the lateral (perpendicular to the main direction of flow) direction are negligible, such as a narrow stratified reservoir.

They are normally applied to water bodies that are long, narrow, and fairly deep as concluded (Martin and McCutcheon, 1999). Additionally, 2-dimensional estuary models typically require more time and resources to setup, calibrate, and validate than 1-dimensional models. However, modelling in 2-dimensions provides the ability to unmask hydrodynamic changes in either the lateral or vertical direction that would not be available with a 1-dimensional model. Therefore, the results obtained from the hydrodynamic model may outweigh, in certain situations, the time, effort, and resources required for model setup and calibration, 2-dimensional, depth-averaged flow: For 2-dimensional, incompressible, depth averaged flow the continuity equation (2.15) (Montes, 1998) as:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{2.15}$$

Where:

$\frac{\partial u}{\partial x}$ The change in the longitudinal velocity component per unit is channel length, *and*

$\frac{\partial v}{\partial y}$ is the change in the lateral velocity component per unit channel width.

The equations of momentum (2.16 and 2.17) for the corresponding flow regime are provided by Rahman (1988):

Longitudinal (x) direction as;

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + X + \upsilon\nabla^2 u \qquad (2.16)$$

And for Lateral (y) direction as:

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{1}{\rho}\frac{\partial P}{\partial y} + Y + \upsilon\nabla^2 v \qquad (2.17)$$

Where:

u = velocity in the longitudinal direction,

v = velocity in the lateral direction,

X = body force per unit mass in longitudinal direction,

Y = body force per unit mass in lateral direction,

P = pressure

υ= kinematic viscosity, and

∇^2 = Laplace transform = $\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial x^2}$

2-Dimensional, laterally-averaged flow

For 2-dimensional, incompressible, laterally averaged flow the continuity equation (2.18) is:

$$\frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} = 0 \qquad (2.18)$$

Where:

∂ is the change in the vertical velocity component per unit channel depth. The equations of momentum (2.19 and 2.20) for the corresponding flow regime are (Rahman, 1988):

Longitudinal (x) direction*:*

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + w\frac{\partial u}{\partial z} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + X + \upsilon\nabla^2 u \qquad (2.19)$$

Vertical (z) direction;

$$\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + w\frac{\partial w}{\partial z} = -\frac{1}{\rho}\frac{\partial P}{\partial z} + Z + \upsilon\nabla^2 v \qquad (2.20)$$

where:

w = velocity in the vertical direction,

Z = body force per unit mass in vertical direction, and

∇^2 = Laplace transform = $\dfrac{\partial^2}{\partial x^2} + \dfrac{\partial^2}{\partial z^2}$

2.7.4 3-Dimensional Equations of Motion

Three-dimensional estuary models enable the engineer or hydrologist to simulate hydrodynamics in the longitudinal, lateral, and vertical directions. As a result, they can be applied to all flow situations (1-, 2-, and 3-dimensional) and generally produce fairly accurate results. Since there are no dimensional limitations, 3-dimensional models can be used to simulate hydrodynamics in water bodies of all types. For instance, they can be used on long, narrow, and shallow rivers or on wide and deep reservoirs with varying water density in the vertical direction. However, the time, effort, and resources required to set up, calibrate, and validate 3-dimensional models is quite extensive as compared to 1- or 2-dimensional river models. Therefore, the engineer or hydrologist must make a judgment before model selection and implementation. The use of a 3-dimensional hydrodynamic model when it is not warranted could entail a substantial misuse of time and funds.

For 3-dimensional, incompressible flow Rahman (1988) and Martin and McCutcheon (1999) provide the continuity equation (2.21):

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{2.21}$$

The equations of momentum for 3-dimensional flow are similar to those for 2-dimensional flow. The main difference between the two is that the 3-dimensional equations contain terms for all flow directions, which is shown in equations 2.22 through 2.24 (Rahman, 1988):

Longitudinal (x) direction:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=-\frac{1}{\rho}\frac{\partial P}{\partial x}+X+\upsilon\nabla^2 u \tag{2.22}$$

Lateral (y) direction:

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-\frac{1}{\rho}\frac{\partial P}{\partial y}+Y+\upsilon\nabla^2 v \tag{2.23}$$

Vertical (z) direction:

$$\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{1}{\rho}\frac{\partial P}{\partial z}+Z+\upsilon\nabla^2 w \tag{2.24}$$

where*:*

u = velocity in the longitudinal direction,

v = velocity in the lateral direction,

w = velocity in the vertical direction,

X = body force per unit mass in longitudinal direction,

Y = body force per unit mass in lateral direction,

Z = body force per unit mass in vertical direction,

P = pressure

υ= kinematic viscosity, and

∇^2 = Laplace transform = $\frac{\partial^2}{\partial x} + \frac{\partial^2}{\partial y} + \frac{\partial^2}{\partial z}$

It should be noted that the complete 3-dimensional equations of motion (2.22 through 2.24) could be simplified in order to represent 2-dimensional or 1-dimensional flow patterns. They are an extremely powerful set of equations that can be applied to a number of different water bodies. However, a great deal of computing power is required to simultaneously solve a set of partial differential equations. As a result, a number of different solution (approximations) techniques have been developed and employed with the aid of personal computers. With regards to open-channel flow, the two most robust numerical solution schemes are finite differences and finite elements, which are discussed in the next section. Simultaneously solve a set of partial differential equations. As a result, a number of different solution (approximations) techniques have been developed and employed with the aid of personal computers.

2.8 Numerical Solution Techniques

Hydrodynamic models are based upon the conservation of mass (or continuity since water is assumed to be incompressible) and conservation of momentum, which are expressed as a set of partial differential equations. (See equations 2.15 through 2.17 for the complete equations of motion for a 3-dimensional, incompressible flow). In order to simultaneously solve the equations of motion a number of solution techniques have been developed. The two most robust solution techniques in the area of open-channel flow are finite differences and finite elements. These solution methods are easily implemented through the use of personal computers, and they provide fairly accurate approximations to the exact solution of the complete equations of motion. In order to gain a better understanding of the finite difference and finite element solution methods, one must investigate the theory and equations behind each technique.

2.8.1 Finite Difference Solution Method

Finite difference methods were first used to analyze heat diffusion as well as solve stress analysis problems (Montes, 1998). Since the early 1900s, finite differences have been applied to a number of different situations including open-channel flow. The Saint Venant equations are a set of nonlinear partial differential equations describing the conservation of mass and momentum for 1-dimensional, open-channel flow assuming lateral inflow is negligible. Since the Saint Venant equations are expressed as nonlinear partial differentials, a closed-form solution is only available for very simple cases. As a result, an approximate solution to the Saint Venant equations can be obtained using finite differences (Chaudhry, 1993). The basic principle behind all finite difference solution methods is the substitution of finite differences for partial derivatives. With regards to open-channel flow and the Saint Venant equations, the partial derivatives for velocity (V) and depth (y) would be replaced by discrete differences to be evaluated at fixed intervals for distance (Δx) and time (□ t) (Montes, 1998).

Consider the finite difference grid depicted by Chaudhry (1993). The x-axis represents the variable distance (x) and the y-axis represents the variable time (t). Point i denotes the $i\ \Delta x$ grid point, and point (i+1) designates the (i+1) Δx grid point. The same applies for the y-axis. Point k denotes the k Δt grid point, and point (k+1) designates the (k+1) Δt grid point. In addition, point k is specified as the known time level and point (k+1) is the unknown time level. Once the finite difference grid has been generated, calculations are performed to determine the dependent variables at each grid point. Therefore, the dependent variable flow depth (y) at point (i, k) is designated as k i y. Typical finite difference grids have straight edges and square corners. In addition, most grids utilize uniform x- and y-axis spacing. Since most finite difference grids make use of parallel lines, error is introduced when simulating natural boundaries. As a result, grid spacing may have to be reduced near places of rapid variability to accurately and effectively represent the system.

There are two distinctly different finite difference solution techniques, the explicit and implicit finite difference solution method. Each of these general solution techniques has three different solution approximations, the forward, backward, and central finite difference approximation. Chaudhry (1993) noted that the central finite-difference approximation is the most accurate.

2.8.1.1 Explicit Finite Differences

Explicit finite difference schemes utilize discrete differences for the dependent variables in terms of the known time level (k) for the partial derivatives (Chaudhry, 1993). The partial derivative $\frac{\partial f}{\partial x}$ at x or point (i, k) can be estimated utilizing the three different finite difference approximations (equations 2.25 through 2.27):

Forward:

$$\frac{\partial f}{\partial x} = \frac{f_{i+1}^{k} - f_{i}^{k}}{\Delta x} \qquad (2.25)$$

Backward:

$$\frac{\partial f}{\partial x} = \frac{f_{i}^{k} - f_{i-1}^{k}}{\Delta x} \qquad (2.26)$$

Central:

$$\frac{\partial f}{\partial x} = \frac{f_{i+1}^{k} - f_{i-1}^{k}}{2\Delta x} \qquad (2.27)$$

It should be noted that these equations could also be modified and applied to the partial derivative of the function (f) with respect to time (t), $\frac{\partial f}{\partial t}$. When the finite difference approximations for $\frac{\partial f}{\partial x}$ and $\frac{\partial f}{\partial t}$ are solved simultaneously, they produce a solution for the function (f) for each Δx and Δt combination located on the finite difference grid. There are a number of different explicit finite difference solution schemes. They include the Diffusive scheme, McCormack scheme, Lambda scheme, and the Gabutti scheme. (Chaudhry, 1993) summarizes the formulations, boundary conditions, stability, and solution procedures for each method.

2.8.1.2 Implicit Finite Differences

Implicit finite difference schemes utilize discrete differences for the dependent variables in terms of the unknown time level (k+1) for the partial derivatives (Chaudhry, 1993). The partial derivative $\frac{\partial f}{\partial x}$ at point (i, k) can be estimated utilizing the three different finite difference approximations (equations 2.28 through 2.30):

Forward:

$$\frac{\partial f}{\partial x} = \frac{f_{i+1}^{k+1} - f_i^{k+1}}{\Delta x} \qquad (2.28)$$

Backward:

$$\frac{\partial f}{\partial x} = \frac{f_i^{k+1} - f_{i-1}^{k+1}}{\Delta x} \qquad (2.29)$$

Central:

$$\frac{\partial f}{\partial x} = \frac{f_{i+1}^{k+1} - f_{i-1}^{k+1}}{2\Delta x} \qquad (2.30)$$

There are a number of varying solution schemes for implicit finite differences. They include the Preissmann scheme, Beam and Warming scheme, and Vasiliev scheme. The formulations, boundary conditions, stability, and solution procedures for each solution method are presented in Chaudhry (1993).

It should be noted that equations (2.25) through (2.30) present the approximation of partial differential equations utilizing two finite difference grid points. Solution techniques have been developed that utilize three or more grid points for performing approximations (Falconer, 1990).

2.8.2 Finite Element Solution Method

Finite elements provide a second solution technique to the same partial differential equations presented earlier in this chapter. However, the finite element solution method is a newer technique, which has not been used as extensively as finite differences.

There are a number of advantages for using finite elements in 2- or 3-dimensional open-channel flow simulation. As noted by Chaudhry (1993) and Jiang (1998), finite elements provide model users with the ability to perform simulations on irregular geometries.

Therefore, they can be applied to rivers and estuaries with complex natural boundaries without the additional grid refinements required by finite difference methods. In addition, finite elements can be organized anywhere in the estuary domain. Therefore, grid refinements with finite elements are typically easier to perform than those performed when using finite differences (Jiang, 1998). As a result, finite elements may prove to be more accurate and efficient in the solution of 2- and 3-dimensional open-channel flow problems with irregular boundaries.

The 1-, 2-, and 3-dimensional equations of motion for open-channel flow are nonlinear partial differential equations. As a result, some of the most complicated finite element methods must be employed to reach a solution. The main steps used in finite element analysis are (Kaliakin, 2002):

1. Domain discretization. The model domain (Δ) is arranged into a grid of elements and nodes. A typical rectangular finite element mesh is shown as indicated by Wang and Anderson (1982). Element numbers are circled, and node numbers are not circled.

2. Equations for each element are determined and are assembled into a series of global equations that apply to the entire domain. This assembly process is based upon the fundamental concept of continuity. Element equations typically have the following form (30):

$$K^{(e)}\phi_n^{(e)} = f^{(e)} \tag{2.31}$$

where:

$K^{(e)}$ is the element coefficient matrix,

$\phi_n^{(e)}$ is nodal unknowns vector associated with the element, and

$f^{(e)}$ is the nodal forces vector associated with the element.

The element equation assembly process results in a series of global equations typically in the following form (31):

$$K\phi_n = f \tag{2.32}$$

where:

K is the global coefficient matrix,

ϕ_n is the total nodal unknowns vector associated with the model, and

f is the total nodal forces vector associated with the model.

3. Nodal specifications (boundary conditions) are specified along the entire model boundary (Δ), along element boundary nodes, or at nodes contained within any element. When known values of the principal dependent variables are specified along the model boundary they are referred to as essential

(Dirichlet) specifications. Natural (Neumann) specifications refer to known gradient values of the principal dependent variables specified along the model boundary.

4. Due to their nonlinear nature, the global equations are solved utilizing an iterative process such as the Newton-Raphson method. The Newton-Raphson solution scheme is discussed in detail in chapter 6 of Chaudhry (1993). In addition, completeness and compatibility requirements must be satisfied before the finite element method will converge upon the correction solution. Due to its ability to handle complex irregular boundaries, which is typically the case of rivers and estuaries, the finite element solution method may prove to be a more accurate representation of the model network over finite differences. However, due to the nonlinear nature of the 1-, 2-, and 3-dimensional equations of motion, the finite element method is harder to implement than the finite difference solution method. As a result, the Capability of finite elements to represent irregular water-body geometry has not yet been fully exploited.

2.9 Conceptual Framework of Water quality model

The water quality model used in this study was built based on three-dimensional conventional water quality analysis simulation program (called WASP5) developed originally by Ambrose *et al* (1988). It constitutes a complex of four interacting systems: dissolved oxygen, nitrogen cycle, phosphorus cycle, and phytoplankton dynamics. Eight water quality components are included: dissolved oxygen (DO), phytoplankton as carbon (PHYT), carbonaceous biochemical oxygen demand (CBOD), ammonium nitrogen (NH_4), nitrate and nitrite nitrogen (NO_3), ortho-phosphorus or inorganic phosphorus (OPO_4), organic nitrogen (ON), and organic phosphorus (OP). The conceptual framework for the water quality model is presented in Fig. 2.2.

A mathematical formulation of the conservation of mass can be written as:

$$\frac{\partial C}{\partial t}+\frac{\partial(uC)}{\partial x}+\frac{\partial(vC)}{\partial y}+\frac{\partial(wC)}{\partial z}=\frac{\partial}{\partial x}\left(A_h\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_h\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_h\frac{\partial C}{\partial z}\right)+S+W_0\quad-A_1 \qquad (2.33)$$

Where C is the concentration of the water quality components; u, v, and w are the water velocity components corresponding to the conventional Cartesian coordinate system (x, y, z); A_h and K_h are the coefficients of the horizontal viscosity and vertical eddy diffusion, respectively; S is the function that represents the internal source or sink of the water quality component (see Appendix A); and W_0 is the external loading from point (river discharge) and non-point sources (ground water input and atmospheric deposition) of the water quality components.

Dissolved oxygen is one of the most important water quality indicators. One source for DO in the water column is photosynthesis carbon fixation. It is proportional to phytoplankton density and growth rate. Wind- or flow-induced reaeration can be either the source or sink for DO. If DO concentration in the water column is under-saturation, reaeration will act as a source for DO. Otherwise, reaeration is a sink for DO. Dissolved oxygen in the water column is diminished by the processes associated with Sediment Oxygen Demand (SOD), phytoplankton respiration, nitrification, and oxidation of CBOD (Fig2.2). The growth rate of phytoplankton is the function of solar radiation, water temperature, nutrient availability, and euphotic depth. The effect of nutrients on growth rate is assumed to follow the Michaelis–Menten function, which indicated that phytoplankton growth rate is linearly proportional to nutrient at a low level of the concentration but is independent of nutrient at a high level of the concentration. The light-limiting factor used here was developed by Zheng *et al* (2004).

It shows that growth rate only occurs in the euphotic zone and increases as a function of light intensity until an optimum intensity is reached. The productivity of phytoplankton is affected by endogenous respiration, effect of viral lysis, grazing by zooplankton, and settling to the bottom as sediment layer. Zooplankton grazing may play an important role in phytoplankton productivity in the estuarine system.

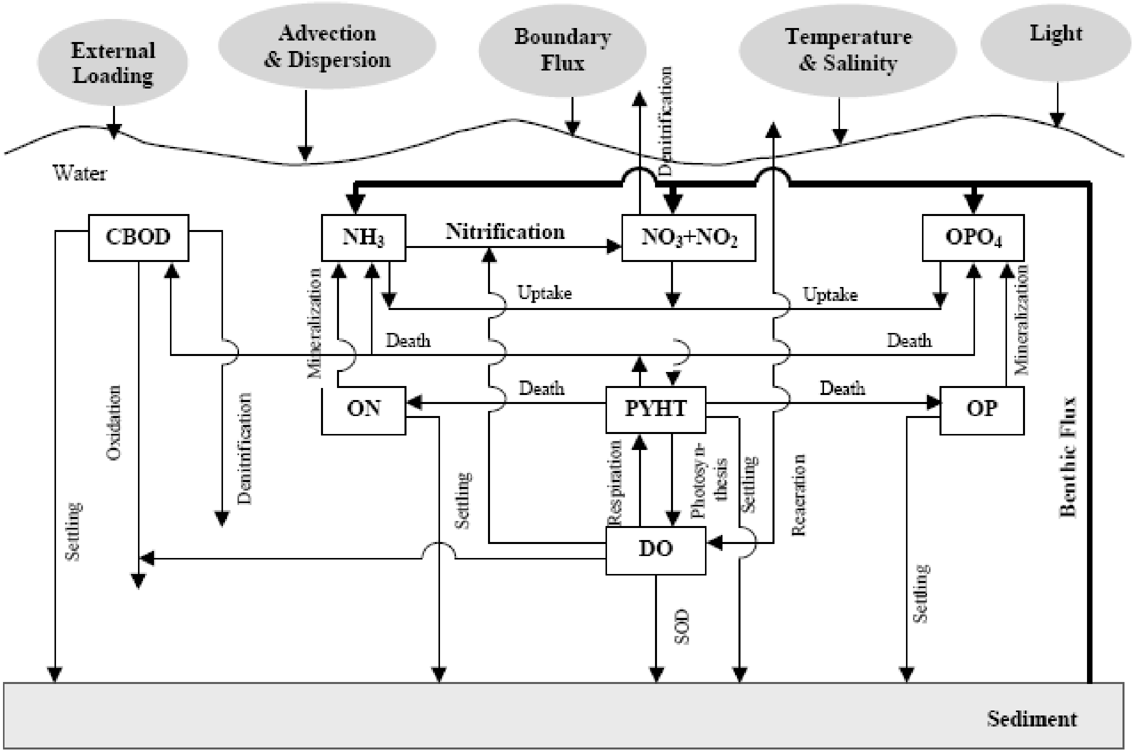


Fig.2.2: Schematic of water quality model used for a typical River Estuary

Detailed specifications of zooplankton predation are required for predictive modelling of planktonic biomass and their interaction. Instead of being an attempt to model the complex and dynamic processes of zooplankton grazing and growth, a constant grazing rate is assumed in the model. The primary internal source of CBOD comes from the detrital phytoplankton carbon as a result of death of primary producers, such as phytoplankton and benthic algae, and zooplankton predation. The internal sinks for CBOD include carbonaceous oxidation and settling of particulate carbonaceous material to bottom sediment. When the DO concentration in the water body is low, the denitrification reaction also provides a sink for CBOD by the reaction in Equation (2.34):

$$5CH_2O + 4NO_3^- + 4H^+ \rightarrow 5CO_2 + 2N_2 + 7H_2O \qquad (2.34)$$

In the nitrogen cycle, ammonium nitrogen, nitrate and nitrite (hereafter called nitrate) nitrogen, and organic nitrogen are included. During phytoplankton growth, they directly uptake inorganic ammonium and nitrate nitrogen, while when phytoplankton respire or die due to zooplankton predation, they return a certain fraction to the organic nitrogen pool and the other to inorganic ammonium nitrogen pool. In the presence of DO, the ammonium nitrogen can be converted to nitrate nitrogen (nitrification). This process is affected by pH, flow condition, salinity, and turbidity under low DO condition; nitrate nitrogen can be converted to dinitrogen (called denitrification). In the organic nitrogen pool, its particulate fraction will settle and deposit on the bottom sediment when the water body is calm. Also the organic nitrogen can be converted to ammonium nitrogen by bacterial decomposition or mineralization before it can be taken up by phytoplankton.

A study on the Satilla River Estuary (Pomeroy and Wiegert, 1981) indicates that there is a large amount of particulate organic material inputs from intertidal salt marsh into the River. The majority of these organic materials is deposited and buried on the bottom sediment layer. Excess particulate organic nitrogen in the sediment layer is then mineralized to inorganic ammonium nitrogen by heterotrophic bacterial activity. Further, through nitrification, some ammonium nitrogen in the sediment layer can be converted to nitrate nitrogen. As a result, there might be a large ammonium and nitrate nitrogen pool within the bottom sediment. When bottom current is strong enough to erode and re-suspend sediment, it will transport nutrients from the sediment layer into upper water column by vertical mixing. In addition, when there is a nutrient concentration gradient between the water column and sediment layer, there will be nutrient flux between them by diffusion. These imply that nutrient flux from the bottom sediment layer might be a potentially important nutrient source in River Estuary. The importance of benthic nutrient flux in lakes has been reported (James *et al*, 1997), bays: Giblin *et al*, 1997, and estuary by Cowan and Boynton, 1996; Kemp *et al*, 1997; Wang *et al*, 1999; Zheng *et al*, 2004).

In the phosphorus cycle, ortho-phosphorus and organic phosphorus are included. Two internal sources of inorganic phosphorus are (1) recycled directly from phytoplankton respiration and death, and (2) converted from organic phosphorus via mineralization or bacterial decomposition. The ortho-phosphorus is consumed by phytoplankton uptake. The main source of organic phosphorus is recycled from phytoplankton respiration and death. Under calm condition, particulate organic phosphorus will sink and deposit on the bottom sediment layer. Like the nitrogen cycle, ortho-phosphorus flux from the bottom sediment layer might be an important source in the system.

The water quality equations are solved using the same finite difference method used in ECOM-si. To avoid negative concentrations and artificial numerical diffusion, the advection terms are calculated by using the MPDATA scheme. Horizontal and vertical diffusion terms are solved by explicit and implicit schemes, respectively (Zheng *et al,* 2004).

Review of Available, Applicable Hydrodynamic and Water Quality Models

The following hydrodynamic and water quality models were taken into account and reviewed for this research. Hydrodynamic and water-quality model summary matrices were developed and are shown in Tables C.1 in Appendix C. Table C.1 were developed in order to identify previous USEPA modelling experience for each water quality and hydrodynamic model being reviewed.

Below is a brief discussion of model formulation and implementation as well as model availability.

2.9.1 Water Quality Analysis Simulation Program

Water Quality Analysis Simulation Programme (WASP) is an uncoupled, unsteady, continuous simulation, 3-dimensional water quality model for simulating contaminant fate and transport in river systems including tidal estuaries (Wool *et al*, 2003). The major components of WASP include EUTRO (sub-model for simulating conventional water quality constituents), TOXI (sub-model for simulating toxicants), HEAT (sub-model for simulating heat transport), and hydrodynamic model linkage capabilities. WASP uses finite differences to solve mass balance equations, contaminant kinetics equations, and transport equations at each simulation time step. Furthermore, the model is capable of automatic time stepping in order to ensure model stability. Data requirements for WASP can be quite extensive especially for highly complicated systems that include contaminant transport within river or estuary beds. However, the data requirements for simulating bacteria concentrations are limited, therefore, greatly simplifying the implementation of the WASP modelling system to this research. WASP has been successfully used in numerous USEPA water quality studies.

WASP6.1 is the most current version of the WASP modelling system. It is distributed and supported by USEPA's Watershed and Water Quality Modelling Technical Support Centre located in Athens, Georgia. Since WASP6.1 is an uncoupled water quality model, a hydrodynamic model is needed to provide the estuary water volumes and velocities required for simulation. WASP6.1 is currently configured so that it can be linked to three hydrodynamic models. They include the Dynamic Estuary Model (DYNHYD5), River Hydrodynamics Model (RIVMOD-H), and Environmental Fluid Dynamics Code (EFDC).

2.9.2 Hydrodynamic and Water Quality Model Selection

After carefully reviewing all of the compiled data, the research team recommends that WASP6.1 coupled with DYHHYD5 be used to model the fate and transport of faecal Coliforms within the lower Appomattox River. The team's recommendation is based on the following arguments:

- WASP6.1 coupled with DYNHYD5 has sufficient hydrodynamic and water quality capability to model the fate and transport of faecal Coliforms within tidal estuaries.
- WASP6.1 can be linked to Hydrologic Simulation Program – Fortran (HSPF) for watershed loading inputs.
- WASP6.1 and DYHHYD5 were both developed by USEPA and have been used extensively in order to perform USEPA water quality studies for tidal estuaries.

- WASP6.1 and DYNHYD5 along with extensive documentation are readily available from the USEPA website (www.epa.gov). Therefore, model availability and user support is not a critical issue.
- WASP6.1 and DYNHYD5 can be used for long-term simulation over many tidal cycles. Also, WASP6.1 can automatic time step in order to ensure model stability.

2.9.3 Case Studies Utilizing DYNHYD and WASP Modelling Software

The original WASP modelling software released by Di Toro et al. (1983) consisted of 2 previously developed sub-models. They are TOXI, which is still used to simulate toxic substances and EUTRO, which is still used to simulate eutrophication. Thomann *et al* (1976) utilized EUTRO to simulate phytoplankton in Lake Ontario.

Di Toro and Connolly (1980) simulated the water quality of Lake Erie, and Di Toro and Matystik (1980) estimated the water quality of Lake Huron. In addition, Thomann and Fitzpatrick (1982) simulated the eutrophication processes in the Potomac River estuary. Also, Ambrose (1987) used the WASP modelling software to simulate volatile organic compounds within the Delaware River estuary. These modelling studies effectively document the historical use of the WASP modelling software. In addition, there are a number of current case studies that have been performed utilizing the WASP modelling software coupled with DYNHYD.

2.9.4 QUAL2E (The Enhanced Stream Water Quality Model)

This is developed by the United States Environmental Protection Agency. The model is capable of modelling temperature in streams and rivers throughout a watershed (i.e. basin model). It can also predict water quality constituents other than water temperature.

The QUAL2E Model can predict 15 water quality constituents including Dissolve Oxygen (DO) Nitrogen, (organic, nitrite and nitrate) Phosphorous (organic and dissolved) algae as Chlorophyll a an arbitrary non- conservative, carbonaceous biochemical Oxygen Demand (CBOD) (ULTIMATE OR 5-DAY), up to three conservative minerals and Coliform bacteria.

The QUAL2E model does not incorporate the influence of shade on water temperature thus QUAL2E is not helpful in assisting shade management question and may be better at modelling large wider waters which have less shade influence than small mountainous streams The QUAL2E is steady-state models, thus assuming flow is constant over a 24 hour period due to their input and output being based on daily averages.

Steady-state model is used for simulating well-mixed rivers and streams, commonly used for assessing the impact of changes in point-source discharges on water quality. This model is, especially, suited for analyzing the effects of nutrients on algae concentration and dissolved oxygen and this is widely applied in the United States and elsewhere.

2.9.4.1 The Scope and Components of QUAL2E

The model is intended as a water quality planning tool for developing total maximum daily loads (TMDLs) and can also be used in conjunction with field sampling for identifying the magnitude and quality characteristics of nonpoint sources. QUAL2E has been explicitly developed for steady flow and steady waste load conditions and is therefore a "steady state model" although temperature and algae functions can vary on a diurnal basis. Although the core of the model has not changed since 1987 (Brown and Barnwell, 1987), there have been some modifications on the interfaces and other associated tools to assist the users. The conceptual representation of a stream used in the QUAL2E formulation is a stream reach that has been divided into a number of sub-reaches or computational elements equivalent to finite difference elements. For each computational element, a hydrologic balance in terms of flow, a heat balance in terms of temperature, and a materials balance in terms of concentration is written. Both advective and dispersive transports are considered in the materials balance. The model uses a finite-difference solution of the advective-dispersive mass transport and reaction equations and it specifically uses a special steady-state implementation of an implicit backward difference numerical scheme which gives the model an unconditional stability (Walton and Webb, 1994).

BOD—Ultimate carbonaceous biochemical oxygen demand (BOD) is modelled as a first-order degradation process in QUAL2E, which also takes into account removal by settling and does not affect the oxygen balance.

DO—The process discussed above represents the primary internal sink of dissolved oxygen in the QUAL2E computer programme. Other sinks include sediment oxygen demand (SOD), modelled as a zero order reaction, respiration by algae, and nitrification which includes the oxidation of both ammonia and nitrite. The major source of dissolved oxygen, in addition to that supplied from algal photosynthesis, is atmospheric reaeration. Nine methods are available to calculate the reaeration coefficient in case of free water surface. Reaeration under ice cover and above dams is also considered. All sources and sinks (but SOD) are modelled as first order reactions.

The nitrogen cycle is composed of four compartments: organic nitrogen, ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen. The nitrogen balance considers mineralization and settling of the organic nitrogen, nitrification which is divided into the oxidation of ammonia in nitrite and then the oxidation of nitrite into nitrate, uptake by the algae, regeneration from the sediment and from algal respiration..

The phosphorus cycle is similar to, but simpler than the nitrogen cycle, having only two compartments. The phosphorus balance considers the settling and the mineralization of the organic phosphorus into inorganic phosphorus, regeneration from the sediment, uptake and respiration from the algae.

Algae—QUAL2E uses chlorophyll a as the indicator of planktonic algae biomass. The model assumes a first order reaction to describe the accumulation of algae biomass. The accumulation of biomass is calculated as a balance between growth, respiration and settling of the algae. Maximum growth rate is modelled as being light and nutrient limited. There are three mathematical options to estimate nitrogen and phosphorus limitations. For nitrogen uptake, the model favours ammonia uptake by algae over nitrate uptake by an algal preference factor. Three light functions are available to calculate the light limitation factor. They express light limitation due to: (1) the diurnal and climatic changes of radiation, (2) the light extinction in the water column due to turbidity and/or self-shading.

Temperature—all reactions between all state variables expressed above are temperature dependent and QUAL2E calculates a correction factor for all coefficients in the source/sink terms using a Streeter-Phelps type formulation. Water temperature is automatically calculated by the model.

Coliforms are used as an indicator of pathogen contamination in surface waters. A simple first order decay function is used, which only take into account coliform die-off. One non-conservative constituent concentration can be modelled with QUAL2E. Three reactions are considered: first-order decay, a first order settling and zero order regeneration from the sediment (Birgrand, 2003).

2.10 QUAL2K Input File Generation

2.10.1 Dissolved Oxygen

Dissolved Oxygen concentrations refer to the amount of oxygen dissolved in water. Oxygen is a sparingly soluble gas and its concentration in water is usually measured in parts per million or milligrams per litre. The capacity of water to hold oxygen in solution is inversely proportional to the water temperature. Increased water temperature lowers the concentration of dissolved oxygen at saturation. The amount of oxygen that can dissolve in water increases with increasing atmospheric pressure (USEPA, 1991b). Dissolved oxygen is critical for the biological community in a stream. Plant respiration and decomposition of dead vegetation consume dissolved oxygen in the water. A lack of dissolved oxygen creates stress for all aquatic organisms and can cause fish kills. A fish farmer may have seen fish gulping for air at the water surface during warm weather indicating a lack of dissolved oxygen.

Increases in primary productivity can increase the number of invertebrates and fish in rivers and streams. However, excessive plant growth and decomposition can limit aquatic population by decreasing dissolved oxygen concentration. Nocturnal respiration can cause oxygen depletion in waters with high primary productivity and low aeration rates. Reduced base flow, either naturally occurring (drought) or through anthropogenic actions will also result in higher temperatures, slower water movement and therefore decreased dissolved oxygen levels.

The following are examples of factors that can contribute to low dissolved oxygen level:

1. Sources of organic matters that can contribute to increased levels of BOD, such as:

    - Point source nutrient contributions can come from wastewater ineffectively treated
    - Non-point sources of nutrients can be related to agricultural activities such as over-application of fertilizer on fields or animal waste runoff, including confined animal operations and grazing activities
    - Storm water runoff in urban areas can include fertilizer from lawns and pet waste
    - Septic tanks, cesspool or any other mechanism for removal of liquid waste from human habitation are large contributors to surface water nutrients when ground water is shallow or systems have been improperly installed
    - Recreational areas such as heavily used fishing areas where the riparian vegetation has been removed or reduced can contribute nutrients if waste materials are transported by runoff into the stream. When vegetated riparian areas are removed, the filtering mechanism for the runoff is also removed.

2. Any increases in water temperature leading to decreases in dissolved oxygen levels including:

- Any losses of shade provided by riparian areas that are removed or reduced
- Removal of water through diversion can reduce base stream flow and may possibly contribute high nutrient levels and temperature increases.

The Atuwara watershed covered by this research is from the Iju Water Corporation along Idiroko Road to its headwater at Owode along Lagos Abeokuta Expressway is approximately 10.8 kilometres long. It has 3 major tributaries that form confluences at Kilometre 10.5 at Mosafejo, Kilometre 10.7 at Balogun and kilometres 6.35 at Afara meje respectively from the upstream. During the 2008/2009 surface water quality monitoring effort in the Atuwara River watershed, dissolved oxygen (DO) data showed several violations of the NESREA/FEPA water quality standard. *See Tables 4.7, 4.11, 4.15 and 4.19*. Data were collected on 14/10/ 2008; 17/02/ 2009; 18/03/ 2009 and May 11/05/ 2009. Grab samples for statistical data were computed with the summary as shown in Tables 4.8, 4.12, 4.16 and 4.20. All data were analyzed at least twice each to obtain data accuracy .Replication of the analyzes were made in the dry and wet season and the average of the results were determined for the complete data set. (Adewumi and Ogbiye 2009).

2.10.2 Model Framework and Scientific Details

The steady state QUAL2K model was selected for the following reasons:

- The critical low flow condition can be reasonably assumed to be steady state
- The model conforms to the standard practices for developing waste load allocations
- It can be developed with limited data set
- It can handle branching tributaries
- It has an established history in modelling dissolved oxygen for total maximum daily loads.

The model software assumes a flow balance and steady-state non – uniform flow, daily average model that uses a modified Streeter-Phelps DO equation to solve the advection. QUAL2K also assumes that the channel has a trapezoidal cross- section.

An empirical function is applied to obtain the dispersion coefficient. The governing equation is solved with an implicit scheme in time and backward difference in space. The Streeter-Phelps equation ties together two mechanisms governing DO in a stream decomposition of organic material and oxygen reaeration. The QUAL2K model simulates ultimate carbonaceous biochemical oxygen demand CBOD) decay, nitrification and reaeration. Although the model can simulate algal photosynthesis and respiration, they were omitted for this application because data on and knowledge of algal growth in Atuwara watershed were not available and were not sampled.

Reaction rates for the in-stream processes are input by the author and corrected for temperature by the model software. The software output includes water quality conditions in each computational element for DO, CBODu and Nitrate Nitrogen (NO_3-N) concentrations. Refer to the user’s manual document for a more detailed discussion of simulated processes and model parameters, .structural description of model internal linkages, such as one- dimensional model, internally coupled watershed and one dimensional stream models. (Brown and Barnwell, 1987; Chapra, 1997).

2.10.2.1 Model Inputs

There are several user interface programmes available to assist in setting up input data set, Windows-based. The Windows interface user's documentation provides some guidelines for selecting the inputs (USEPA, 1995).

QUAL2E requires some degree of modelling sophistication and expertise on the part of a user. The user must supply more than 100 individual inputs, some of which require considerable judgment to estimate. The input data can be grouped into three categories: a stream/river system, global variables and forcing functions. The first group, input data for the stream/river system, describes the stream system into a format the model can read. The general variable group describes the general simulation variables such as units, simulation type, water quality constituents and some physical characteristics of the basin. The forcing functions are user-specified inputs that drive the system being modelled. The input data values depend on the type of simulation and the number of state variables used. Table 1 below lists all the input parameters and information needed to simulate all 15 state variables for steady state and dynamic conditions (USEPA, 1995).

2.10.2.2 Model Outputs

QUAL2E produces three types of tables- hydraulics, reaction coefficient, and water quality- in the output file. The outputs can be easily imported into other application such as spreadsheets for analysis. The Windows based version (USEPA, 1995) includes some graphic analysis of the model results. State variables can be plotted at defined distances along the reaches. In addition, the user can input field observations for dissolved oxygen with minimum, average and maximum values. The model uses those values to plot the observed data versus the estimated ones. In case of dynamic simulations, the model produces temperature and algae values on the defined time step (Birgrand, 2003).

2.10.3 Transport Processes

As seen from equation (2.33), the transport of dissolved substances in rivers is governed by advection and turbulent diffusion. The initial mixing in the “near field” zone may depend on momentum transport; this is a phenomenon that is important if the discharge flow is large (e.g. thermal pollution). Two mixing lengths, characterize the transport process. These are the distances of “complete” mixing along the depth and over the entire cross-section, respectively. For shallow rivers the depth is short and thus a depth integrated 2D form of Equation. (2.33) can be applied. As a result of the integration, the impact of shear or spatial non-uniformity in the advective velocity appear in a term assumed to be of Fickian type, and the “lumped” parameters of diffusion thus obtained are called dispersion coefficients.

Their values strongly depend on slope, morphology, roughness etc. and can be taken from empirical formulas or from in - situ tracer measurements. For water quality studies of rivers which are quite long and dominated by longitudinal and temporal changes, further integration is possible along the width which leads to the 1D advection-dispersion equation (Rauch, *et al* 1998). Alternatively the dispersion effect can be approximately described by dividing the river cross-section into an advective and a stagnant zone, (. Reichert and Wanner, 1991) .In a vector form corresponding to Equation (2.35), this 1D equation can be written as:

$$\frac{\partial(AC)}{\partial t}+\frac{\partial(QC)}{\partial x}=\frac{\partial}{\partial x}\left(AD_L\frac{\partial C}{\partial x}\right)+AR(C,P) \qquad (2.35)$$

where A = cross-sectional area; Q = stream flow rate; DL = longitudinal dispersion coefficient (Fischer *et al*., 1979); C = vector of cross-section averaged concentrations of various constituents; R(C, P) = vector of rates of change of cross-section averaged concentrations due to conversion processes which are now a function of model parameters, P expressed in terms of C. It is stressed that due to integration, the R functions and P parameters differ from r and p, respectively. Initial and boundary conditions are also needed to solve Eqn. (2.35) The water quality model described by the function R can be developed step-wise and independently of the description of hydraulics.

For steady problems, the dispersion term can be often neglected and the resulting ordinary differential equation (ODE) can be solved by introducing the travel time as an independent variable. Often another simplification is made:

Equation (2.36) is integrated for subsequent river stretches within which complete mixing is assumed. This procedure leads to a sequence of interlinked reactors (and the application of the “reactor principle”) for which the mass balance is expressed by the vector equation

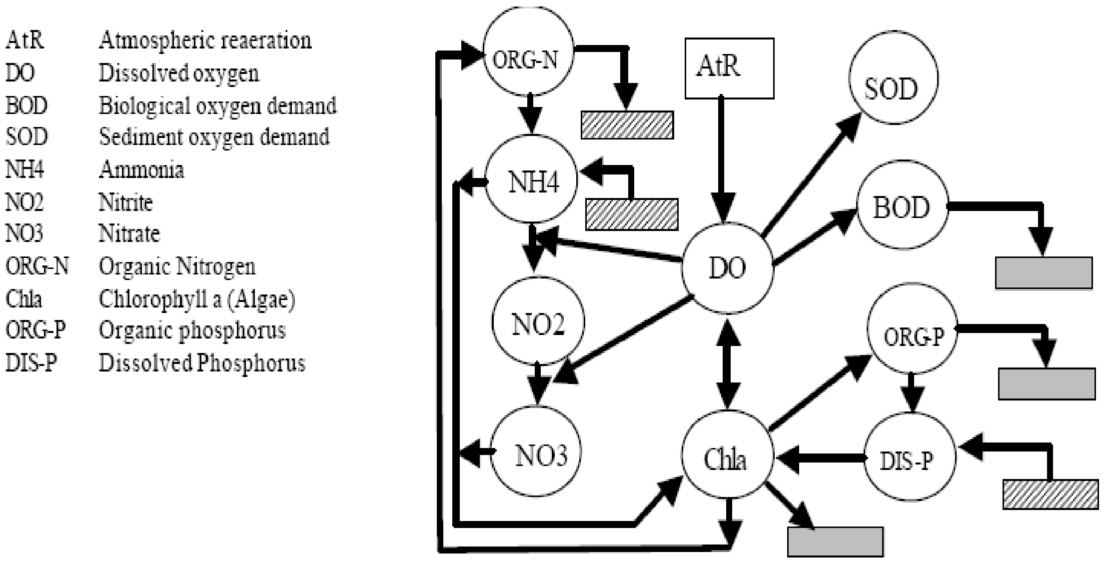
$$\frac{\partial(VC^*)}{\partial t}=Q_iC_i-QC^*+VR^*(C^*,P^*) \qquad (2.36)$$

Where C* = concentration vector; C_i = inflow concentration; Q_i = inflow; Q = outflow; V = reactor or tank volume and R* (C*, P*) = conversion rate vector (stars denote that the interpretation of C, R, and P is again different than in the 1D case). If the number of reactors is m, the n x m ordinary differential equations should be solved. Selection of the size of tanks should be done such that the introduced implicit or numerical dispersion is roughly equal to that of the actual system. Such box models are frequently used; (Rauch and Harremoes, 1996), particularly due to the easier formulation of methods of calibration, validation, etc. in comparison to partial differential equation (PDE) model structures.

2.10.4 Conversion Processes

As noted, conversion processes describe changes in the constituent concentrations that are due to biological, chemical, biochemical, and physical processes. The historical development of O, N, and P models shows step-by step extensions and increasing complexity as follows: (i) the starting point was the pioneer Streeter-Phelps model describing the increase and following decrease of the oxygen deficit downstream of a source of organic material, (ii) it was later extended to include nitrogen processes (EPA’s detailed model with nitrification was called QUAL1 and (iii) finally phosphorus cycling and algae were added in creating the QUAL2 model family. For today, several versions of the state-of-the-art model QUAL2 are available (which also include refinements and extensions) depending on the purpose of the use either for research, regulation etc. (Rauch, *et al* 1998).

Fig.2.3 Schematic description of the water quality model QUAL2E



CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1 The Research Design

The study was conducted to elicit necessary information from the population sample in the selected industries in Ado-Odo/Otta industrial zone of Ogun State.

The population sample frame for this research consists of 45 identified industries in Ado-Odo/Otta Industrial zone, with a sample size of at least 100 respondents from selected industries as will be classified appropriately from the various industrial zones in Ado-Odo/Otta Local Government Area of Ogun State, Nigeria.

The research methodology employed in this study is in three parts:

- Estimate on field study to cover two industrial zones in Ado-Odo/Otta Local Government Area of Ogun State.
- A set of questionnaires was prepared and administered on respondents from selected industries to elicit information from stakeholders in each industrial set up. The set of questionnaires were used to characterize the installed capacity, output, and treatment facility capabilities and efficiencies of the respective industrial pollutants of concern.

3.1.1 Design Brief Formulation

The design brief formulations includes but were not limited to the followings:

- Survey of industries, their products and effluents
- Survey of other contributors
- Survey of other users of the receiving stream
- Sampling of industries whose purposive effluents will be characterized

The field study is the primary source of data collection for this research hence it requires an extensive and articulate fieldwork necessary to provide first hand information. The field study included:

- The appropriate maps, topography details, photographs, flowcharts, statistical details, etc. where needed
- Inventory of all of the existing industries discharging effluent and the distribution path within Ado-Odo/Otta industrial zone.
- Location, identification and quantification of industries discharging effluents among different sectoral groups within Ado-Odo/Otta Industrial Zone
- Characterizing the effluents especially the physico-chemical, biological and microbial properties of the industrial effluents in Ado-Odo/Otta industrial sector.
- Appraising and analyzing treatment options and strategies for the industrial effluents discharge into Atuwara River
- Modelling of point source discharge into Atuara watercourse in Ado-Odo/Otta environment.
- Several efforts have been made on data collection on Industries by Private Consultants, which had been relied on in the zone by the State Ministry of Environment and Physical Planning (MEPP). This research examined the World Environmental Systems (WES) report. The total numbers of industries covered by WES report were in excess of 2000. However many of these industries were not effluent producers.
- The directory of the Manufacturers Association of Nigeria (MAN) was examined to extract the effluent producing industries studied during the course of this research. The following Ten Sectors were examined (Table 3.1): Vegetable Oils; Food Processing and Beverages; Breweries; Industrial Chemicals and Pharmaceuticals; Petrochemicals, Meat Processing and Abattoir, Domestic and Industrial Plastic Rubber and Foam; Basic Metal, Iron and Steel and Fabricated Metal Products.

3.1.2 Survey Approach and Survey Instrument

The principal survey method used was administration of a comprehensive questionnaire (Appendix B), which was designed to elicit information as follows:

- Name of the industry
- Address/location of the industry
- Raw materials used
- Products and by products
- Daily water consumption
- Source of water
- Amount of water discharged

Table 3.1: Location of the 10 Sector Industries

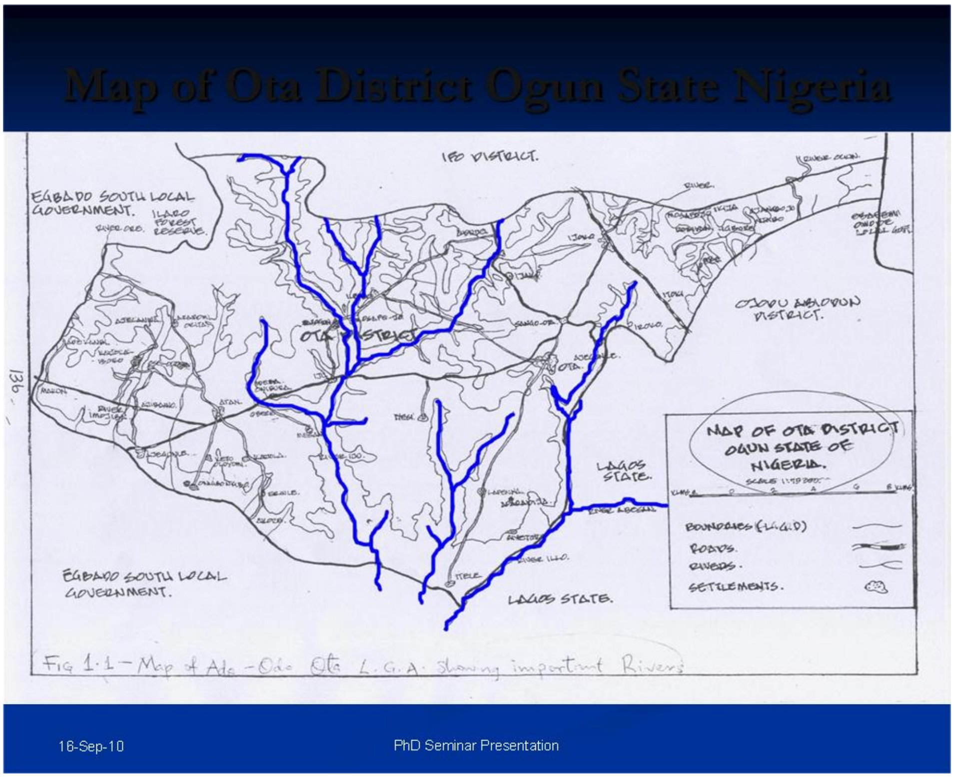
S/N	**Industrial sector**	**Address of Industries**	**Sector code**	**Sample industry**
1	Vegetable Oils	Km 36,Lagos-Abeokuta Expressway, Sango-Otta	D	Real Oil Mills Ltd
2	Food Processing	Km 5, Idiroko Road, Sango-Otta Km 38 Lagos-Abeokuta Expressway, Sango-Otta	D	De- United Foods Nigeria Limited, Trufood Nigeria Limited
3	Petrochemicals	Km 38, Lagos-Abeokuta Expressway, Sango-Otta	G	A-B Rubber Related Products.
4	Breweries	Km 38, Lagos-Abeokuta Expressway, Sango-Otta	D	Sona Breweries Limited
5	Industrial Chemicals	Lagos-Abeokuta Expressway, Sango-Otta	B	Nigerian – German Plc. Purechem Nigeria Limited Classic Soap
6	Pharmaceuticals	Km 11, Idiroko Road, Sango-Otta	B	Fermex Meyer Nig. Plc. Industries, Leady–Pharma Nig. Ltd.
7 8	Pharmaceuticals, Food and Beverages	Km 10, Idiroko Road, Sango-Otta	A	M & B Nigeria Plc, Pardee foods Nig. Ltd.
9	Meat Processing and Abattoir	Lagos-Abeokuta Expressway, Sango-Otta	A	Ado-Odo/Otta Local Government Area Abattoir
10	Distilleries	Lagos-Abeokuta Expressway, Sango-Otta, Km 11,Idiroko- Road Sango - Otta	A	Nigerian Distilleries Intercontinental Distilleries Ltd.

- Types/source of wastewater
- Treatment of wastewater if any
- Disposal of wastewater or reuse

In addition to the questionnaire administration, interview of senior officers of the target industries were done. The relationship of outfalls, discharge paths, drainage channels and watercourses were determined.

Relevant Ado-Odo/Otta Industrial Map from OGEPA and Surveyor-General of the Federation with scale 1:50,000 were obtained. The maps cover all the hinterlands and showed watercourses, wetlands, land use, etc.

The instruments applied on site include: Ranging Pole Measuring Staff, Eurolab Digital Thermometer(-50 ^{O}C - + 200 ^{O}C),Speed Tech (Depth Sounder) Instruments 55506, Geo - Packs Flow Meter (Velocity) Speedboat (Local Boat) ,Steel and Leather Tapes ,Garmin GPS Map 76, Stop watch Cutlass and Safety Boots and Jackets.



Map of Ota District Ogun State Nigeria

MAP OF OTA DISTRICT OGUN STATE OF NIGERIA.

SCALE 1:150 000

BOUNDARIES (L.G.A.)

ROADS.

RIVERS.

SETTLEMENTS.

Fig 1.1 – Map of Ado-Odo Ota L.G.A. Showing important Rivers

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Figure 3.1 Map of Otta District, Ogun State Nigeria

3.2 Study Site

The River Atuwara was purposely selected for the study. It is a tributary of the River Ogun in the Ogun/Oshun River Basins as shown in Figure 3.1. The hydrographic catchments were determined and limnographic stations sited to measure the basic water quality variables /parameters such as intake leaching and DO-BOD cycle in the rivers.

The sewerage outlets and effluent sources along the River Atuwara were located to estimate the quality and contribution of industrial, domestic, or agricultural wastes and untreated effluents. A comprehensive survey of industries, entailing processes involved, raw materials used, the number of waste streams, was carried out. Flow chart was also provided. Indication of any in house reuse or recycle steps involved in the processes was noted.

3.2.1 Survey of Industries

The location of industries was established using a Germin GPS Map 76 Global Positioning System (GPS), which operates by triangulating orbiting satellites.

The GPS is a hand-held digital navigational instrument simply made to determine the exact location of any given place by fixing the geographical coordinates. The GPS acquires information from a minimum of three satellites to generate the coordinates which determine the location of an industry in Longitudes and Latitudes .The coordinates generated are then logged into a computer database, which is built into a digitized map for the generation of industrial maps.

The first step in the execution of this research consist of a survey of existing industries and effluent treatment facilities, and a study of effluent constituents and generation patterns in those industries.

The questionnaires and interviews will be structured to provide information on: -

Types and quantities of industrial output, i.e.

- Raw materials
- Water

Types and quantities of plant outputs, **i.e.**

- End products
- By products
- Waste products both solid and liquid

3.2.2 Determination of pollutant sources, types and quantities

The field study involved a comprehensive estimation of the following:

- Study of pollutant volume, pattern composition, generation rate and changes in generation rate
- Collection of effluent samples for analysis
- In-situ or off- site analysis of effluent if any
- In situ or offsite treatment of effluent, location of treatment plants if any, efficiency and associated problems of such efficiency and associated problems of such plants.
- Discharge path and drainage efficiency
- Effect on environment of effluent discharge.

3.3 Sampling Techniques

Environmental sampling can be tedious because the materials being sampled are variable and complex. It is imperative to develop precise sampling protocols to ensure valid and accurate data. Table 3.2 is an outline of a general sampling protocol for environmental applications (Keith, 1988).

This work provided comprehensive tools in supporting the decision-making processes by generating practical resolution to water quality problems for the basin. The tools consist of the QUAL2E, Water Quality Analysis Simulation Program (WASP) and stakeholder analysis module that is based upon spreadsheet and data base software and a serious consideration for the use of TMDLs (Total Maximum Daily Loads) as a basic model for industrial wastewater management. QUAL2K is a Windows based computer model for designing and analyzing effluent disposal systems which use land irrigation for a wide range of industries such as piggeries, feedlots, abattoirs, sewage treatment plants, and food processing factories (Truong *et al*, 2003).

Design brief formulation:

Show some level of details: structures, receiving bodies, retention times and probable dimensions as well as types of drains used.

Design parameters*:*

- Development and analysis of treatment options and strategies:
  - Primary
  - Secondary

Table 3.2: Outline of a generalized sampling protocol

Main Point (program purpose)	**Sub-elements**
Analyses of interest	Primary and secondary chemical Constituents and criteria for representatives
Locations	Site, width, depth ,slope and frequency
Sampling points	Design, construction and performance evaluation
Sample collection	Mechanism, materials and methodology
Sampling Handling	Preservation, filtration and field control samples
Field determinations	Unstable species and additional sampling Variables
Sampling storage and transport	Preservation of sample integrity

Keith, (1988).

  - Tertiary
  - Any pre-treatment and final polishing of effluents involved; nature; flow chart;
  - While giving the options, indicate available local technology, cost effectiveness, any secondary effects on the ecosystems.
- Volumes and date and time;
- While presenting the effluent data, the following were provided:
  - Total volume generated (minimum, maximum, and peak flow)
  - Variation in the volumes on 24hour cycle/ weekly cycle
  - Details may be given as Appendices
  - Any special problems observed or encountered were indicated and the engineering solution applied on the site was reported.
- The research indicated the effluent path analysis and the recipient bodies, e.g. stream/river, land, ocean, or others.
- Provision were made for the receiving body characteristics, e.g. flow in streams, available dilutions, seasonal variations, type of soils, and rainfall data of the geographical/ ecological zones.

3.4 Field Sampling and Analyses.

Water samples were collected from the river directly at purposive locations on the site. Sampling locations were chosen along the river course.

Sample (effluent characterization)

Effluent characteristics followed the guidelines provided by the FEPA Green Book, according to the category/ classification of the industry: Wet and dry industries or by the final product of the industries:

- e.g. aluminium, automobile, cane sugar processing, beverage, canned and preserved fruits/vegetables, confined livestock feeding, diary, fertilizer, flat glass/cement, etc., asbestos, grain milling, inorganic chemicals/alkaline/chlorine, leather tanning and finishing, meat products, metal finishing, organic chemicals, petroleum refining, plastic/ synthetics, pulp and paper, steam/ electric power generation, steel, textile industry…

- Effluents characteristics such as pH, BOD, COD, TSS, TDS, etc which are crucial for the treatment design were determined.

3.4.1 Site Characterization Studies

In order to achieve the stated objectives, several work tasks must be executed, prior to implementation of the site survey. A thorough site investigation was necessary to obtain background information and determine the extent of contamination of the water body for the pilot studies.

The site assessment includes the following:

- Development of a surface water-sampling plan.
- Analysis of water characteristics
- Assessment of water quality of the receiving water.

The exact locations for sample collection on the receiving water were determined using the Germin GPS Map 76 Global Positioning System (GPS).These were illustrated on the industrial map given sample number.

The effluent sample and the water sample at the respective location were collected and in- situ measurements covering pH, Dissolved Oxygen (DO) turbidity, temperature and salinity for the water samples were determined

3.4.2 Method of Sample Collection

The samples were collected by dipping a clean ‘fresh’ plastic bucket into the water bodies or putting the bucket in the mouth of the discharged point for industries until the bucket was filled up. The above mentioned wastewater parameters were quickly measured in the field using a U -10 water quality instrument which is capable of measuring all the parameters earlier listed.

The geographical location (longitude and latitude) of the sampling point of the industry were obtained using the Geographical Positioning System (GPS). The industries outfalls were located just outside the premises. The water samples were poured into a clean white 2 Litres plastic bottle (the bottles were properly rinsed before filling). These were taken to the Covenant University, Chemistry Research Laboratory. The field equipment were recalibrated, cleaned and sterilized immediately after use. Samples were preserved in the laboratory and stored in the refrigerator at a temperature of 4°C prior to analysis.

3.5 Laboratory Test Studies and Pilot – Scale Studies

The major studies focused on:

- Laboratory analysis of the effluents samples and samples collected in- situ from selected points along the river
- Physico-chemical, Biological and Microbial analysis of samples collected were also determined.

Electrical conductivity was carried out using a conductivity meter at the room temperature of 25^0C. The Fiske and subbarow method (Ogunfowokan *et al*, 2005) was adopted for the colorimetric determination of available phosphate. This is done by preparing a standard curve of ($\mathbf{PO_3^{3-}}$) by diluting 0.2, 0.4, 0.6, 0.8, and 1.0 ml of 0.001 M KH_2PO_4 measured into separate test tubes with 4.8, 4.6, 4.4, 4.2 and 4.0 ml of distilled water respectively. To each of the test tube was added 1.0 ml of 5N H_2SO_4 and then 1 ml ammonium molybdate solution then 0.3ml of Fiske reagent (1.0 ml of Fiske reagent in 6.3ml distilled water were added and mixed thoroughly and allowed to stand for colour development.

The BOD determination of the samples (mg/l) were carried out using the standard methods (Standard Methods, 1995; Ademoroti, 1996).The dissolved oxygen content was determined before and after incubation. Sample incubation stood for 5 days at 20^0C in BOD bottles and BOD was calculated after the incubation period.

Trace metals analysis: The nitric-perchloric-hydrofluoric, acid digestion method (Carrondo, et al, 1979) was adopted. 10 ml of water sample were taken for analysis in a Teflon beaker (must have been soaked in 10% nitric acid for 72hours and rinsed with de-ionized water) and 30.0 ml of concentrated HNO_3 were added and the sample was evaporated to dryness on a hot plate in a fume cupboard. This was allowed to cool and 5.0 ml of conc. HNO_3, 2.0 ml of 60% perchloric acid $HClO_4$ and 6.0 ml of 40% HF was added. The mixture was evaporated to dryness at a temperature not exceeding 280^0C. Furthermore, 2.0 ml of HNO_3 and 2.0 ml of $HClO_4$ acids were added and evaporated to ensure that silicon and fluoride were removed. Again, the beaker was cooled and 20.0 ml of 5% v/v HNO_3 was added to dissolve the salts. The solution was transferred to a 100.0 ml standard flask and made up to mark with de-ionized water washings from the digestion beaker.

3.6 Engineering Model Design and Pilot –Scale Studies (Modelling, Simulation and Treatability Studies)

The research adopted a pilot study in which river water quality modelling was formed to create a scientific and technical base from which we can formulate standardize consistent river water quality models and guidelines for their implementation. Statistical and spatial analyses were employed to examine the statistical and spatial relationship of land use and the flow and water quality in receiving water on a regional scale in Otta Industrial Zones. A treatability bench scale studies were operated to demonstrate the level of purification of the pollutants of concern in the industrial effluents

Version of QUAL2E (QUAL2K) was used in this research to characterize the flow and water quality conditions in the watershed. Several water quality parameters (Dissolved Oxygen, Biochemical Oxygen Demand, Nitrates, Phosphates and Faecal Coliforms) were examined in detail. The models were calibrated and validated using flow and water quality data from historical records retrieved from WES, LASEPA, OGEPA, and FEPA. The efficacy of the models in representing the real world runoff and water quality conditions under different geographical scale was assessed.

Statistical (such as non-parametric correlation analysis and analysis of variance and geographic information systems (GIS)) analyses were adopted. They were used to examine the general associations of land use and flow and water quality and locate watersheds that are enriched with contaminated and with strong relationships with land use.

The GIS spatial analyses were employed to examine the spatial relationship of land use and water quality. With data extracted using GIS technology for a local watershed, the model is calibrated for the hydrologic response and validated for the water quality components.

CHAPTER FOUR

4. MODEL APPLICATION TO RIVER ATUWARA

4.1 Model Study Area: Atuwara River, Ogun State Nigeria

Ogun State is a state in South-western Nigeria. It borders Lagos State to the South, Oyo state to the North, Ondo State to the east and the republic of Benin to the west. Abeokuta is the capital and largest city in the state The Ado-Odo/Otta Local Government Area is one of the 19 Local Governments and is the third largest Local Government Areas of Ogun State. Ado-Odo/Otta borders on by metropolitan Lagos to the south and Ifo Local Government to the west. The capital of the Local Government is Otta at 6°41′00″N 3°41′00″E / 6.68°N 3.68°E / 6.68; 3.68 to the north of the Area. Other towns and cities include Ado-Odo, Igbesa,Ijaliye, Agbara, and Itele Iju,Oko - Omi,Ilasa,Odo - Itele,Odo-Ogbe,Onirowo,Igbala,Ewupe and Orente. Otta has the third largest concentration of industries in Nigeria http://en.wikipedia.org/wiki/Ota,_Nigeria - cite_note-2#cite_note-2. It also possesses a large market and an important road junction, found just north of the tollgate on the Lagos-Abeokuta Expressway. Otta is also well-known as the home of former Nigerian President Olusegun Obasanjo's farm, the Canaanland premises of the mega church Winners' Chapel(Faith Tabernacle)the world acclaimed largest single church auditorium that has a seating capacity of 50,400 worshippers (Winners Chapel Official Website 2010), and the Africa Leadership Forum. There are also two Universities in Otta: Covenant University and Bells University of Technology . This local government is the most industrialized in Ogun State .Its people are mercantile and industrially disposed in terms of occupation. The local government also boasts of a 5- star hotel (Gateway Hotel) Temperance Hotel, Sango Plaza Hotel, Fat – Lam Hotels and a number of other commercial centres.

It has an area of 1,460 km² and a population of 526,565 by the 2006 census. The population has continued to experience a progression in its growth due to its proximity to Lagos State. Consequently there is a large urban – urban drift caused partly by movement of urban populace from the overpopulated Lagos state to the local government for a better lease of life .Again, this is largely due to the rapid industrialization and a consequent increase in its population.

4.1.1 River Atuwara Origin and Course

Atuwara is a major tributary to Ogun River in Ogun - Oshun River Basin Development Authority and has been located along a fast growing municipal settlement of Ado-Odo Otta, a suburb situated outskirt of Lagos which population explosion had necessitated a spill over of both industrial and commercial hurbs. The Headquarters of the Ado-Odo Otta Local Government in Ogun State is Otta. .River Atuwara took its course from Igbo-Elerin near Ifo, and traverses several villages thereby providing the needed water and economic activities to the surrounding villagers .The portion of the basin covered by this research has an estimated area of about 4420 ha. River Atuwara flowed westward towards the Atlantic Ocean where it joined other rivers covering approximately 65 km from its source.

This is reflected in the use of GIS to provide the map on Atuwara. (Figure 4.1). The Atuwara River flows in westerly direction and joins the Lagoon creek ultimately emptying into the Lagoon and the Atlantic Ocean at Ijanikin in Lagos State, Nigeria. The Atuwara River watershed is located within the Atuwara River hydrologic unit. The drainage area of the Atuwara River watershed is approximately 147.333 square kilometres ($147x10^3$ hectares) with up to 50% forested, 10% agricultural, 25% water and/or wetland, 7% residential and 8% commercial (Figure 4.2).

Portions of the Atuwara River have been observed as being impaired by this research due to high dissolved oxygen depletion, bacteria (faecal Coliform) concentrations chemical oxygen demand (COD) and biochemical oxygen demand (BOD), total dissolve solids (TDS) and total suspended solids (TSS). One impaired segment of interest is the tidal portion of the Atuwara River. This river segment is approximately 10.8km long and passes through villages and industries in Ado Odo/Otta Municipal Council, Due to the tidal influence, the Atuwara River is an ideal study area for research on model implementation and the prediction of hydrodynamics and water quality in tidally influenced areas.

4.1.2 River Atuwara: Geology, Climate and Hydrology

a) Geology

Primary research of the stratigraphy of formation in pitted holes at a distance of 150m apart and cross the bed evidently shows the body of rock deposited during the Cretaceous deposition (Paleocene Age). The rock is dipping South-South and under lay by Ilaro formation (limestone, phosphate and grits) in the same direction, which is maestrichain in age. The deposit continues to Idogo formation, which is excene in age. The southern part of the face is covered by the top soil (overburden which is blackish humic in nature mixed with lateritic in origin. Underneath the soil cover, there is the sandy mottle clay with irregular patches with colour overlaying shale which lies on the calcareous sequence (Biomicrite deposit).

Nigeria as a whole is quite abundant in surface water resources, but deficient in groundwater resources. This is because of the extensive areas of the country that is covered by the crystalline rocks of the basement complex which are poor aquifers. These rocks cover about 50% of the country but contribute little to the groundwater supply. The basement complex rocks consisting mainly of igneous and metamorphic rocks are neither porous nor permeable except areas where the rocks are cleaved, shattered, jointed or fissured. Solid rocks of the basement complex have porosities ranging from 1% to 5%. Permeability is also small because the pores are small and disconnected (Azeez, 1972). Although folds, faults joints and shear zones are common they are too localized to be of significant importance as reservoir of water.

The River Atuwara watershed (Figure 4.2) belongs to this geologically complex. Most of the lower basin is underlain by the sedimentary limestone and sandy soil that are common in the lower Oyo-Ogun River basin. The mainstem water were fortified by main tributaries like Afara-meje, Balogun, and Mosafejo which rise among very complicated sets of sedimentary rocks that result from sedimentary formation. The drainage pattern is geologically controlled outside as a result of various discharges from activities around the river. The three principal tributaries channels are with high load of suspended sediment due to increased flow rates as the river emerges into the plain.

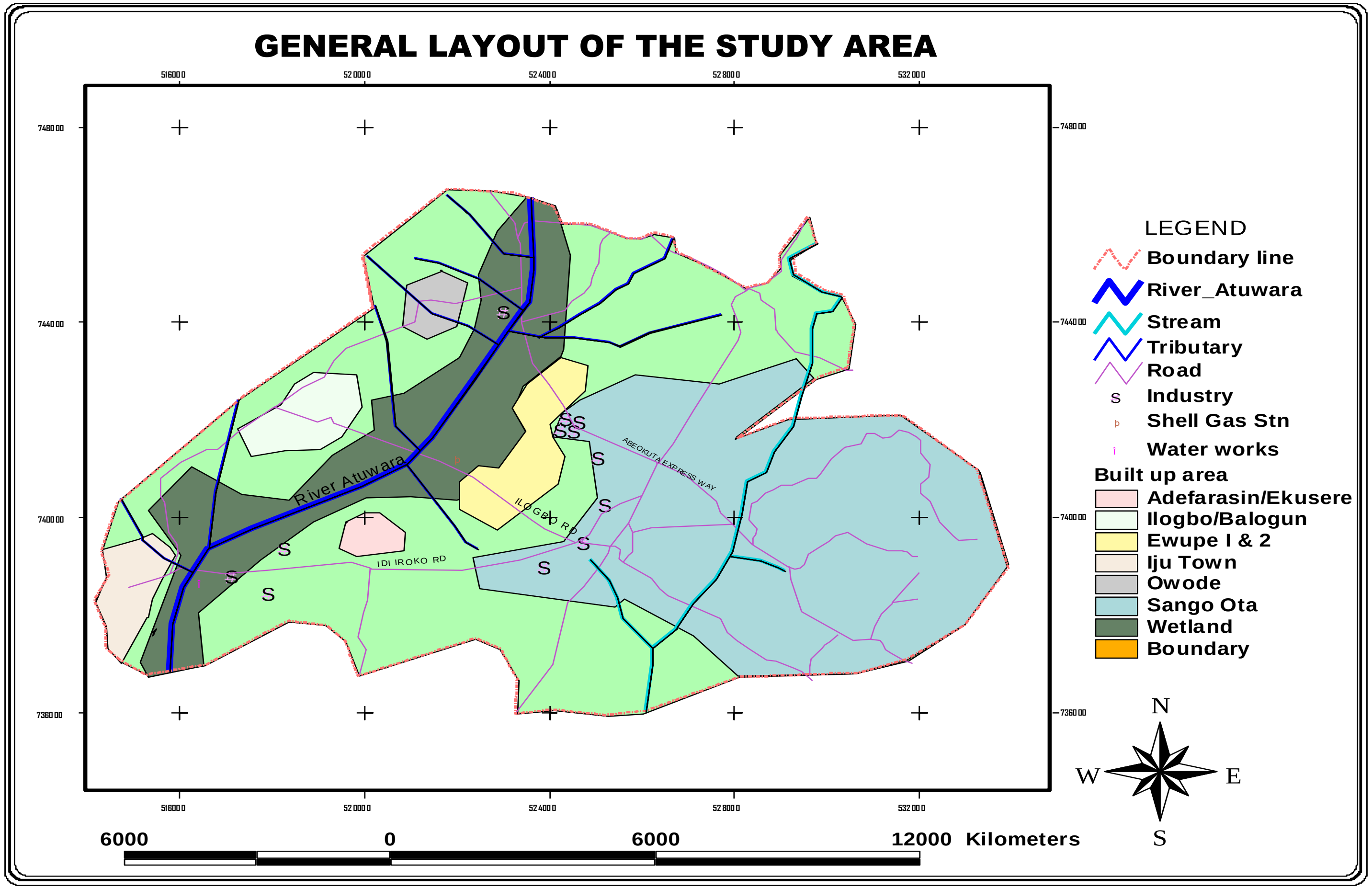


Figure 4.1: General Layout of the Study Area

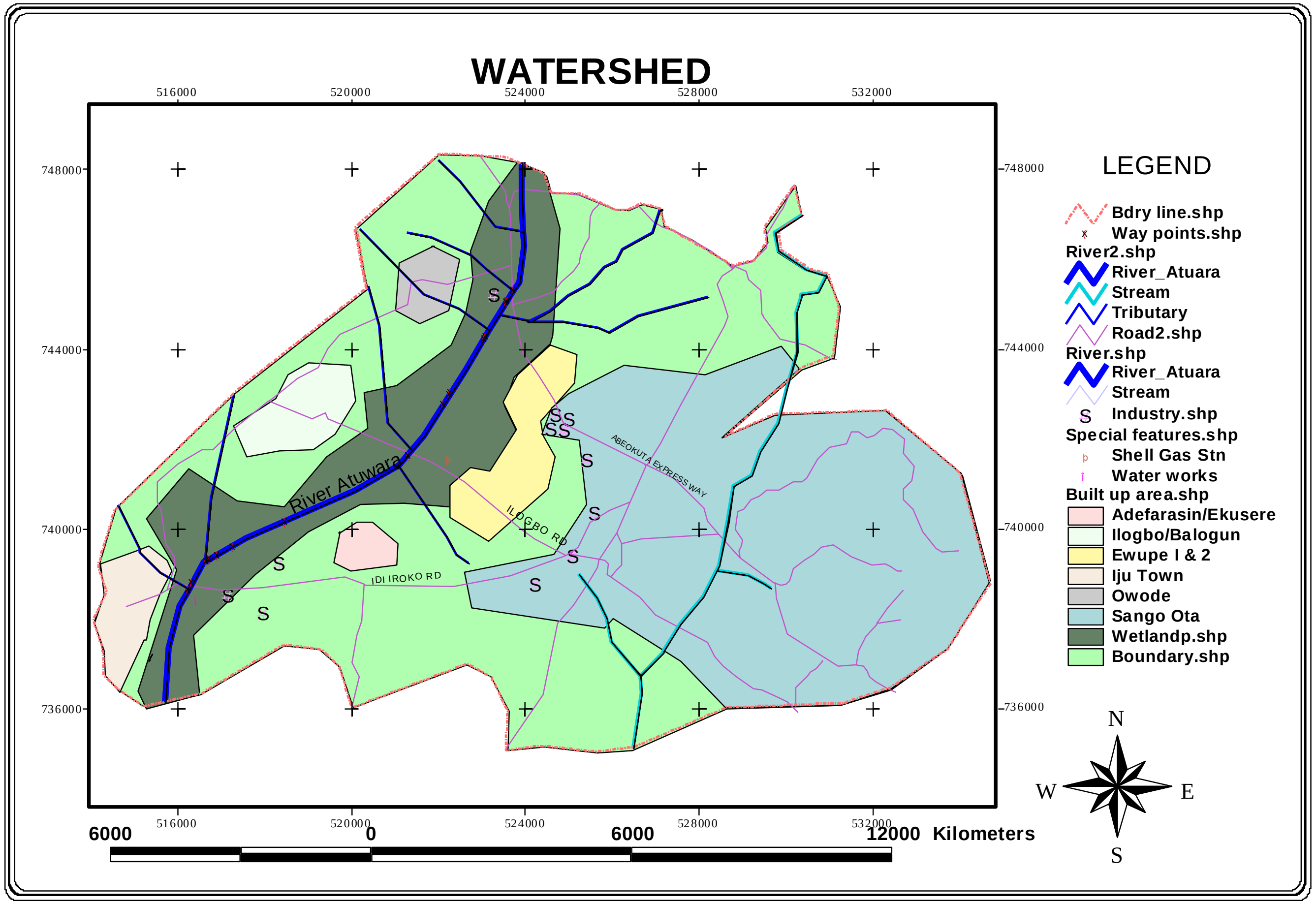


Figure 4.2: River Atuwara Watershed

b) Climate

The area lies within the Dahomey basin and western part of Nigeria. The climate of the cover area map is dominated by the influence of two major types of wind; from the North east is dusty and dry, while wind from the South West is warm and moist. The hotter north easterly current rises over the south westerly one so that at the surface there is a zone variation during the year being either north or south. This gives rise to a warm raining season from April to October and hot dry season from November to March. Cloud cover is usually extensive, the average cloud cover for the years is 72% whilst, in January it can be expected to fall below 50%.

The mean annual rainfall is approximately to 1352 mm with June being the wettest month and February /March the driest. At, 1,000 hours the mean monthly relative humidity ranges from a low of 77% in February to a high of 87% in July, August and September. At 1600 hours, the mean monthly relative humidity ranges from low of 42% in February to a high of 77% in July. The monthly mean daily maximum temperature varies from low of 27.7 ^{0}C in August to a high of 34.0 ^{0}C in February with yearly mean of daily maximum temperature of 30.8 ^{0}C. Monthly mean of daily maximum temperature varies from a low of 20.7 ^{0}C.

c) Hydrology

The monthly discharge of the River Atuwara when measured at the water corporation withdrawal point shows high seasonal variability. The average discharge was 2.884 m^3/s with a low flow period from December to March and a high flow period from April to November. The significant variations in river flow are the result of seasonal rainfall and constant discharges from production processes of the industrial setup, around the river.

The Afara-meje, River Balogun and River Mosafejo which formed the tributaries account for about 30%-40% of the measured discharge. The whole area is very humid and rainfall influence is largely masked by industrial discharges. The tributaries are also from high rainfall down stream of the Ewupe discharge point of the major tributary of the River Atuwara made a major confluence at Afara-meje (i.e. where seven streams converge). The average discharge of the streams is about 40% of the River Atuara flow.

4.1.3 Vegetation, Agriculture and Hunting

a) Vegetation and Agriculture

The forest vegetation found in Ogun State can be sub divided into two. These are the fresh water swamp forest and the lowland rain forest. Of the two, the lowland rain forest is more widespread while the fresh swamp forest is confined to the riverine areas.

Ado Odo/Otta local Government and indeed Irogun West and Idogo to the North district entirely fall in lowland rainforest found in Ogun State and belong to the secondary group of forests as they have been affected several times or other by human activities. The forest contains recognizable physiognomy of structure and organization, which consist of horizontal layers of strata. The upper tree layers consist of very tall trees of 35-45 metres in height. These trees are scattered in the forest and therefore do not form a continuous canopy. The next layer is about 12-25m in height and also discontinuous. The surrounding village land is cultivated for cash crops such as cocoa, plantain, Sugar cane, cassava and okro. They also rear animals like goats, sheep and hens. They are peace-loving people.

The River Atuwara is diverted into a large wetland which irrigate over three-fifth of the River Atuwara basin. This has improved agricultural yields, but the original formation patterns were inadequate drainage and this has led to considerable water logging and wetlands. Water which does return to the river often contains industrial chemicals, as a result of indiscriminate discharges directly or indirectly by the variety of industries along the water course.

b) Hunting

The river is used for sport hunting. The main hunting season starts from April as soon as the rainfall set in and last till November. The main game along the River Atuwara basin is grass-cutters and monkeys. The rain forest flanked with deciduous plants on the wetland provides the available shelter and game for the animals.

4.1.4 Human Population

The town of Otta is the first major town on the River Atuwara, the headquarters of Ado-Odo/Otta Local Government Area of Ogun State. The River flows through the emerging municipal council from Owode-Egba through Ewupe I and Ewupe II, through Ilogbo, Balogun ,Ekusere,Benja, Adefarasin,Igboloye, Iju,Ijaliye, Agbara, and Itele,Oko - Omi,Ilasa,Odo - Itele,Odo-Ogbe,Onirowo,Igbala, Orente.and across other villages before the River enters the Lagoon creeks at Ijanikin via Badagry in Lagos. Within the study area, the River Atuwara ran through about 7 towns and villages with estimated population of about 500,000 people. The Rivers Afara – Meje, Mosafejo and River Balogun flowing from the right side joined River Atuwara and they greatly increase the discharge of the watershed as depicted in Figure 4.3.

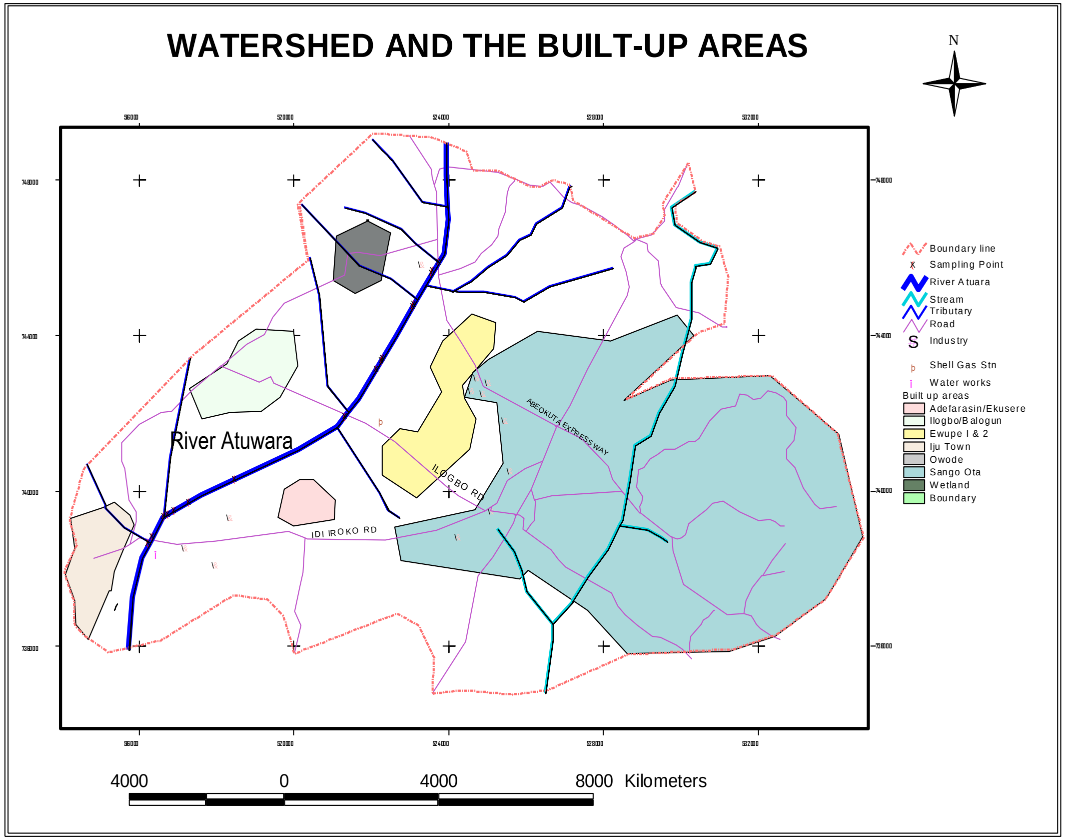


Figure 4.3: River Atuwara Watershed and Built-up Areas

4.1.5 Uses of the River Atuwara

4.1.5.1 Irrigation

The area around the River Atuwara comprises large irrigated area within the municipal council. The river was diverted into several canals which irrigate the area, forming large stretches of wetland. The inundated area has definitely improved and encourages agricultural practice, market gardening and animal husbandry. The river and canal are also used to water and wash livestock. A major abattoir is located at the Northern part of the River near Owode.this abattoir depends solely on the River for their commercial operation, and in a way constitutes impairment to the river. The river water is mainly used for drinking, agriculture, effluent and waste disposal, watering livestock, fishing, and recreation, transport, washing and bathing.

4.1.5.2 Fisheries and Livestocks

The entire River Atuwara and its tributaries are used for both domestic and commercial fishing. Various methods of fishing are utilized such as Dragnets, castanet, gillnets loglines and boats are often used for commercial purposes at the Ewupe and Iju villages. The River water was the main source of all domestic activities and agricultural practices. At Afara-meje both piggery and goats are being reared with major supplies from the River water for some fish ponds which are located at various points along the watershed.

Some of the villagers along the course of the river depend on the river and tributaries as their main source of livelihood in fish production. The dry season is the best earning season for the fishermen. During the course of this study several unauthorized and highly undesirable method of fishing such as insecticides were observed. Iju a sprawling town depended solely on River Atuwara for all domestic activities including agriculture and recreation.

4.1.5.3 Recreation around the Watershed

Boating, fishing and hunting are currently the main recreational uses of the river. Huts and river view apartment are present along the river bank. Notable also are the presence of villagers searching for herbs use for various medicinal proposes. Plate I and Plate II shows the point where Iju Villagers were fetching water for domestic uses.

4.1.6 Industry along River Atuwara

A survey of Ado-Odo/Otta Municipal District list about 100 large and small scale industries of which about 35 industrial and industrial units discharge their untreated or partially treated effluents directly or indirectly into the River Atuwara (Figure 4.4). Among these are Abattoir and livestock (2) Industrial Rubber and Plastics (12) Basic Metals ,Iron and Steel Fabrication (2) Soap and Soap Making (2), Breweries (2), Distilleries (2), Chemical & Pharmaceuticals (10), Food and Beverages (2) Wood and Wood Products (1), See Appendix C: (Sectoral Groupings of Ado Odo /Otta Industries).

4.1.6.1 Industrial Pollutants

Different industries located along the entire stretch are discharging a number of organic and inorganic pollutants in their effluents into the River Atuwara. The field survey carried out between 14/10/ 2008 and 11/05/ 2009 showed certain important polluting industrial effluents and the pollutants being discharged into the main river or its tributaries.

Two major breweries and distilleries constitute the main industries that discharge largest loads of high oxygen demanding waste with high BOD and COD. The discharge entrants are located about 1.260 km from the upstream.

PLATE I River Atuwara and Iju Villagers

PLATE II River Atuwara soon recovers after receiving effluents from a Food Processing Firm

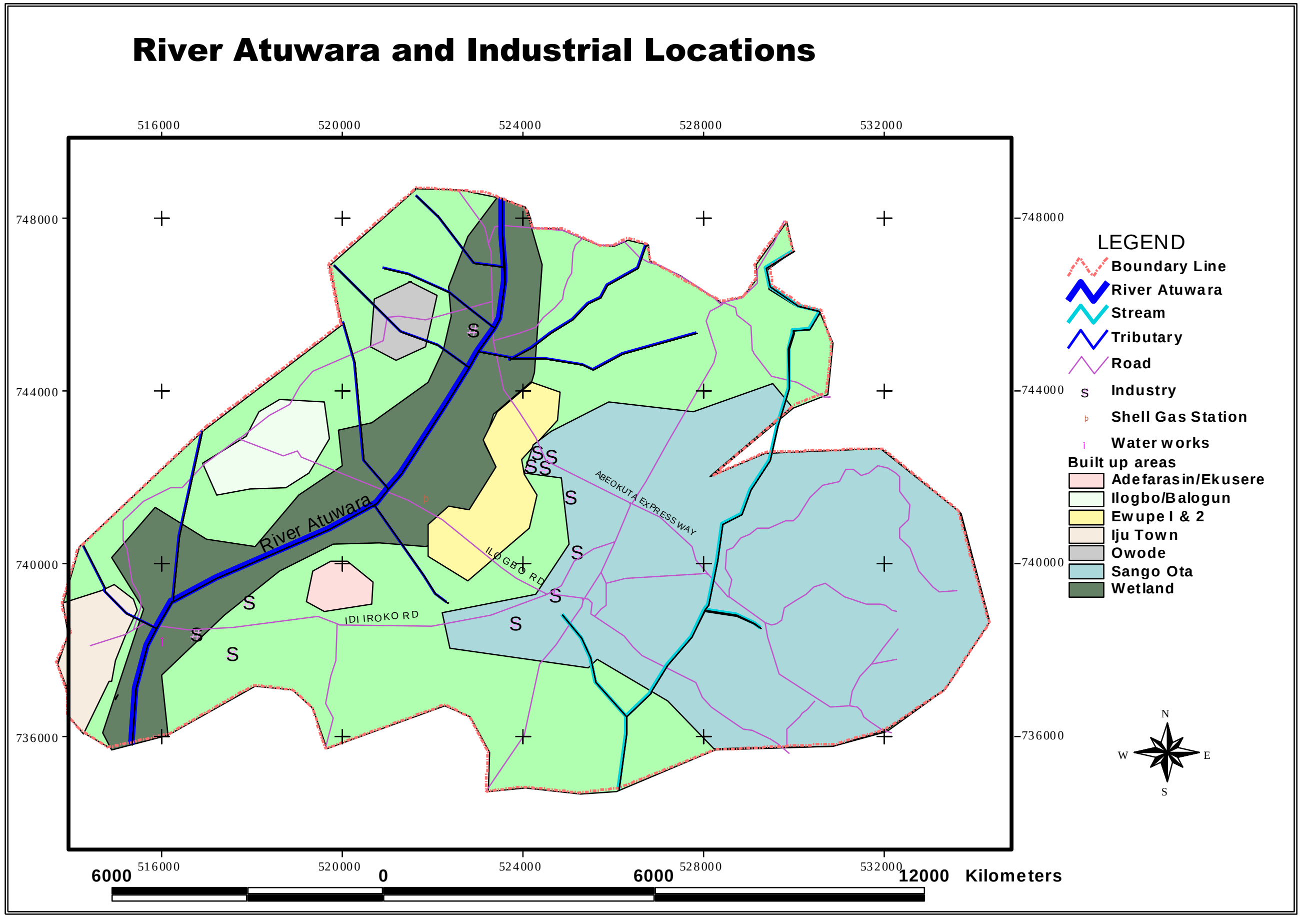


Figure 4.4: River Atuwara and Industrial Locations

These effluents also contain chemicals that increase alkalinity, total suspended solids (TSS) total dissolved solids (TDS), NO_3^-, NO_2 and NH_3^-. They discharge high strength waste water bearing high organic pollutants which further deteriorate the quality of the river water. A large local slaughter house located (just within 50 m off the river course) at the vicinity of the about 200 m downstream from the River Atuara headwater at the Northern stretch discharge into the river their toxic effluents with high BOD, COD, TSS, TDS, SO_3^{2-} SO_4^{2-} Na^+ NO_3^- NO_2^- Cl^- alkalinity and different forms of nitrogen and phosphates beside Sulphides.

The second largest high Oxygen demanding effluents are discharged by the chemical and pharmaceutical laboratories at Ewupe area about 2.830 kilometres downstream from River Atuwara headwaters, having high BOD, COD and other pollutants causing an increase in the heavy metals, TSS, TDS, Fe^{3+}, Cad+ NO_3^{2-}, NO_2^-, total nitrogen and phosphate in the river water. Metals and plastic industries contribute toward deterioration of the overall quality of the river water as effluents from these industries contain materials responsible for the increase in BOD and COD, and other parameters like TSS, TDS, Oil and Grease and Heavy Metals.

At Adefarasin was located Afara-meje, a large tributary making a confluence at about 8.4 kilometres downstream from the headwater to the river Atuwara. This tributary has about the size of the river volume with high flowing velocity and flowing from non - industrial regions, the over all recovery capacity of the river was partly due to the contribution of this highly pure discharge into the mainstream.

The river passes through agricultural areas such villages as Ekusere Adefarasin and Igboloye where livestock, fisheries and market gardening are practiced and the population around these zones depended strictly on the water from the river. .A large Food and beverages processing industry discharges its high oxygen demanding effluents that enters the river at about 9,300 metres downstream of River Atuwara headwaters, having high BOD, COD and other pollutants causing an increase in the TSS, TDS, Fe^{3+}, Cd+ NO_3^{2-}, NO_2^-, total nitrogen and phosphate into the river water. Also at a point about 500 metres downstream from the food processing discharge was located a point where paid trucks discharges untreated or partially treated effluents of varying composition into the river water. about 200 metres below this point was a continuous discharge of highly acidic effluents from a large distillery industry into the river water and beyond this discharge are two tributaries of Mosafejo and Balogun rivers making their confluence at about 10,500 and 10,700 metres downstream of the river’s headwaters,. Plates III through Plate VIII were pictures of various points of industrial discharges into River Atuwara. Plate III specifically painted a sordid perspective of frequent indiscriminate discharge of not only industrial but municipal effluents of diverse pollutants concentrations into the river course.

PLATE III A truck discharging combined effluents into River Atuwara at Ekusere

PLATE IV Abattoir on River Atuwara upper boundary at Owode – Ijako along Lagos Abeokuta Expressway

PLATE V River Atuwara upper boundary at Owode – Ijako along Lagos Abeokuta Expressway

PLATE VI River Aturwara receiving solid wastes from the environment

PLATE VII Sampling from Distilleries effluents along River Atuwara Watershed

PLATE VIII Distilleries effluents cascading into River Atuwara

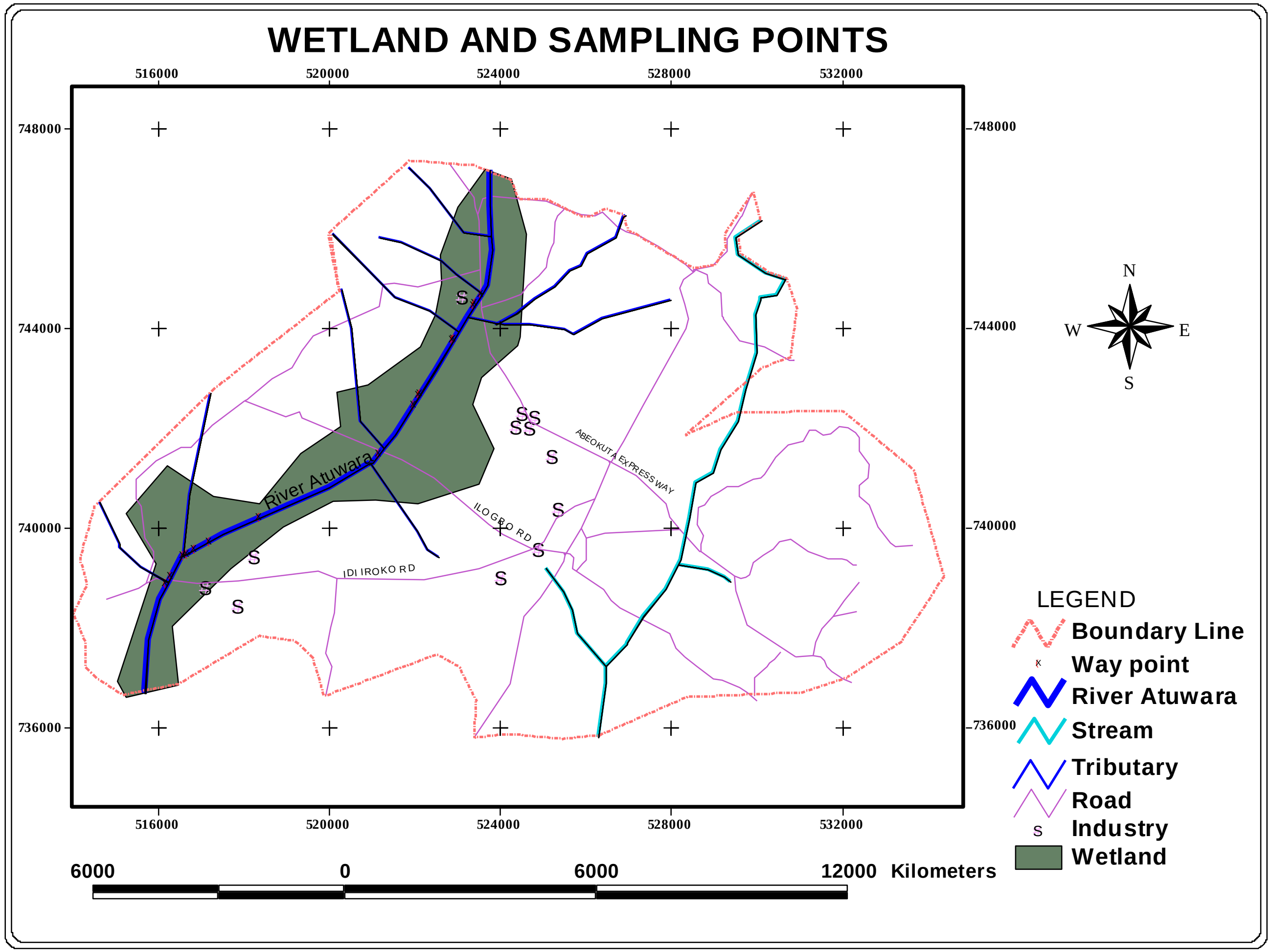


Figure 4.5: River Atuwara Wetland and Sampling Points

4.2 Data Collection and Processing

4.2.1 Flow Types

Distinct flow types and durations perform different geomorphic and biological functions and have varying degrees of impact on human resources. The following flow types–low flow dominant discharge and flood flows–describe flow relative to stage (elevation of water surface within channel) and its relation to physical boundaries and conditions within the channel and flood plain environments.

4.2.1.1 Low Flow Analysis: Flow and Pollution Loads

Base flow conditions dominate the hydrograph of many streams, in terms of flow duration, A low flow channel is often forward as an inset to the larger active channel. The low flow channel may be broken down to smaller segments with distinct geomorphic feature such as riffles and pools. The stage in the low-flow channel is important to examine if the project's goals include specific revegetation and/or habitat requirements. For example designing an adequate water depth and velocity will be critical to fish survival.Likewise, the survival of riparian plant communities and other deep-rooted species and is an essential part of bioengineered treatment, vegetation must be planted at the proper bank elevation to make use of soil moisture sustained during the growing season by base flows in the low-flow channel.

Water quality modelling has employed the steady low-flow seasonal period as its design condition. Therefore the question on how to establish the low flow condition applied the principle of low flow as considered by the 7-day flow that would be expected to occur every 10 years (Chapra, 1997)..It is generally accepted as the standard design flow called 7Q10. This value can be determined for the entire year by month or for a season. In tropical rain forest climate such as the one existing in Nigeria, the existence of the rainy season between April and November of each year peaking in the months of June through October and that of the dry season culminating in harmattan between December and March, peaking in the months of February and March.

This research examined the data for the year 2008 and 2009 for which the smallest flow that occurred happened during the dry season. Chapra, (1997) tabulated the flows in ascending order and assign them a rank m. The cumulative probability of occurrence is given by

$$P = \frac{m}{N+1} \tag{4.1}$$

and the occurrence interval is then defined as

$$T = \frac{1}{P} \tag{4.2}$$

Probability paper can be used to pick off the 7Q10.

In this study, average river flow in the dry season (December to March 2009) was considered for simulation. Pollution load details of head water as well as point sources and withdrawals are given in Table 4.7, 4.11, 4.15 and 4.19. The surface water recharge through ground water was assumed to be poor along the Atuara basin; therefore the incremental flow to the river in the model was considered zero (Ritu and Prateak, 2006).

Consideration of Seasonal Variation

Data used in the calculation of this model were collected during the rainy (wet season) and dry (winter season) of years 2008 and 2009 in order to ensure coverage of any potential seasonal variation in the system. Critical conditions were set to low-flow for Dissolved Oxygen and Biochemical Oxygen Demand. Data violations were measured during low winter flows. A flow measurement taken during the 2009 winter sampling number was used in the calculations.

4.2.1.2 Oxygen Reaeration Formulae: Internal Calculation of the Reaeration Ratio

$$K_a = \sqrt{D_L}\,\frac{U^{0.5}}{H^{1.5}} \tag{4.3}$$

K_a = oxygen reaeration

D_L = liquid diffusion coefficient

The diffusivity of oxygen in natural waters is approximately

$2.09x10^{-5}$ cm^2/s

This research adapts the O’Connor-Dobbins Formula out of several models postulated by researchers in river hydraulics.

$$K_a = 3.93 \frac{U^{0.5}}{H^{1.5}} \quad \text{[Units } K_a \text{ (d}^{-1}\text{), U(m/s), H(m)]} \qquad (4.4)$$

Depth (m) 0.30—9.14

Velocity (m/s) 0.15—1.6

This is appropriate for moderate to deep streams with moderate to low velocities.

4.2.2 Channel and Flow Data

Arc-view GIS in conjunction with field measurement was used to determine the coverage top width of each model channel. To do so approximately 3 points of measurements of top-width were taken across the cross-section along the length of each channel reach. These measurements were then averaged to determine the top width for each channel reach, In addition to channel widths, channel lengths were established with the aid of Arc view GIS. The coordinate and the longitude/latitude of each junction centre were determined, hence distance were easily measured with the Arc view software established hydrodynamic utilizes the assumptions that irregular channel cross-sections can be represented with hydraulically equivalent (hydraulic radius remains approximately the same) trapezoidal cross-section.

Hydraulic radius was replaced with average channels depth within the QUAL2K inputs file. While collecting bathymetry data on the Atuwara River, the research team paid close attention to river bed and bank vegetation. This is done in order to establish a Manning's roughness coefficient (n-value) for each channel in the model network. Figure from Chow (1959) were used to provide initial estimates of Manning's roughness coefficient and served as the main QUAL2K parameter used for model calibration.

4.2.2.1 Flow Data

The flow data was computed by the following relationship:

Known Data

- mean flow
- mean velocity
- slope

Calculated

- real time flow
- real time velocity
- depth
- Width
- area

Calculation of Real Time Parameters

Given: for each reach in Q_{mean}, V_{mean}, T_{mean} and Length

Steps:

Retrieve real time flow (Q_{rt}) from selected gauge

Calculate real-time velocity (Vrt)

—V_{rt} = aQbrt (4.5)

Calculate velocity factor (VF)

—VF = V_{rt}/V_{mean} (4.6)

Scale Vmean for each reach by V_f

4.2.2.2 Instantaneous Release

The instantaneous release can be computed by the relationship stated below (Thomann and Mueller, 1987):

$$C = \frac{M_0}{A\sqrt{4\Pi Dt}} \; e^{\frac{-(x-V_t)^2}{4Dt}} \; e^{-kt} \qquad (4.7)$$

Where:

C = concentration (m/L^3)

Mo = Initial Mass (M)

A = cross sectional area (L^2)

D = Longitudinal Dispersion (L^2/T)

K = Decay rate (0.693/half life)

V = velocity (L/T)

t = time (T)

X = distance (L)

Dispersion

The dispersion is the function of the formula below (Fischer *et al*, 1979)*:*

$$D = \frac{0.011V^2W^2}{dU^*} \qquad (4.8)$$

Where:

D = Dispersion (L^2/T)

d = depth or stage (L)

g = acceleration due to gravity (L/T2) = $9.8/m/s^2$

s = slope (L/L) (channel slope)

= W = width (L)

$U^* = \sqrt{gHS}$

H = mean depth or (d)

4.2.2.3 Continuous Release

The continuous release was computed using the functions below (Runkel, 1996):

$When \ t \ \leq \ \tau$

$$C(x,t) = \frac{C_0}{2}\left[\exp\left\{\frac{V_x}{2D}(1-F)\right\} erfc\left\{\frac{x - V_t r}{2\sqrt{Dt}}\right\} + \exp\left\{\frac{V_x}{2D}(1+r)\right\} erfc\left\{\frac{x + V_t r}{2\sqrt{Dt}}\right\}\right] \qquad (4.9)$$

Where:

C = concentration m/L^3

Co = concentration of the substance after mixing of the input over the cross section

Ʈ = input time interval

A = cross section area (L^2)

D = Longitudinal Dispersion (L^2/T) = calculated by equation 3

K = decay rate (0.693/half life for chemicals)

V = velocity (L/T)

t = time (T)

x = distance (L)

4.2.2.4 Biological Decay

The biological decay rate could be computed as postulated below (Thomann and Mueller, 1987):

$$N = No \exp(-KBt^*) \tag{4.10}$$

Where:

N = concentration of the organism (Mμm/L^3 or num/100ml)

t* = time of travel

KB = net first order decay rate (1/day).

In this system, only decay rate by temperature effects is considered.

The temperature effect are approximated by

$$(KB)_\tau = (KB)_{20}\,(1.07)^{T-20} \tag{4.11}$$

4.2.3 Hydrodynamics Predictions

Hydro-geometry requires model users to provide boundary conditions for all upstream and downstream boundaries contained within the model network. Boundary conditions include model inflows for upstream boundaries, model outflows for downstream boundaries or time-variable tidal heights for downstream boundaries. The downstream Hydro-geometric boundary for this research was established and the most appropriate boundary condition was chosen.

The Atuwara River flows in a westerly direction until it empties into the Lagos Lagoon near Badagry in Lagos State. The Ogun State Water Corporation Pumping Station serves as the downstream hydro-geometric boundary for this research. In addition, the Atuwara River and the other tributaries are both tidally influenced. As a result of the tidal influence, the research does not operate or maintain a streamflow gauge near or around Atuwara River watershed. This is due to the fact that streamflow measurements are determined with the aid of rating curves and Manning’s equation, which are linked directly to river stage (depth). However, in tidally influenced waters, a given river stage can have a number of different streamflows associated with it, which is directly related to the coupling of dry or wet weather flows with flood or ebb tides. Due to the highly complicated relationship between tidal height and streamflow as well as the lack of a streamflow gauge, model outflows were not chosen as the downstream boundary condition for this research.

Downstream boundary was chosen to coincide with a point of withdrawal, the Ogun State Water Corporation Pumping Station. In addition to the lack of a streamflow gauge, the municipal authority does not currently operate a tidal stage recorder at the confluence of the Atuwara and other tributaries. Therefore, real-time tidal heights could not be utilised as the downstream boundary condition within hydro-geometry. As a result, no tide predictions were used as the input for the downstream Hydro-geometric model boundary.

4.2.4 Continuous Variable Hydrodynamics

To facilitate the calibration and validation of the hydrodynamic model, this study applied recording of field data to calibrate the tidal height gauge and the data collection device was configured to take stage readings during every sampling periods. In addition, the raw data was processed with Microsoft Excel. After processing, collected data points were placed within a Microsoft Access database for use by the Hydro-geometric /QUAL2K postprocessor during Hydro-geometric calibration and validation sample processed tidal heights are presented as Tables in the next chapter.

4.2.5 Hydro- geometric Data

To establish junction bottom elevations (measured from a common datum) as well as channel hydraulic radii, the author collected hydro geometric data along the Atuwara River and the Atuwara watershed. Sixteen cross-sections (perpendicular to the longitudinal direction of flow) were taken with the aid of a boat and a depth finder. A global positioning system (GPS) unit was utilised to determine the location of the cross-sections within the river system. Figure 4.2 shows the River Atuwara Watershed, Fig.4.6 is a plot of cross-section location of the cross-sections within the river system, and their respective hydro-geometric channel number.

After collecting the necessary cross-sections data, the hydrogeometric data was processed with the aid of Microsoft Excel. The study utilizes the assumption that irregular channel cross-sections can be represented with hydraulically equivalent (hydraulic radius remains approximately the same) trapezoidal cross-sections as shown in Figure 4.6. As a result, the hydro-geometric data was processed to determine the average depth of each cross-section, assuming the top-width of each cross-section remained constant. Methods and processes of measurements, data collection and recordings employed along the river course are shown in

Plate IX and Plate X, even as the calculated average depths are shown in Table 4.9, 4.13, 4.17 and 4.21

PLATE IX Hydrogeometric Measurement on River Atuwara

PLATE X Hydrogeometric Measurement at Iju Water Works lower down stream

4.3 Condition for Simulation with QUAL2K

The conditions for the simulation of data points with QUAL2K include:

- Steady-stream flow
- Constant-emission conditions
- Point sources of pollutants

From literature, there is currently no readily available widely accepted water quality model for the following limitation arises from the use of QUAL2K or its variants.

- river regulated by hydropower or other dams that cause significant diurnal fluctuation in streamflow;
- combined sewer overflows and urban storm water effects
- the effects of diurnal variation in the flow of municipal effluents, and
- the effects of industrial effluents discharged on a batch basis or with significant variation in flow during different working shifts. (Shanahan, *et al* 1998).

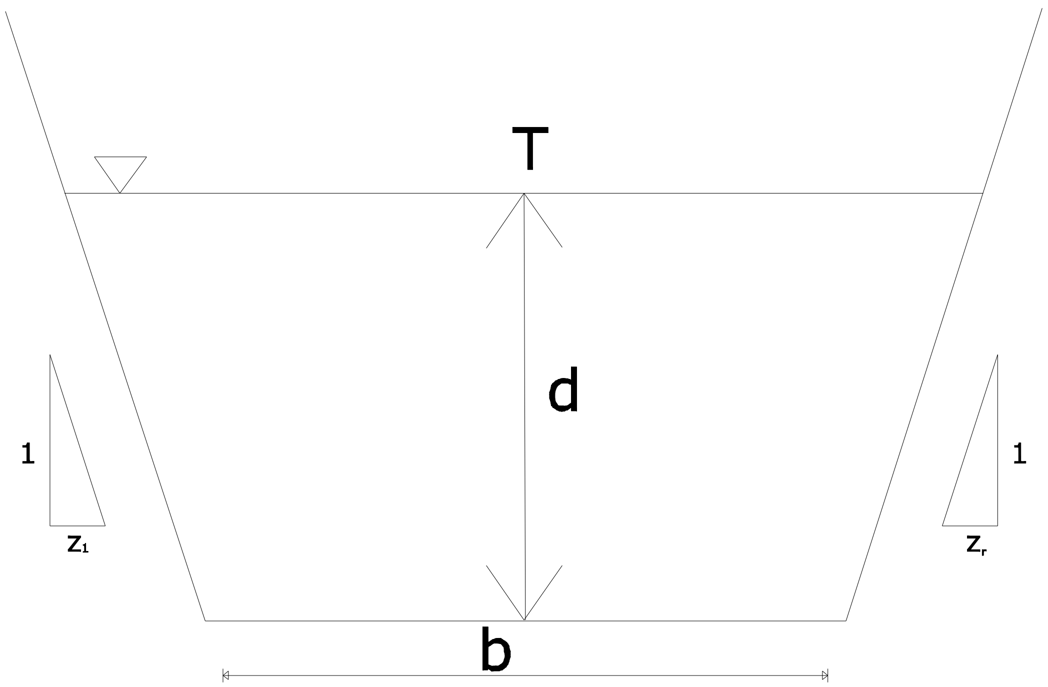
Planning and management activities require the assessment of hydraulic and water quality conditions often beyond the range of observed field data. In this context, both hydraulic and water quality models must be formulated enough to:

1. Describe observed conditions, and
2. Predict planning scenarios that may be substantially different from observed conditions.

In stream water pollution control, the main objective is to assess if the system complies with the main maximum pollutant releases, allowed from point and non-point source pollution, so that pollutant levels in the receiving streams meet the water quality standards. Two aspects of adequacy of the model results are highlighted viz: model accuracy and model speed.

Model accuracy is defined as the difference between the modelled and observed values, while Model speed is considered very important to be able to perform long-term simulations and to analyze the river water quality state in a statistical way.

Measurements of depth and water velocity are taken at a transect across the stream. The depth data are used to estimate the mean depth and cross sectional area. This is done via integration.



Figures 4.6 Cross – Section of the basin to calculate other parameters

Figure 4.6 shows a stream cross-section along with a transect showing depth and velocity measurements needed to calculate mean depth, flow and other hydro geometric parameters. Note that the velocity measurement

$$A_C = \int_0^B z(x)\,dx \tag{4.12}$$

$$H = \frac{A_C}{B} \tag{4.13}$$

where: A_C = cross-sectional area (m^2)

x = distance measured across the stream (m)

z(x) = depth measured at location x(m)

H = mean depth (m)

B = stream width

At each depth measurement a corresponding velocity measurement can be taken. There are several ways to do this (Gupta, 1989). The most common are:

1. For deepen waters, depth >0.61m (2ft) the velocities taken at 20% and 80% of the total depth are averaged
2. For shallower water, depth <0.61m a single velocity measurement is taken at 60% of the depth.
3. It can be shown that these choices have a mathematical basis.

Mathematical basis of the two-point and six tenth depth methods

Dickinson (1967) determined that the distribution of velocity in streams could be fitted by the simple power law.

$$U_{(z)} = U_0 \left(\frac{z_b - z}{z_b - z_0} \right)^{\frac{1}{m}} \tag{4.14}$$

where: $U_{(z)}$ = velocity at depth z

U_0 = known velocity at a depth z_0 from the surface

z_0 = depth from the bottom

m = is a constant that varies from 6 to 10 depending on the Reynolds number, which is approximately 7.

Emphasis was placed on low flow season which in this case was December 2008 —March 2009

This study calculated the load in tonne/day from the industries as point discharges /sources.

The QUAL2K software evaluates the water quality between Owode on Lagos Abeokuta Expressway and Iju water works on Sango- Otta Idiroko Road in terms of Dissolve Oxygen (DO) and Biological Oxygen Demand (BOD). The DO and BOD concentrations were predicted to assess the impact of various point loads on the river for the low flow conditions.

The QUAL2K analysis involves a comprehensive application that can determine the assimilative capacity of the river from where we can recommend different remedial measures to improving the river water quality.

The output generated by QUAL2K was interfaced with the GIS what was to identify pollution zones along the river stretch under study.

4.3.1 Mass Balance

The mass balance equations as reviewed in earlier chapter 2 are:

$$V\frac{\partial c}{\partial t} = \partial\frac{\left[AE\,\frac{\partial c}{\partial t}\right]}{\partial x}dx - \frac{\partial(A\ U)}{\partial x}dx + V\frac{dc}{dt} + S \qquad (4.15)$$

where:

V = volume

c = concentration of constituent

A = element cross-sectional area

E = longitudinal dispersion coefficient

x = distance (in the direction of flow from point load)

U = average velocity

S = external somas (positive) or sink (negative) of the constituent

4.3.2 QUAL2K Calibration

In this study QUAL2K is calibrated for the month of February and to March 2009 representing a low flow period. The model software is operated as a one-dimensional steady state and completely mixed system. The 10.8km long stretch from upstream of Owode to Iju waterworks was divided into 7 reaches with further segmentation of 0.30km each

The input variables for the software considered the:

- Hydraulic constants to stimulate the transport of pollutants.
- Reaction rate constant to simulate kinetics of decay of pollutants.
- Flow rates and concentration of sources and sink to simulate flow/load balance.

Hydraulic constants

Manning’s coefficient was taken as 0.05 for Atuwara watershed (natural stream channel with weed pool and windy; (Chapra, 1997).

The power equation were used to calculate coefficient and exponent of depth and velocity, utilizing depth, width, velocity and flow rate for different reaches (CPCB, 1982-83; Ghosh, 1996; Chapra, 1997) .These are summarized in Table 4.1.

Table 4.1: Ranges of discharge coefficients and exponents

Input variable	Value (Range)
Coefficient on flow for velocity	0.032—0.08
Exponent on flow for velocity	0.300—0.425
Coefficient on flow for depth	0.126—0.33
Exponent on flow for depth	0.245—0.475

$$U = aQ^b \tag{4.16a}$$

$$D = cQ^d \tag{4.16b}$$

$$B = eQ^f \tag{4.16c}$$

Where:

U = average cross-sectional velocity

B = average cross-sectional width

D = average cross-sectional depth

Q = flow rate

a, c, e = coefficients for flow on velocity width and depth respectively

b, d, f = exponents for flow on velocity, width and depth respectively

4.3.3 Reaction Rate Constants

The BOD decay constant had the optimum value of 0.95/day for a reach; otherwise its value fluctuated between 0.2/day and 0.4/day for other reaches. The settling rate and sediment oxygen demand (SOD) were calculated for the entire course of the river (CPCB, 1982-83 Paliwar and Sharma 2006) The O’Connor and Dobbins (1958) stream reparation equation were used for this slow moving river with depth of about 1m (PDER, 1981). The penetration of light to deeper layers prevented the growth of phytoplankton (Kazmi, 2000). Therefore, photosynthetic oxygenation was taken as zero.

4.3.4 Flow and Pollution Loads

The low-flow conditions of the harmattan period prevailed for most of the season of the year from December to March. Thus, in this study average river flow in the dry season (December to March) was considered for simulation. Pollution load details of headwater as well as point sources and withdrawals are given in Table 4.9, 4.13, 4.17 and 4.21. The surface water recharge through ground water was poor for Atuwara watershed. Therefore, the incremental flow to the river in the 2009 model was considered zero.

4.3.5 How QUAL2K Obtain Solutions Numerically

Equation 4.17 showed how to obtain numerical solution in the QUAL2K software

$$\underset{\text{Accumulation}}{V\frac{\partial c}{\partial t}} = \underbrace{\underset{\text{Dispersion}}{\frac{\partial\left(A_c E\frac{\partial c}{\partial x}\right)}{\partial x}dx} - \underset{\text{Advection}}{\frac{\partial\left(A_c U_c\right)}{\partial x}dx}}_{\text{Transport}} + \underset{\text{Kinetic}}{V\frac{dc}{dt}t} \qquad (4.17)$$

Dividing *Eqn. 4.17* by volume

$$\frac{\partial c}{\partial t} = \frac{\partial\left(A_c E\frac{\partial c}{\partial x}\right)}{V\partial x}dx - \frac{\partial\left(A_c U_c\right)}{V\partial x}dx + rc + p\ \frac{s}{v} \qquad (4.18)$$

It should be noted that the kinetics term have been separated into two terms which are advection and dispersion .The advection terms are expressed in equation 4.19 through 4.27.

Advection:

$$\frac{\partial c}{\partial t} = rc + p \qquad (4.19)$$

Manning's

$$Q = \frac{1}{n}A_c R^{2/3} S_e^{1/2} \qquad (4.20)$$

n = (given)

Q = Ac (calculated)

R = H for H ≤ 2.4

$$S_e = \sqrt{\frac{Q_n}{A_c R^{2/3}}} \qquad (4.21)$$

$S_e = S_1 = S_2$ (4.22)

$S^2\text{—}h^2 = b^2$ (4.23)

$$b = \sqrt{s^2 - h^2} \tag{4.24}$$

$$B - (b_1 + b_2) = B_0 \tag{4.25}$$

Rating Curves

In this study the power equation was used in transport calculation for the advection

$$\begin{aligned} &Q_{Li} \pm Q_{xi} - Q_i = 0 \\ &U = aQ^b \\ &H = \alpha Q^\beta \end{aligned} \tag{4.26}$$

H = mean depth, a, b, α, β are empirical constants that are determined from stage discharge rating curves. Once velocity has been determined, the cross sectional area can be calculated from the continuity equation.

$$A_c = \frac{Q}{U} \tag{4.27}$$

Dispersion

Equations 4.28 through 4.30 utilized the QUAL2K software for the following relationship to compute dispersion as a function of the channel's characteristics (Fischer *et al*, 1979)

$$E = 3.11KnUH^{5/6} \quad or \quad E = 0.011\frac{U^2B^2}{HU^*} \tag{4.28}$$

where:

E = longitudinal dispersion coefficient m^2/s

n = channel's roughness coefficient (dimensionless)

U = mean velocity (m/s)

H = mean depth (m)

K = a dispersion parameter (dimensionless)

defined as: $K = \frac{E}{HU^*}$ (4.29)

$$U^* = \sqrt{gHS} \tag{4.30}$$

where: U^* = shear velocity (m/s) which is related to more fundamental characteristics by S = the channel slope

Flow Relationships

Velocity, depth and width calculation method based on US Streams as in (Leopold and Maadock, (1952) can be restricted as :

$$\text{Velocity} = aQ^b \tag{4.31}$$

$$\text{Depth} = cQ^d \tag{4.32}$$

$$\text{Width} = eQ^f \tag{4.33}$$

For which the pertinent data are given in table 4.2

Table 4.2 Average values and ranges of exponents in hydro geometric correlations.

	Velocity		**Depth**		**Width**	
	a	**b**	**c**	**d**	**e**	**f**
Minimum	0.032	0.3	0.126	0.1	1.00	0.05
Maximum	0.08	0.7	0.33	0.6	1.00	0.25
Mean	0.056	0.45	0.228	0.4	1.00	0.15

4.3.6 Model Configuration/Model Segmentation

Model configuration involved setting up the model computational grid and setting initial conditions, boundary conditions, and hydraulic and kinetic parameters for the hydrodynamics and water quality simulation. This section describes the configuration and key components of the model.

Computation Grid Set Up

The model of Atuwara River includes the analysis of the mainstream from its headwaters at Owode to the Iju Waterworks. This section was listed for Dissolved Oxygen impairment because of the large industrial set-up along the course of the river. The river carries flow from a large portion of the watershed approximately 10.8 km having tributaries merge with the mainstream at Afara meje (kilometre 6.35), Mosafejo (kilometre 10.7) to the headwaters. The river was divided into sections called reaches to provide hydrologic ordering of the river. These reaches begin or end where changes occur in the hydrology of the end where changes occur in the hydrology of the water body in order to maintain hydrologic connectivity. Distances were assigned to the water body, beginning with zero at the headwaters. Within each reach, the modelled segments were divided into computational elements of 0.3 kilometres. The hydrologic and water quality characteristics were calculated by the model software for each computational element shown in Figure 4.7. Computational Grid set up and Figure 4.8 the location map showing sampling points and is a representation of the model domain.

4.3.7 Model Parameters

The DO impairment was identified and listed based on the field data collected in 2008 and 2009. The data were collected at upstream discharge entry points and at downstream locations. The two major seasons that characterized the tropical rain forest are the wet seasons (raining) April—October and dry seasons (winters) November—March.

DO impairment was observed in both seasons due to non-point and industrial discharges during the wet seasons and at winter under a low flow condition. Since a stream or river is affected by heavy loads of oxygen consuming pollutants, either natural or man-made, it will exhibit low DO concentrations during winter low flow periods with high SOD. The critical condition for this research was selected at winter low flow condition, the observed low flow condition on 17/02/2009 and 18/03/2009 were therefore assumed to be representative of critical conditions in the watershed during the winter low-flow period. Best professional judgments were made to set the initial condition for 5-day CBOD and ground water DO concentration, in which no observed data are available.

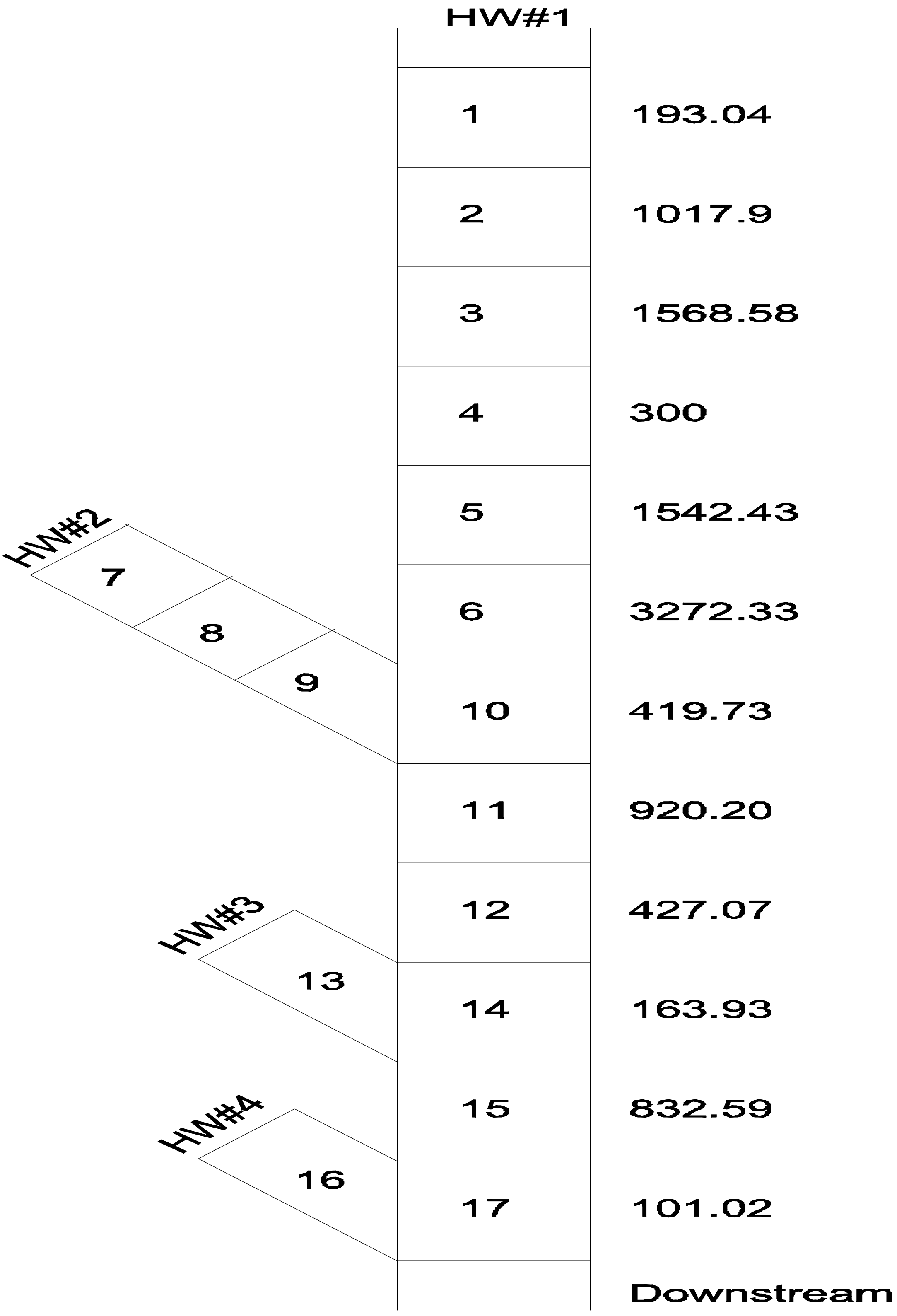


Fig. 4.7: Computational Grid Set - Up

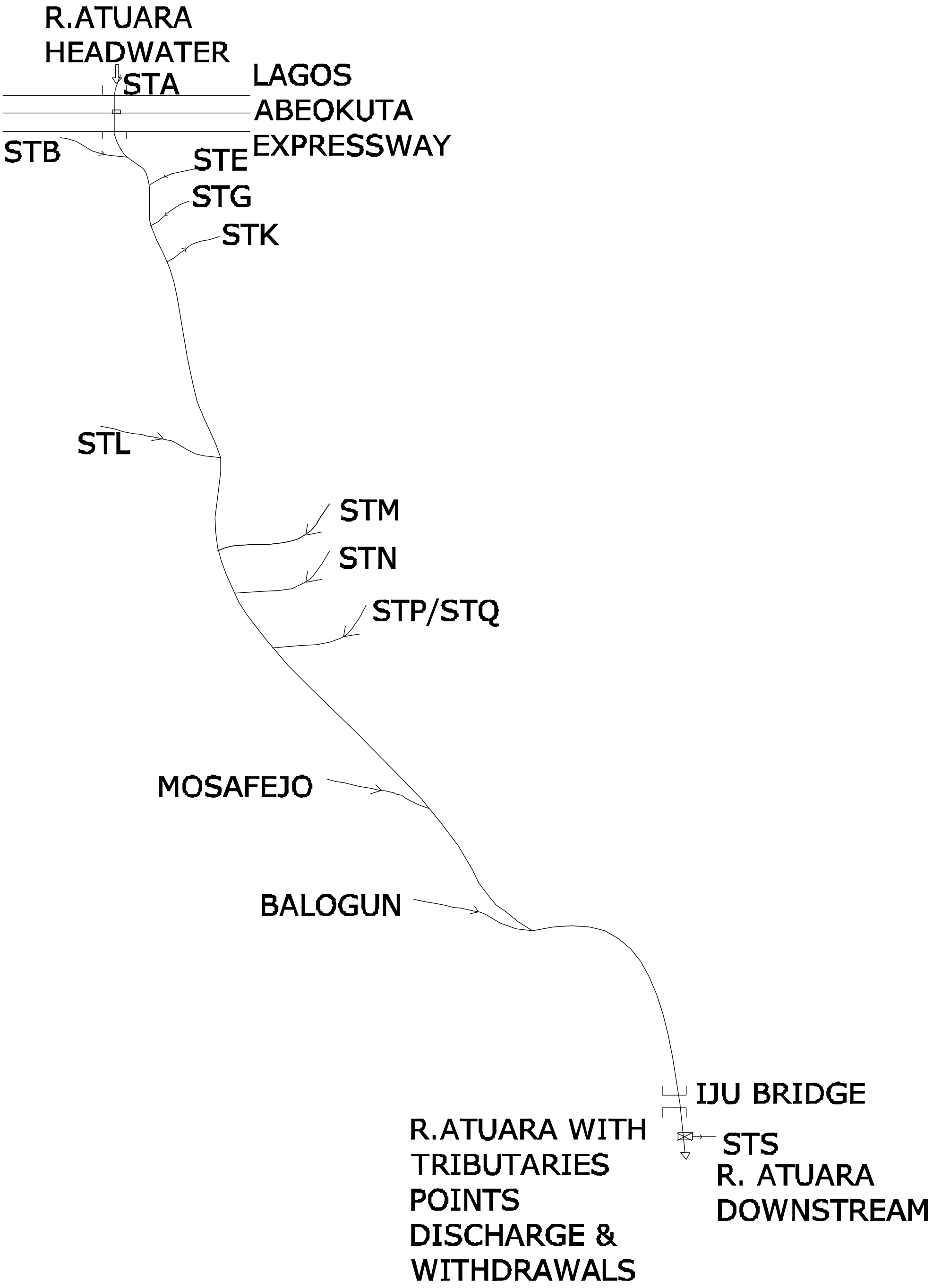


Figure 4.8 Location Map showing sampling Points and Tributaries

4.3.7.1 Initial Condition Based on Observation from Atuwara River Watershed

- Model temperature was set to 27.0^0C observed on 18/03/2009 and 26.0^0C observed on 17/02/2009.
- Dissolved oxygen was set to 90% saturation (6.3 mg/l) for inflow based on the observed temperature and elevation of the Atuwara watershed.
- The observed low flow of 0.477 m^3/s on 17/02/2009 was set as the critical stream flow.
- Instream organic Nitrogen and Nitrate nitrogen NO_3-N was set at 0.1mg/L and 0.1mg/L respectively as observed on 17/02/2009.

4.3.7.2 Initial Condition Based on Best Professional Judgment

- Ultimate carbonaceous oxygen demand (CBODu) was assumed as 56 mg/l based observed data of 5-day CBOD in the river on 17/10/2008 at 8:30am. The observed data was obtained at an altitude within 30m elevation of the main River. The effects of non-point sources were not considered at both season, since the samples were obtained in period of no-rain storm. Therefore, the 5-day CBOD in the watershed reasonably represents the initial condition of Atuwara River where primary source of impairment is point sources from industrial discharges.
- Atuwara River is a sandy stream (lots of fine sharp sand) and the oxygen replenishment in the interstitial places is very limited. In general, the ground water entering the river at this condition may have a low concentration of dissolved oxygen. Therefore, one can assume that the watershed has low DO concentration. As a conservative assumption, the DO of groundwater was assumed to be 2.0mg/L.

Saturation DO is sensitive to elevation or atmospheric pressure and temperature. The QUAL2K model software estimates the saturation DO based on the atmospheric pressure. The average elevation of Atuwara watershed is approximately 30m. By comparing the February—March, the model atmospheric pressure was set to 0.8atm.

Coefficients are needed to describe the water quality reaction rates within the river. Initial estimates were obtained from QUAL2K software default values, general literature values and from the QUAL2K user's manual (Chapra, 2007). Water quality coefficients are presented in table 4.3.

Channel hydraulics, reaeration rate and SOD substantially influence the concentration of DO in the streams. Due to the lack of data, the following assumptions were made:

- Based on field observation, the channel profile was assumed to be an upturned trapezium from a parabolic/hexagonal section.
- In sandy bottom streams, SOD values range from 0.2 to 1g/m2-day (Chapra, 1997). As Atuwara watershed is a sandy river the baseline existing SOD rate was set to 0.86g/m^2-day.
- The reaeration rate is either set by the user or by formulas available in QUAL2K. As reported by Chapra (2007) the empirical formulas which estimate reaeration rate based on hydraulic parameters and/or flow work was well within the depth range of 1 to 3.5 metres. The flow depth is between 0.49 m on 17/2/ 2009 and 3.17 m on 14/10/ 2008 at the Atuwara watershed. Therefore the reaeration coefficient was used as a calibration parameter of the Atuwara river DO model.

Assumptions

- No surface runoff driven non-point loadings are entering the river during the flow winter condition.
- The main cause of low DO during low flow is attributable to the SOD.

Table 4.3 Water Quality Calibration Rates and Coefficients

Parameter	Description	Units	Value
K_1	Carbonaceous biochemical oxygen deoxygenation rate	0.3/day	0.1
$CKNH_2$	Organic nitrogen hydrolysis	1/day	0.1
$CKNH_3$	Ammonia oxidation rate	1/day	0.25
$CKNO_2$	Nitrite oxidation rate	1/day	2.5

- Though detailed assessment of channel geometry was performed, there are still some likely instruments and human errors that may undermine the result.

Since flows vary throughout the year in most hydrologic system, water quality standards and target load will vary based on the changing flow. Management of the load should set a goal attainment not meeting the calculated target load.

Waste Load Allocations and Load Allocations

- Waste load allocation

There are no non-point source contributions considered in this study. The waste load allocations are therefore the observed point discharges from the industries.

- Load allocation,

The load allocation was determined using QUAL2K model.

4.3.8 Model Loading Rates/Endpoint Identification

Target Loading Capacity

The target values for dissolved oxygen are determined based on

i. The presence of numeric criteria,
ii. The degree of experience in applying the indicator, and
iii. The ability to easily monitor and produce quantifiable and reproducible results for this study

The target values for dissolved oxygen are based on numeric criteria. By virtue of location and geographic distribution of population and position of Ado-Odo Otta Local Government Area of Ogun State being spill over of the consequent of Lagos population explosion, both industrially and in landscape. The Atuwara watershed is noted to provide irrigation, livestock watering, wildlife habitat, freshwater fishery and secondary contact. It is most importantly utilised as the main source of water supply to the immediate Otta community. The numeric criteria for DO to meet the designated use of a freshwater fishery and drinking standard are that “DO” shall not be less than 4.0 mg/l.

Many factors influence DO concentrations, including:

- Input and oxidation of carbonaceous materials (CBODu)
- Input and oxidation of nitrogenous materials (NBODu)
- Input and oxygen demand of sediments in the water body (SOD)
- Reaeration

The pollutant of concern is biochemical oxygen demand both carbonaceous (CBODu) and nitrogenous (NBODu), which is expressed in terms of TBODu. Equation 4.36 shows this relationship. The TBODu is expressed based on the water body's assimilative capacity for oxygen-demanding substances

$$\text{TBODu} = \text{CBODu} + \text{NBODu} \qquad (4.36)$$

where $$\text{5-day CBOD} \times 2.54 = \text{CBODu} \qquad (4.37)$$

or $$30\%\ \text{CBOD} = \text{NBOD (Chapra 1997)} \qquad (4.38)$$

Over the time scale years, stream bottom sediments act as sinks for oxygen with carbon and nitrogen removed from the water column (Thomann and Mueller 1987; Chapra, 1997). Oxygen is consumed by the oxidation of organic carbon (CBODu) in the bottom sediment. This process is known as sediment oxygen demand (SOD). The role of sediments in the system-wide nutrient budget is especially important during the summer when seasonal low flows diminish tributary nutrient loads. During the winter (dry season), warm temperatures enhance biological processes in the sediments (USEPA, 1993) Oxygen-consuming constituents from point source pollution are delivered to the river during industrial discharge. Sources include brewery discharges, abattoir effluents, pharmaceutical discharges, food and beverages and distillers. These constituents settle out of the effluents and become a part of the river bottom. In slow flowing rivers/streams with a high bed-to-channel-volume ratio, large portions of the organic material will settle to the sediment surface and thus increase the SOD, wash off of settleable material (CBODu and NBODu) accumulates and exerts an additional SOD attributable to land-disturbing activities. A stream impacted by heavy loads of oxygen consuming pollutants either natural or manmade will exhibit low DO concentration during warm low flow periods (Woods, 2001; USGS, 2007). There have been numerous studies for establishing a SOD/TBODu relationship. According to the Streeter-Phelps SOD model, SOD is approximately 130 percent of the downward flux of TBODu (Chapra, 1997). This research thus employs the following relationship to link TBODu and SOD

$$\mathrm{SOD} = 1.3 \times \mathrm{TBODu} \tag{4.39}$$

4.3.9 Reaeration rate constants

The general equation for the flux of any gas is:

$$J = V_v \left(\frac{P_g}{H_e} - C_l \right) \tag{4.40}$$

where:

J = mass flux from the bulk liquid to the interface (mole m^{-2} d^{-1})

P_g = the gas pressure in the bulk gas

V_v = mass transfer velocity

C_l = liquid concentration in the bulk liquid

H_e = the gas specific parameter

Oxygen reaeration has a high Henry's constant of 0.8atm $m^3 mol^{-1}$, because oxygen is overwhelmingly liquid film controlled.

For a well mixed open batch reactor, a mass balance for oxygen can be written as:

$$V \frac{d_o}{d_t} = K_L A_S (O_S - O) \equiv V \frac{d_0}{d_t} = K_a V (O_S - O) \tag{4.41}$$

where:

A_s = surface area of the water body.

K_a = reparation rate which is equivalent to K_l / H (4.42)

O = oxygen concentration in the water

O_s = saturation concentration of oxygen

V = volume of the gas

H = mean depth

K_L = mass transfer velocity

Equation 4.41 provides insight into how the mechanism of oxygen reaeration operates. The direction and magnitude of the mass transfer depends partially on the difference between the saturation value and the actual value in the water. If the water is under saturated ($O_c<O_s$) then transfer will be positive (a gain) as oxygen moves from the atmosphere into the water to try to bring water back to the equilibrium state of saturation. Conversely, if the water is super saturated ($O_c>O_s$) then transfer will be negative (a loss) as oxygen is purged from the system. Oxygen reaeration rates can be extrapolated to other temperature by

$$K_T = K_a,20\theta^{T-20} \tag{4.43}$$

Where K_T = reaeration rate at temperature of 7 ^{o}C

K_a = rearation rate at temperature of 20 ^{o}C

Ø = Coefficient

where *f*or river and streams, numerous formulas have been proposed to model reaeration. Among these are the very commonly used: O'Connor-Dobbins (1958), Churchill *et al* (1962) and Owens-Gibbs Formula (1964):

Connor-Dobbins formula (1958)

$$K_a = 3.93\frac{V^{0.5}}{H^{1.5}} \qquad K_{a}/day),\ V\ (mps),\ H\ (m) \tag{4.44}$$

Churchill at al (1962) formula

$$K_a = 5.026\frac{V}{H^{1.67}} \qquad K_{a}/day),\ V\ (mps),\ H\ (m) \tag{4.45}$$

Owens-Gibbs, (Owens et al (1964*)*

$$K_a = 5.32\frac{V^{0.67}}{H^{1.85}} \qquad K_{a}/day),\ V\ (mps),\ H\ (m) \tag{4.46}$$

O'Connor – Dobbins has the widest applicability being appropriate for moderate to deep streams with moderate to low velocities. The Churchill formula applies for similar depths but for faster streams. The Owens-Gibbs relationship is used for shallower systems. This study applied O'Connor-Dobbins for the above reasons.

4.3.10 BOD Loadings, Concentrations and Rates

Table 4.4 gives typical values for the BOD decay rate range from 0.05 to 0.5d^{-1} with a geometric mean of about 0.15d^{-1}. This result can be used to estimate 0.95% response time for the bottle test as $t_{95} = {}^{3}/_{0.15}$=20d. Because such a long measurement period is unacceptable, water quality analysis earlier on adopted a 5- day BOD test.

Shortening the incubation time to 5 day makes the test practical. We must have a means to extrapolate the 5day result to the ultimate BOD level. This is usually done by performing a long term BOD to estimate the decay rate. If the first order decomposition model holds Eqn. 4.47 can be used to compute.

$$L_O = \frac{y_5}{1 - e^{-K_l(5)}} \tag{4.47}$$

where y_5 = 5 – day BOD. Table 4-4 includes typical values for the ratio of 5- day to ultimate BOD.

Table 4.5 provides typical values of flow rate and BOD for raw sewage from both the developing countries. In general the flow rate for United States is higher because higher water use typically accompanies a higher standard of living.

Table 4.4 Typical Values for the ratio of 5=day to ultimate BOD.

Ultimate	**For various level of is the BOD values here**	**Treatment BOD_U is the are to $CBOD_U$**
Treatment	K_1 (20°C)	BOD_s/BOD_u
Untreated	0.35 (0.20 – 0.50)	0.83
Primary treatment	0.20 (0.1 – 0.3)	0.63
Activated sludge	0.075 (0.05 – 0.10)	0.31

Table 4.5: Typical loading rates for untreated domestic sewage

	Per capital flow rate m^3 $capita^{-1}d^{-1}$	**Per capita CBOD m^3 $capita^{-1}d^{-1}$**	**CBOD concentration**
United States	0.57	125	220
Developing countries	0.19	60	32

The average concentration of the developing countries is generally lower because the lower water uses in these countries outweigh the higher per capital BOD contribution for the United States.

4.3.10.1 BOD Removal Rates

The bottle BOD decomposition rate provides a first estimate of the removal rate in natural waters. The rates depend on the degree of treatment of the sewage prior to discharge. Raw sewage is a mixture of compounds ranging from easily decomposable sugars to refractory substances that take longer to break down because waste treatment tends to selectively remove the former. BOD bottle rates trend to be lower for treated sewage. The bottle rate can rarely be directly applied to rivers because the bottle environment is not a good representation of the river. In fact only in deep slow rivers would the two converge. In most other rivers, environmental factors tend to make removal higher than for the bottle. The primary causes of this increase are settling and bed effects.

4.3.10.2 Settling

Settling effects relate to the fact that for sewage with a significant fraction of organic solids, the total removal rate in streams is a combination of settling and decomposition, K_v = total removal rates (d^{-1})

$$K_r = K_d + \frac{V_s}{H} \tag{4.48}$$

where V_s = BOD settling velocity (md^{-1}) and H = water depth (m) k_d = decomposition rate in the stream (d^{-1}). Using some typical settling velocities show that settling effect can be particularly significant for raw sewage in shallow streams (i.e. H<1m)

Figure 4.9a is a plot of total removal rate versus stream depth for BOD that is 50% in settleable form a range of settling velocities is depicted. A decomposition rate of 0.35 d^{-1} is used. (Chapra, 1997)

4.3.10.3 Bed Effects

All other things equal attached bacteria generally are more effective decomposers than free floating bacteria. Bottom decomposition can be parameterized as a mass-transfer flux of BOD. This is a way similar to settling, Bottom decomposition becomes more pronounced in shallower systems because the effect becomes more significant relative to the volumetric decomposition in the water.

Hydroscience (1971) gives

$$K_d = 0.3\left(\frac{H}{8}\right)^{-0.434} \qquad \mathit{for}\ 0 \le H \le 2.4m \tag{4.49}$$

$$K_d = 03 \qquad \mathit{when}\ H > 2.4m$$

CBOD = 25.83

$$K = 20(25.83)(1.047)^{25.4-20} = 662.01 \tag{4.50}$$

This is up to about 2.4m (8ft) the rate decreases with depth, above 2.4m the rate approach constant value that is typical of bottle rates. Figure 4.9b BOD decomposition rate can be extrapolated to other temperature using the Equation 4.51

$$K = K_{20}\theta^{T-20} \qquad \mathit{with}\ \theta = 1.047 \tag{4.51}$$

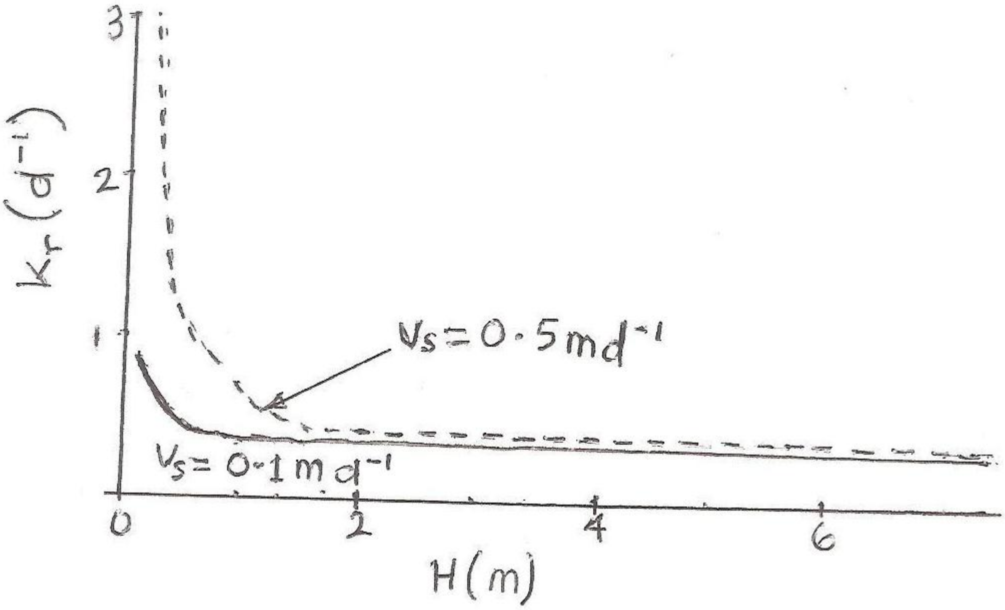


Figure 4.9a Total removal rate versus stream depth for BOD that is 50% in settleable form.

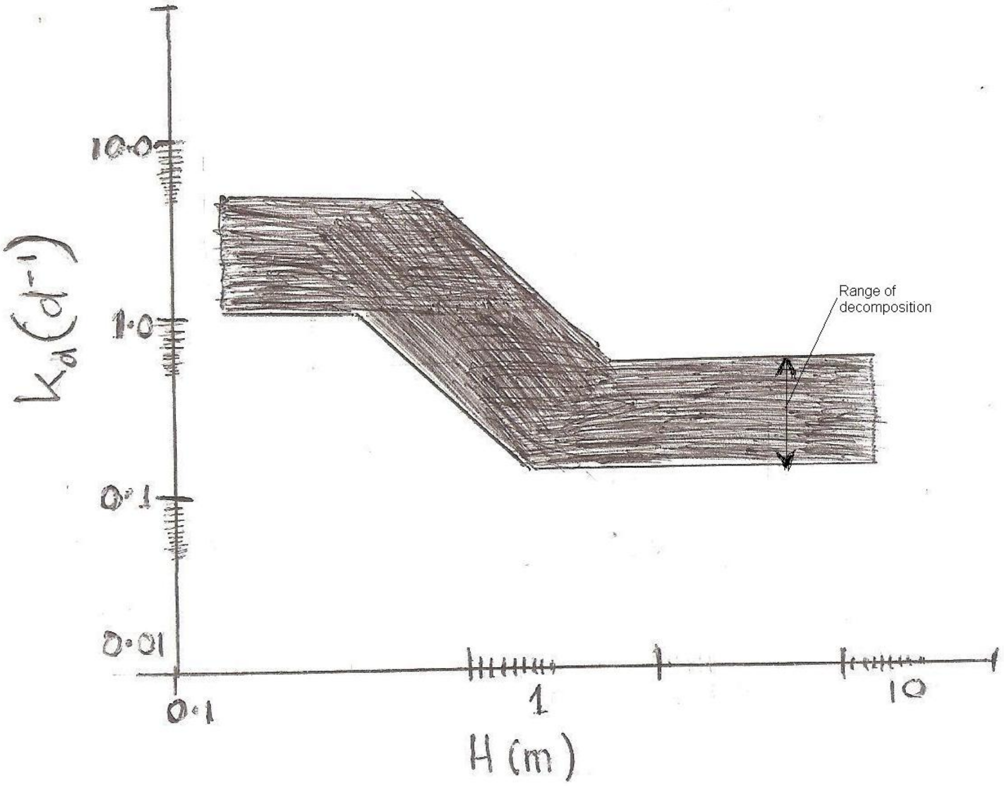


Figure 4.9b In – Stream decomposition rate versus depth (Bowie *et al,* 1985)

BOD removal rates tend to increase with temperature and tend to be higher immediately downstream from point source. The latter effect is more pronounced for untreated waste water. Enhanced settling and bed effects means that shallower systems typically exhibit higher BOD removal rates than deeper waters.

4.3.11 QUAL2K APPLICATION

Fig. 4.4 shows River Atuara that receives sewage from abattoir effluent at 193.04m below.

The de-oxygenation rate of CBOD= 0.5/d@ 20^{o}C

CBOD settling removal rate=0.25/d.

SOD for each reach is calculated.

O’Connor-Dobbins reparation rate is holding.

Elevation of the river is stated.

Channel’s geometry values are listed:-depth, area, width, slope e.t.c

Channel’s hydraulic values are listed:-velocity, flow.

Kinetic parameters

The Reach contains: The head measured distance is listed in a reversed order from downstream to upstream in order to be consistent with QUAL2K (Table 4.6).

Table 4.6 Model reaches Delineation

Reach	MS Head
1	1
2	6
3	2
4	2
5	2
6	2
7	2
8	2
9	2
10	2

7 Element type

1. Head water element
2. Standard element
3. Element just upstream from a junction
4. Junction element
5. Last element in a system
6. Input element
7. Withdrawal element.

In a reach we must have: head water=1, input=6 or withdrawal or both=7, standard element=2

Title Data

Conservative mineral i

Conservative mineral ii

Conservative mineral iii

BOD

DO.

Data type 2

The listing of the reach is from the most upstream point to the most downstream point to the downstream point in the system

Reach system is by Name e.g. Ekusere

River mile/ kilometre of distance= 193m = 0.193km

River mile must be in descending order

Data type 4

Computational element flag field data.

Data type 5

Hydraulic data- look for specification of cards of data type1 and use Manning’s coefficient calculation

Data type 6

BOD5 and DO reaction rate constants. e.g.

1. BOD decay rate coefficient
2. Settling rate
3. SOD
4. Reaeration coefficient

Data type 7

Initial conditions-1

This card group are card per reach establishes the initial values of the system for temperature, dissolved oxygen, BOD and the three conservative minerals. Initial condition for temperature must be specified whether it is simulated or not. For this model when temperature is not simulated the initial conditions are used to determine the temperature correction factors for the constants. Other values can be set at zero for steady-state application.

Data type 8

Incremental inflow-1- Even though this research will not simulate incremental inflows, these cards must be included. All the values can be set to zero.

Data type 10

Head water sources-1- this card group, one card per head water defines the flow, temperature, DO, BOD and conservative mineral concentrations of the head water. Note that the head water numbers are not the same as the reach or element numbers .Rather, the headwater are numbered consecutively (starting at 1) from the farthest upstream headwater.

Data type 11

Point Load – 1: This card group one card per point source or withdrawal defines the percent treatment, in flow or withdrawal, temperature DO, BOD, and conservative mineral concentration of each point load or withdrawal.

Note that the point load numbers are not the same as either the reach or element number rather the point sources or withdrawal are numbered consecutively (starting at 1) from the most upstream to the most downstream

Model Output

The outputs for this run consist of:

- Hydraulic summary
- Reaction coefficient summary
- Water quality variables
- Dissolved oxygen data

4.4 Application of GIS to River Atuwara Watershed/Study Area

Simulation models are powerful tools in support of watershed analysis and assessments of management scenarios at the water shed scale. This study integrates geographic information systems GIS and industrial point source pollution model QUAL2K software to analyze the effect of point source pollution in Atuwara watershed. Arcview point source pollution modelling AVPSM, an interface between Arcview GIS and ILWIS 3.2 Academic is developed to facilitate industrial watershed modelling. The interface consists of four modules, the Google Earth Plus, software for accessing any spatial location in the world, CorelDraw (version 11, 2003), a TIFF image, and ILWIS 3.2 Academic GIS Software.

The interface requires input databases of the river course, digital elevation model by GPS, hydrography and management practices. This is applied to study the watershed to simulate the impact of industrial pollution in the river. More recently, researchers have integrated GIS and hydrologic models within the Windows environment for PC e.g. Better Assessment Science Integrating Point and Non Point Sources (BASINS) by US Environmental protection Agency (Lahlou *et al* 1998, Chansheng He, 2003).

A digital elevation model (DEM) through the use of GPS is used to derive slope, slope length, aspect and other related parameters. The GPS, a global positioning system (Garmin GPS map 76) is navigating equipment. It is a small hand held receivable to provide global positioning information (accurate to within 10-20m) it is a system so cheap, flexible, convenient and accurate to determine the position of people and devices naming anywhere around the globe.

GPS is a satellite based system run by the United State Department of Defence. It uses a total of 24 active satellites orbiting at 3300Km/H. although there are further space crafts in orbit functioning as host spare - ready to take over in case of failure of an operational unit. This study applied the GPS to pick its information by navigating the Atuwara watershed and its geo-spatial environment. The data are used to develop input parameter files for the Arcview mapping of the hydrologic parameters.

The study area was accessed through Google Earth plus, software for accessing any place in the world. The study area was clipped i.e. extracted from the displayed scene, copied and pasted in Corel draw (version 11 2003). The clips were stitched together to form a seamless map. This was later converted to vector format and saved as TIFF image and was exported to GIS software ILWIS. 3.2 Academic, the ILWIS 3.2 environment interfaces the image and was georeferenced to make the coordinate equivalent to real life map. The georeferenced map was digitized. The digitization maps were cloned in different layers, such as road, river, industries, wetland, waypoint (sample points) etc. The files were moved and the layers created were exported again to software to make a clip file roaster format.

The layer created were exported one after the other to Arc view GIS 3.2a for final production of the maps in Arc view GIS .3.2a, attribute were created in order to create a data, and this would be linked with the map. This enables other analysis to be carried out pending further development; decision can be taken to other features. The Arcview GIS is a decision support tool it capture, store and analyse data.

4.5 Measurement of Contamination from Industrial Discharge by GIS

The concentration of a pollutant below the mixing zone resulting from a waste water discharge can be calculated using the following relationship.

$$C = \frac{C_1 \times Q_1 \ + \ C_2 \times Q_2}{Q_1 + Q_2} \tag{4.52}$$

where: C = concentration in combined flow.
Q_1 = quantity of flow in stream.
C_1= concentration of constituent in Q_1
Q_2= quantity of wastewater discharge
C_2= concentration of constituent in Q2

Many pollutants are reactive and dissipate after the mixing zone by adsorption, reaction or biological decay. The four well defined zones in a polluted stream/river are:

- The zone of degradation
- The zone of active decomposition
- The zone of recovery
- The zone of clear water

4.6 SUMMARY OF RESULTS

Table 4.7: October 14, 2008 Atuwara Rivers Model Water Quality Input Data

		Trace Organic Pollutants				**Inorganic Water Pollutants**									**Heavy Metals**				
Sample Code	**Relative Distance to STA-Atuara Upstream (km)**	**BOD_5**	**pH**	**Cond. (mS/cm^{-1})**	**DO**	**T.Hard.**	**Temp (°C)**	**T.Alkal.**	**TSS**	**TDS**	**COD**	**$PO_4^{-\cdot}$**	**Cl^-**	**NO_3^{-1}**	**Cad.**	**Pb.**	**Zn.**	**Fe.**	**Mn.**
FEPA STD		30	6.5 -8.5	**1000**	**4**	150	**20-33**		**30**	**500**	**80**	5	250	50	0.003	**0.01**	3	**0.3**	0.2
STA	0.00	25	7.15	169	6.93	32.6	26.1	102.1	26	203	41	0.1	120.2	0.1	0.009	0.05	<0.001	0.32	<0.002
STB	0.19	23	6.96	212	6.81	53.8	25.4	119.6	28	448	53	0.08	122.2	0.08	0.01	0.06	<.001	0.36	<0.002
STC	0.24	15	6.96	265	6.16	61.4	25.5	128.2	32	461	61	0.09	128.6	0.011	0.006	0.08	<0.001	0.49	<0.002
STD	1.21	42	6.92	273	4.61	65.71	25.6	130.7	41	1089	84	0.101	135.2	0.12	0.008	0.08	<0.001	0.54	<0.002
STE	1.26	56	6.87	289	0	65.12	30.35	134.6	59	1281.3	115	0.121	137.4	0.08	0.015	0.09	<0.001	0.54	<.002
STF	2.78	42	7.41	128	6.43	16.14	25.2	49	53	143	116	0.113	122	0.06	0.017	0.14	<0.001	1.06	<0.002
STG	2.83	8	7.35	131	7.3	18.7	25.2	57	55	152	94	0.108	119	0.06	0.018	0.15	<0.001	1.13	<0.002
STH	3.08	12	6.09	87	1.8	44.3	288	49	56.1	846	288	0.123	809	0.16	0.011	0.18	<0.001	1.14	<0.002
STJ	4.67	14	7.25	134	7.14	23.2	29.2	146	241	657	239	0.181	928	0.13	0.008	0.24	<0.001	1.17	0.1
STK	7.94	26	6.71	2105	3.26	15.4	28.9	217	253	712	249	0.15	1021	0.17	0.16	0.12	0.14	1.31	0.11
STL	8.36	8	5.95	0.2844	0	10.6	30.4	251	268	268	270	0.15	1202	2.04	0.1	0.11	0.23	2.29	0.12
STM	9.28	17	7.9	643	2.81	10.2	30.7	166	421	243	847	1.03	23.4	0.06	0.08	0.17	0.18	0.09	0.06
STN	9.71	56	8.8	746	0	9.73	32.6	125	616	256	1023	1.07	10.8	0.81	0.09	0.13	0.12	0.07	0.1
STP	9.88	32	8	141	4.16	9.91	29.4	122	316	257	189	1.07	68.1	0.68	0.06	0.14	<.001	0.06	0.08
STQ	9.88	26	8.1	156	3.69	10.1	29.6	117	328	263	194	1.09	28.3	0.53	0.005	0.1	<.001	0.06	0.04
STR	10.71	23	8.4	161	3.11	10.4	30.2	114	341	289	206	1.12	22.1	2.15	0.018	0.06	<.001	0.04	0.02
STS	10.81	19	7.61	71.3	4.25	8.5	27.8	9.4	61	118	210	1.17	8.9	3.6	0.08	0.63	0.18	0.61	0.02

All parameters are in mg/L except where stated

Table 4.8: October 14, 2008 Atuwara Rivers Statistical Summary of Analytical Data

Parameters	**Min**	**Max**	**Mean**	**Std dev**	**Range**
BOD_5	8	56	26.1176	15.0120	8 - 56
Ph	5.95	8.8	7.3194	0.7614	5.95 -8.8
Conductivity	0.2844	2105	335.9756	494.8553	0.2844 -2105
Dissolve oxygen	0	7.3	4.0271	2.5488	0 - 7.3
Total hardness	8.5	65.71	27.4006	21.7398	8.5 - 65.71
Temperature	25.2	288	43.5382	63.0402	25.2 - 288
Total alkalinity	9.4	251	119.8588	59.3899	9.4 - 251
Total suspended solids	26	616	187.9471	175.7432	26 - 616
Total dissolved solids	118	1281.3	452.1353	347.6503	118 - 1281.3
Chemical oxygen demand	41	1023	251.7059	270.7087	41 - 1023
Phosphate	0.08	1.17	0.4628	0.4801	0.08 - 1.17
Chloride	8.9	1202	294.4824	406.7758	8.9 - 1202
Nitrates	0.011	3.6	0.6377	1.0109	0.011 - 3.6
Cadmium	0.005	0.16	0.0409	0.0456	0.005 - 0.16
Lead	0.05	0.63	0.1488	0.1335	0.05 - 0.63
Zinc	0.12	0.23	0.0500	0.0826	0.12 - 0.23
Iron	0.04	2.29	0.6635	0.6121	0.04 - 2.29
Manganese	0.02	0.12	0.0394	0.0474	0.02 - 0.12

Table 4.9: October 14, 2008 Atuwara Rivers Field Measured Hydrogeometric Parameters

S/No	Way Points	Relative Distance to STA-Atuara Upstream(km	Station Description	WIDTH (m)		DEPTH(m)				Sides slope		Area (m^2)	Velocity (ms^{-1})	Flow (m^3s^{-1})	Manning's	Wetted Perimeter (m)	Oxygen Reaeration	Dispersion
				Top (B)	Bottom (B_o)	Left	Mid Stream	Right	Mean (H)	S_{s1}	S_{s2}	A_C	U	Q	n	P	K_a	E
1	STA	0.00	Atuara Upstream	13.1	11.56	0.74	0.89	0.8	0.81	1.04	1.13	10.6	0.41	4.351	0.035	13.899	3.452	4.930
2	STB	0.19	Abattoir	4.3	2.85	0.71	0.77	0.74	0.74	1	1.05	3.18	0.43	1.368	0.035	4.956	4.048	4.722
3	STC	0.24	Abattoir Downstream	8.4	6.74	0.86	1.26	0.8	0.97	1.21	1.13	7.58	0.43	3.25	0.035	9.598	2.698	5.743
4	STD	1.21	Sona Upstream	16.2	14.23	0.89	2.25	1.08	1.41	1.26	1.53	22.84	0.42	9.594	0.035	18.594	1.521	8.790
5	STE	1.26	Sona Discharge	8.6	6.51	1.14	2.03	0.95	1.37	1.61	1.34	11.78	0.38	4.477	0.035	10.821	1.511	7.727
6	STF	2.78	Ewupe Upstream	10.4	7.96	0.99	2.53	1.45	1.66	1.4	2.05	17.26	0.38	6.56	0.035	13.441	1.133	9.362
7	STG	2.83	Ewupe Discharge	13.4	10.81	1.02	2.68	1.57	1.76	1.44	2.22	23.58	0.4	9.434	0.035	16.732	1.065	10.450
8	STH	3.08	Ewupe Downstream	13.5	11.56	1.02	2.59	0.92	1.51	1.44	1.3	20.38	0.39	7.95	0.004	16.209	1.323	8.741
9	STJ	4.67	Afara Meje	16.9	15.26	1.32	2.17	2.96	2.15	1.87	4.19	36.34	0.41	14.897	0.004	23.892	0.798	13.083
10	STK	7.94	Ekusere	11.8	8.23	2.34	2.71	1.23	2.09	3.31	1.74	24.66	0.34	8.385	0.004	16.078	0.758	10.547
11	STL	8.36	Ekusere Down Stream	8.9	6.53	1.51	2.56	0.86	1.64	2.13	1.22	14.6	0.36	5.255	0.004	11.895	1.123	8.764
12	STM	9.28	Igboloye Upstream	9.4	6.1	1.79	2.22	1.51	1.84	2.53	2.13	17.3	0.32	5.535	0.004	12.815	0.891	8.740
13	STN	9.71	Igboloye Raw Effluents											0.1107				
14	STP	9.88	Igboloye Discharge	10.2	6.87	2.25	2.06	1.08	1.8	3.18	1.53	18.38	0.28	5.141	0.004	13.464	0.861	7.481
15	STQ	9.88	Igboloye 100m Down Stream	12.3	9.62	1.94	2.19	0.74	1.62	2.74	1.05	19.93	0.31	6.177	0.004	15.133	1.061	7.454
16	STR	10.71	Igboloye 600m Downstream	11.2	7.35	3.45	1.79	0.4	1.88	4.88	0.57	21.06	0.29	6.106	0.004	14.607	0.821	8.092
17	STS	10.81	Iju Water Works	16.9	10.46	5.02	3.11	1.39	3.17	7.09	1.96	15.62	0.32	4.995	0.004	25.362	0.394	4.387

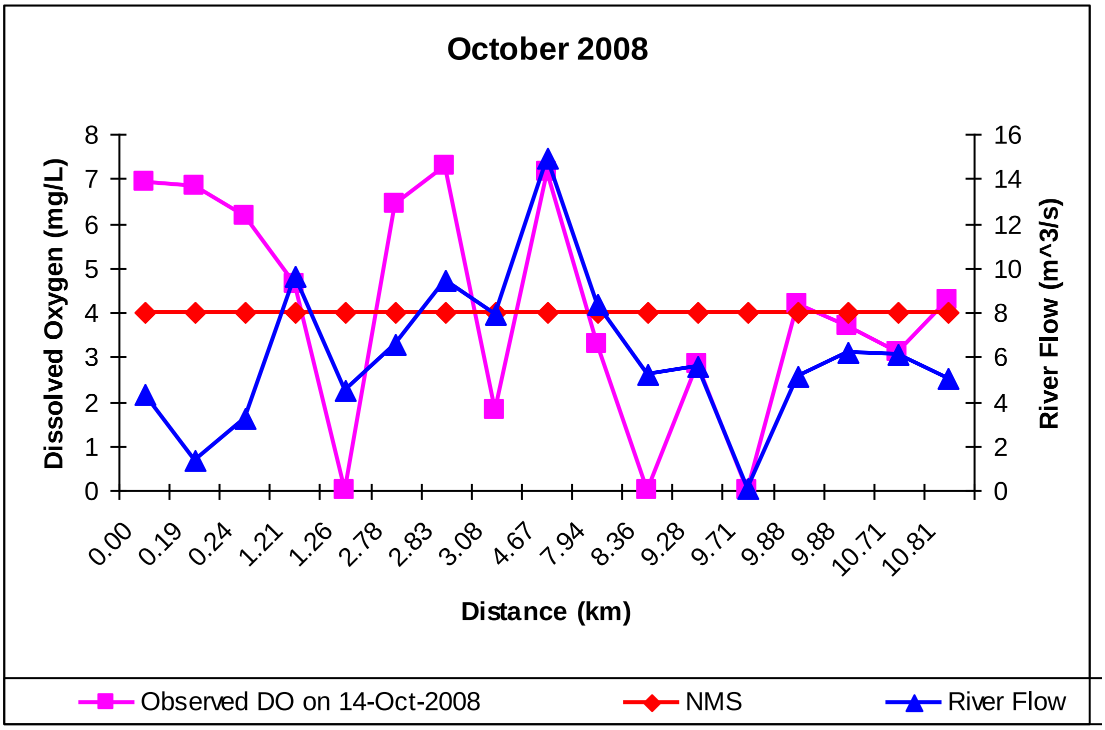


Figure 4.10: October 14, 2008 Atuwara River Dissolved Oxygen Vs River Flow Model Predictions

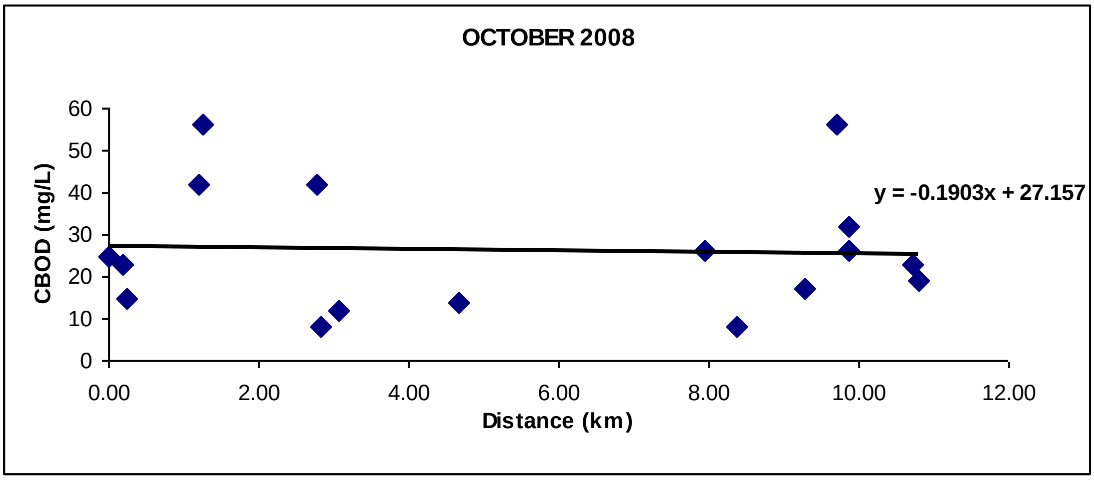


Figure 4.11: October 14, 2008 Atuwara River CBOD Vs River Flow Model Predictions

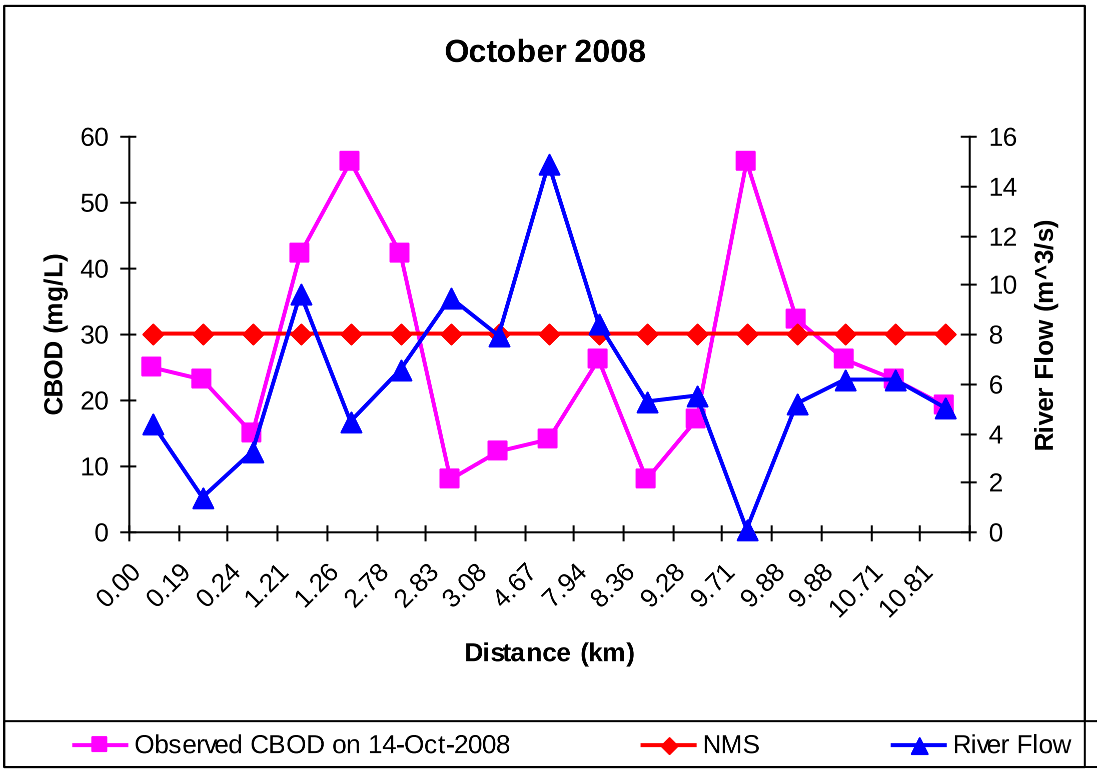


Figure 4.12: October 14, 2008 Atuwara River CBOD and Model Predictions

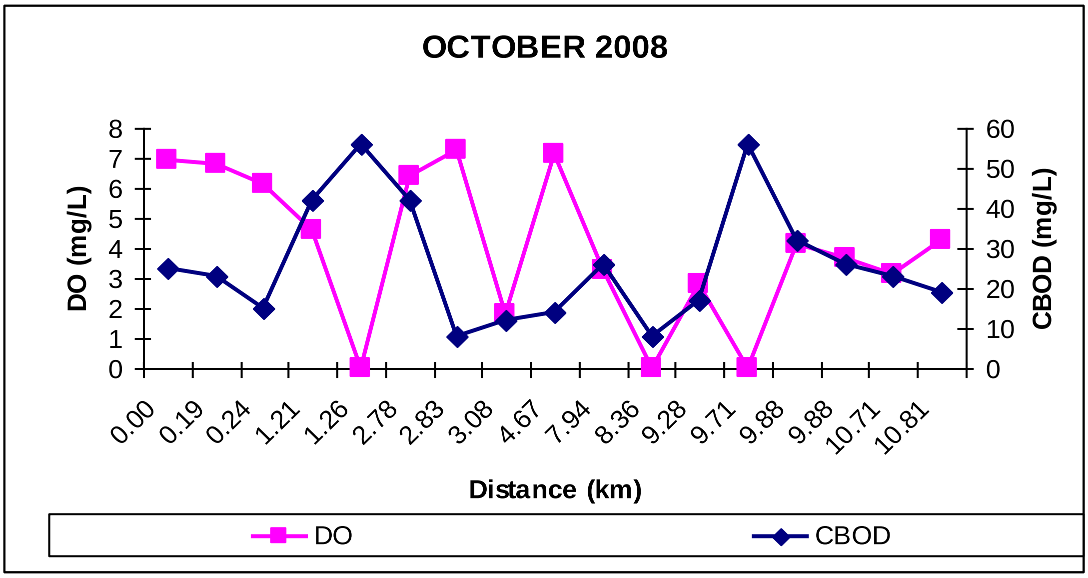


Figure 4.13: October 14, 2008 Atuwara River CBOD, DO and Model Predictions

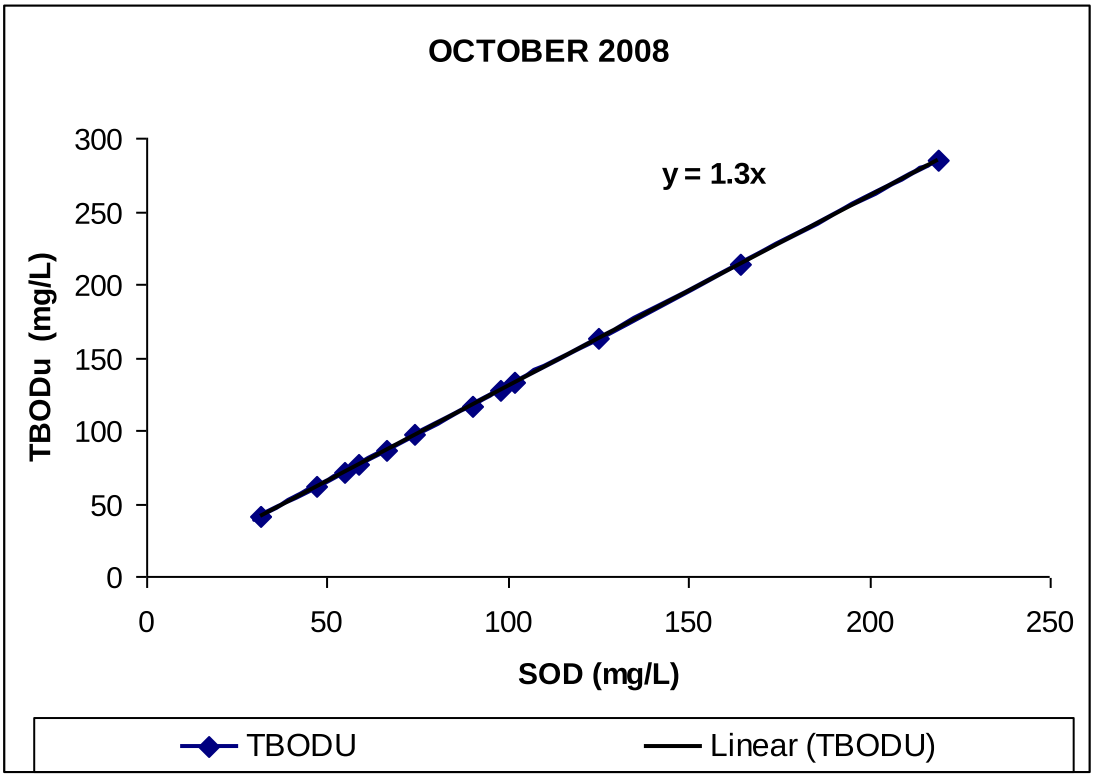


Figure 4.14: October 14 2008 Atuwara River CBOD, Vs SOD Model Predictions

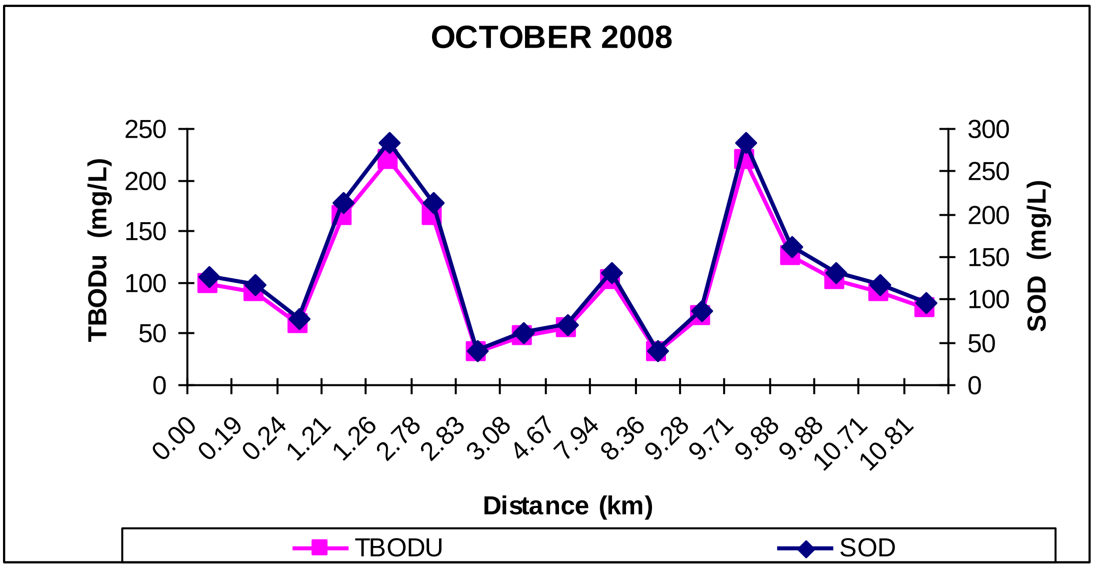


Figure 4.15: October 14, 2008 Atuwara River TBODu, Vs SOD Model Predictions

Table 4.10: October 14, 2008 Atuwara River Water Quality Model Loading Rates

Mean (H)	U	K_a	K_1	K_s	K_d	K_r
0.81	0.41	3.452	0.35	0.506173	0.81055	1.427834
0.74	0.43	4.048	0.35	0.581081	0.842977	1.518653
0.97	0.43	2.698	0.35	0.443299	0.749555	1.265019
1.41	0.42	1.521	0.35	0.297872	0.637237	0.991847
1.37	0.38	1.511	0.35	0.277372	0.645246	1.01021
1.66	0.38	1.133	0.35	0.228916	0.593657	0.894862
1.76	0.4	1.065	0.35	0.227273	0.578775	0.862866
1.51	0.39	1.323	0.35	0.258278	0.618566	0.949692
2.15	0.41	0.798	0.35	0.190698	0.53062	0.763179
2.09	0.34	0.758	0.35	0.162679	0.537179	0.776413
1.64	0.36	1.123	0.35	0.219512	0.596788	0.901666
1.84	0.32	0.891	0.35	0.173913	0.567716	0.839455
0	0	0.000	0.35	0	0	0
1.8	0.28	0.861	0.35	0.155556	0.573158	0.850935
1.62	0.31	1.061	0.35	0.191358	0.599975	0.908616
1.88	0.29	0.821	0.35	0.154255	0.562442	0.8284
3.17	0.32	0.394	0.35	0.100946	0.448335	0.606064

Table 4.11: February 17, 2009 Atuwara Rivers Model Water Quality Input Data

		Trace Organic Pollutants				**Inorganic Water Pollutants**									**Heavy Metals**				
Sample Code	**Relative Distance to STA-Atuara Upstream (km)**	**BOD_5**	**pH**	**Cond. (mS/cm^{-1})**	**DO**	**T.Hard.**	**Temp (°C)**	**T.Alkal.**	**TSS**	**TDS**	**COD**	**$PO_4^{-\cdot}$**	**Cl^-**	**NO_3^{-1}**	**Cad.**	**Pb.**	**Zn.**	**Fe.**	**Mn.**
FEPA STD		30	6.5 -8.5	**1000**	**4**	150	**20-33**		**30**	**500**	**80**	5	250	50	0.003	**0.01**	3	**0.3**	0.2
STA	0.00	10	7.01	123	7.4	5.59	26.2	46	16	63	72	0.208	3.3	0.12	0.007	0.33	<0.001	1.152	<0.002
STB	0.19	18	7.17	14.2	8.2	6.38	25.8	52	18	73	136	0.191	4.9	0.08	0.009	0.28	<.001	1.435	<.002
STC	0.24	12	7.2	143	7.7	6.81	25.8	54	19	74	108	0.211	4.55	0.06	0.006	0.27	<.001	1.22	<.002
STD	1.21	18	6.7	154	7.8	8.08	26	56	40	278	108	0.116	4.2	0.15	0.01	0.21	<.001	7.66	<.002
STE	1.26	24	5.42	405	0	7.136	32.5	58	36	210	208	0.22	4.3	0.04	0.006	0.26	<.001	7.66	<.002
STF	2.78	14	7.92	167	8.4	7.801	25.9	58	16	101	84	121	7.5	0.02	0.011	0.33	<.001	1.525	<.002
STG	2.83	22	7.19	195	7.2	9.093	25.9	60	16	102	60	0.101	4.5	0.06	0.1	0.23	<0.001	1.525	<.002
STH	3.08	16	6.24	62	5.2	2.418	26	50	42	28	48	0.141	3.8	0.18	0.009	0.22	<.001	1.296	<.002
STJ	4.67	24	6.82	139	7.6	6.977	25.9	52	20	72	76	0.236	4.3	0.07	0.006	0.2	<.001	1.512	<.002
STK	7.94	24	7.49	204	8.1	9.606	26.1	70	18	104	44	0.261	6.2	0.05	0.021	0.15	<.001	1.788	<.002
STL	8.36	22	5.42	403	0	3.331	26	182	36	220	218	0.181	3	0.11	0.012	0.23	<.001	7.71	<.002
STM	9.28	20	7.21	193	6.4	9.91	26.1	76	23	100	76	0.188	3.8	0.15	0.0.17	0.32	<.001	1.752	<.002
STN	9.71	32	6.8	243	1.4	16.91	26.2	94	35	126	144	0.262	9.8	0.12	0.012	0.012	0.27	<.001	0.111
STP	9.88	18	6.42	315	0	17.85	26.1	108	23	163	60	0.061	8.1	0.14	0.011	0.29	<.29	<.001	0.132
STQ	9.88	24	8.22	22.8	3.48	7.42	26.1	147.9	33.4	258	62	0.105	8.06	0.13	0.005	0.011	<0.001	1.93	0.125
STR	10.71	20	7.26	256	5.6	11.826	26.2	90	15	136	38	0.321	5.1	0.08	<.002	<.01	<.001	1.339	<.002
STS	10.81	16	7.03	184	5.2	9.424	25.9	66	11	96	72	0.311	6.4	0.09	<.002	<.01	0.0041	1.304	<.002

All parameters are in mg/L except where stated

Table 4.12: February 17, 2009 Atuwara Rivers Statistical Summary of Analytical Data

Parameters	Min	Max	Mean	Std dev	Range
BOD_5	10	32	19.8750	5.4391	10 - 32
Ph	5.42	8.22	6.9056	0.7624	5.42 - 8.22
Conductivity	14.2	405	189.9375	115.7536	14.2 - 405
Dissolve oxygen	0	8.4	5.2800	3.2174	0 - 8.4
Total hardness	2.418	17.85	8.5711	4.1492	2.418 - 17.85
Temperature	25.8	32.5	26.4250	1.6254	25.8 - 32.5
Total alkalinity	46	182	78.3688	38.6539	46 - 182
Total suspended solids	15	42	25.4000	9.7775	15 - 42
Total dissolved solids	28	278	131.7500	73.8119	28 - 278
Chemical oxygen demand	38	218	96.3750	54.9289	38 - 218
Phosphate	0.061	121	7.7377	30.2034	0.061 - 121
Chloride	3	9.8	5.3381	1.9956	3 - 9.8
Nitrates	0.02	0.18	0.0975	0.0463	0.02 - 0.18
Cadmium	0.005	0.1	0.0141	0.0235	0.005 - 0.1
Lead	0.011	0.33	0.2089	0.1113	0.011 - 0.33
Zinc	0.27	0.27	0.0169	0.0675	0.27 - 0.27
Iron	1.152	7.71	2.4690	2.6399	1.152 -7.71
Manganese	0.111	0.132	0.0230	0.0496	0.111 - 0.132

Table 4.13: February 17, 2009 Atuwara Rivers Field Measured Hydrogeometric Parameters

S/No	Way Points	Relative Distance to STA-Atuara Upstream (km)	Station Description	WIDTH(m)		DEPTH(m)				Sides Slope		Area (m^2)	Velocity (ms^{-1})	Flow(m^3s^{-1})	Manning's	Wetted Perimeter (m)	Oxygen Reaeration	Dispersion
				Top (B)	Bottom (B_o)	Left	Mid Stream	Right	Mean (H)	S_{s1}	S_{s2}	A_C	U	Q	n	P	K_a	E
1	STA	0.00	Atuwara Upstream	8.4	7.42	0.46	0.59	0.52	0.55	0.65	0.73	4.62	0.31	1.432	0.035	8.850	5.365	2.530
2	STB	0.19	Abattoir	3.8	2.79	0.52	0.65	0.49	0.49	0.93	0.69	1.862	0.32	0.596	0.035	4.108	6.481	2.328
3	STC	0.24	Abattoir Downstream	5.7	4.71	0.59	0.71	0.49	0.6	0.83	0.69	3.42	0.35	1.197	0.035	6.302	5.003	3.117
4	STD	1.21	Sona Upstream	8.3	7.38	0.46	1.1	0.46	0.67	0.65	0.65	5.56	0.35	1.946	0.035	9.101	4.239	3.480
5	STE	1.26	Sona Discharge	8.1	7.02	0.59	1.39	0.49	0.82	0.83	0.69	6.642	0.36	2.391	0.035	9.196	3.176	4.381
6	STF	2.78	Ewupe Upstream	7.6	6.3	0.62	1.48	0.68	0.93	0.88	0.96	7.07	0.36	2.544	0.035	8.877	2.629	4.968
7	STG	2.83	Ewupe Discharge	7.5	5.89	0.62	1.2	0.99	0.94	0.88	1.4	7.05	0.38	2.679	0.035	8.640	2.658	5.302
8	STH	3.08	Ewupe Downstream	7.6	6.46	0.59	1.14	0.55	0.76	0.83	0.78	5.78	0.4	2.31	0.004	8.502	3.751	4.511
9	STJ	4.67	Afara Meje	11.6	9.93	0.59	0.86	1.08	0.84	0.83	1.53	9.74	0.51	4.969	0.004	12.410	3.646	6.358
10	STK	7.94	Ekusere	6	4.95	0.74	1.17	0.31	0.74	1.05	0.44	4.44	0.48	2.13	0.004	6.905	4.277	5.269
11	STL	8.36	Ekusere Down Stream	6.1	4.84	0.71	0.83	0.55	0.696	1	0.78	4.24	0.39	1.655	0.004	6.754	4.227	4.027
12	STM	9.28	Igboloye Upstream	7	5.47	0.55	0.8	0.98	0.78	0.78	1.39	5.46	0.3	1.638	0.004	7.723	3.125	3.473
13	STN	9.71	Igboloye Raw Effluents	-	-	-	-	-	-			-	-	0.03276				
14	STP	9.88	Igboloye Discharge	7.3	5.61	0.89	1.02	0.8	0.86	1.25	1.13	6.28	0.21	1.318	0.004	8.155	2.258	2.680
15	STQ	9.88	Igboloye 100m Down Stream	5.7	3.97	1.05	1.08	0.68	0.94	1.48	0.96	5.36	0.27	1.446	0.004	6.771	2.241	3.765
16	STR	10.71	Igboloye 600m Downstream	6.8	5.41	0.71	0.92	0.68	0.77	1	0.96	5.24	0.31	1.623	0.004	7.577	3.238	3.543
17	STS	10.81	Iju Water Works	8.8	5.38	2.34	1.23	1.08	1.55	3.3	1.53	13.64	0.28	3.819	0.004	11.109	1.078	6.441

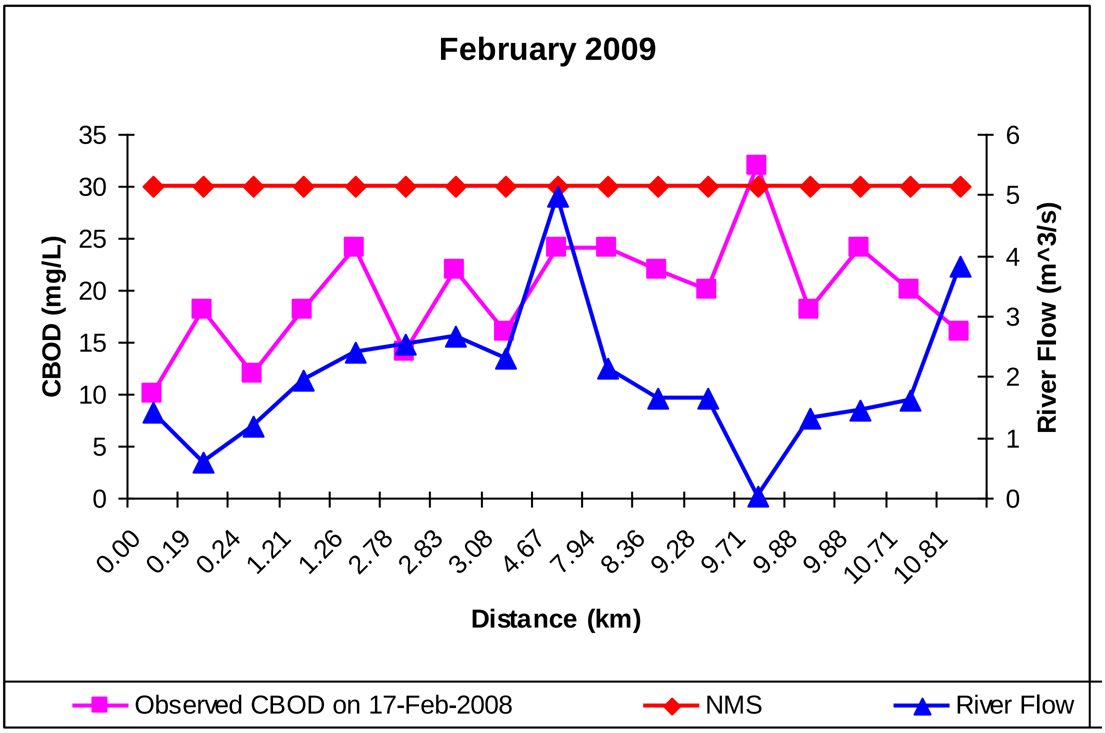


Figure 4.16: February 17 2009, Atuwara River Dissolved Oxygen Vs River Flow Model Predictions

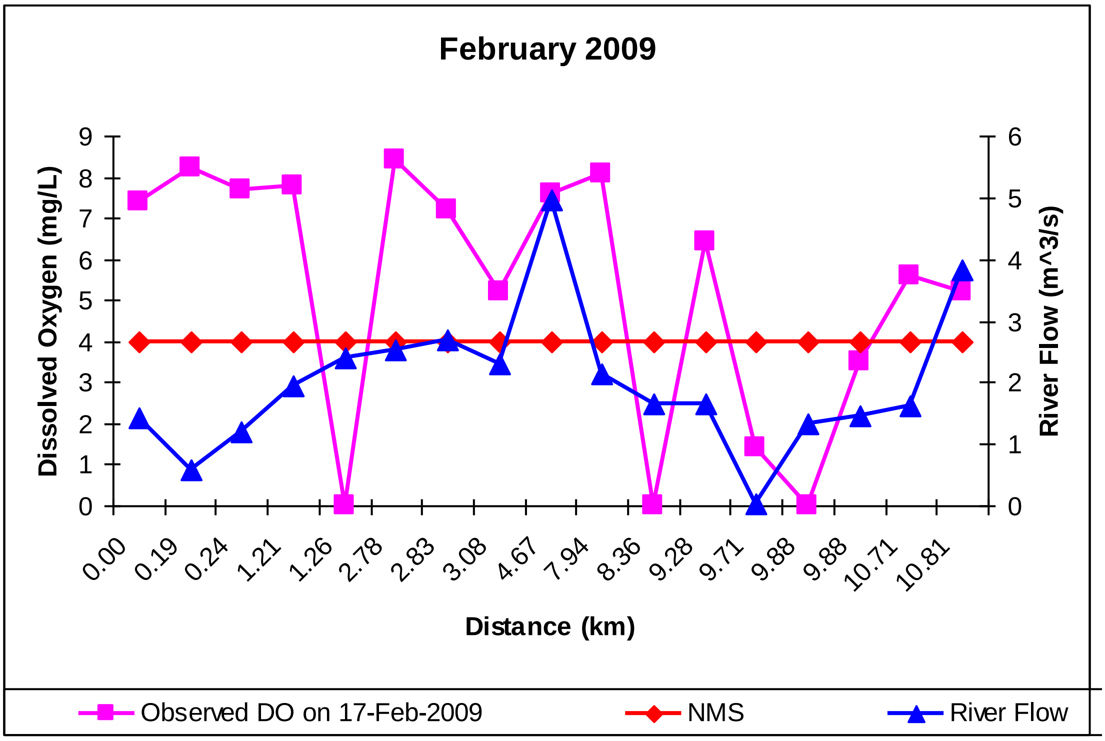


Figure 4.17: February 17, 2009 Atuwara River CBOD Vs River Flow Model Predictions

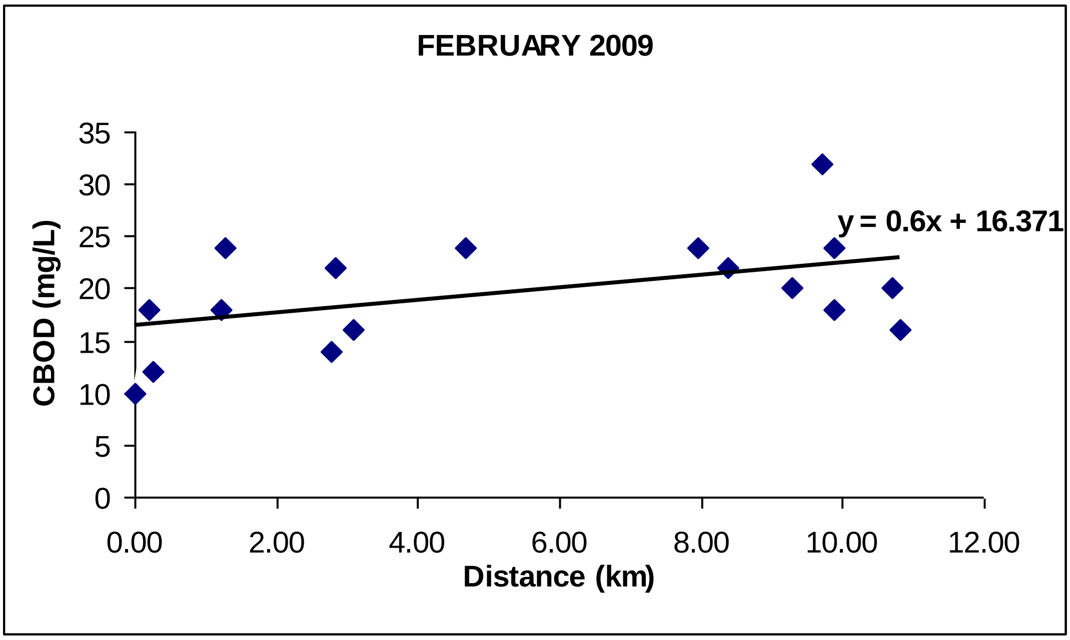


Figure 4.18: February 17, 2009 Atuwara River CBOD and Model Predictions

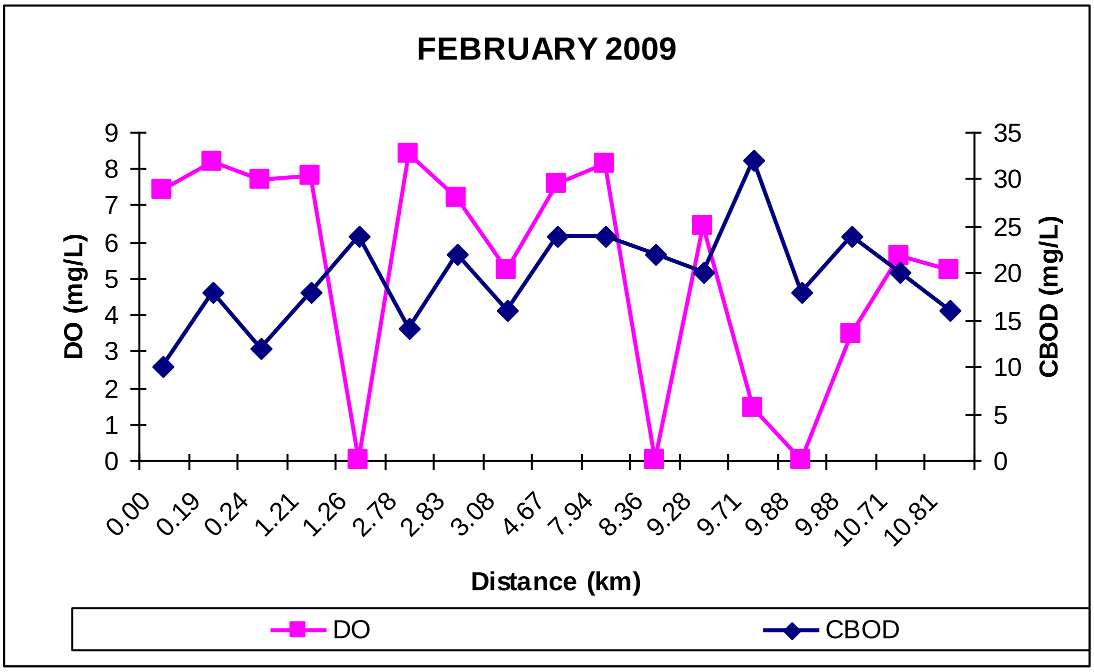


Figure 4.19: February 17, 2009 Atuwara River CBOD, DO and Model Predictions

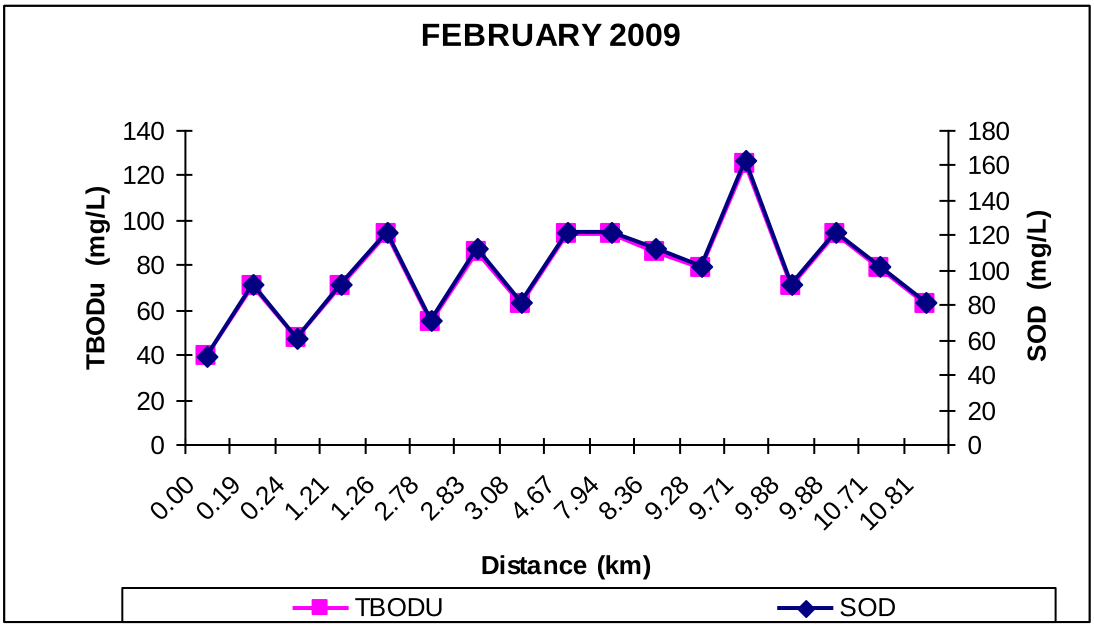


Figure 4.20: February 17, 2009 Atuwara River CBOD, Vs SOD Model Predictions

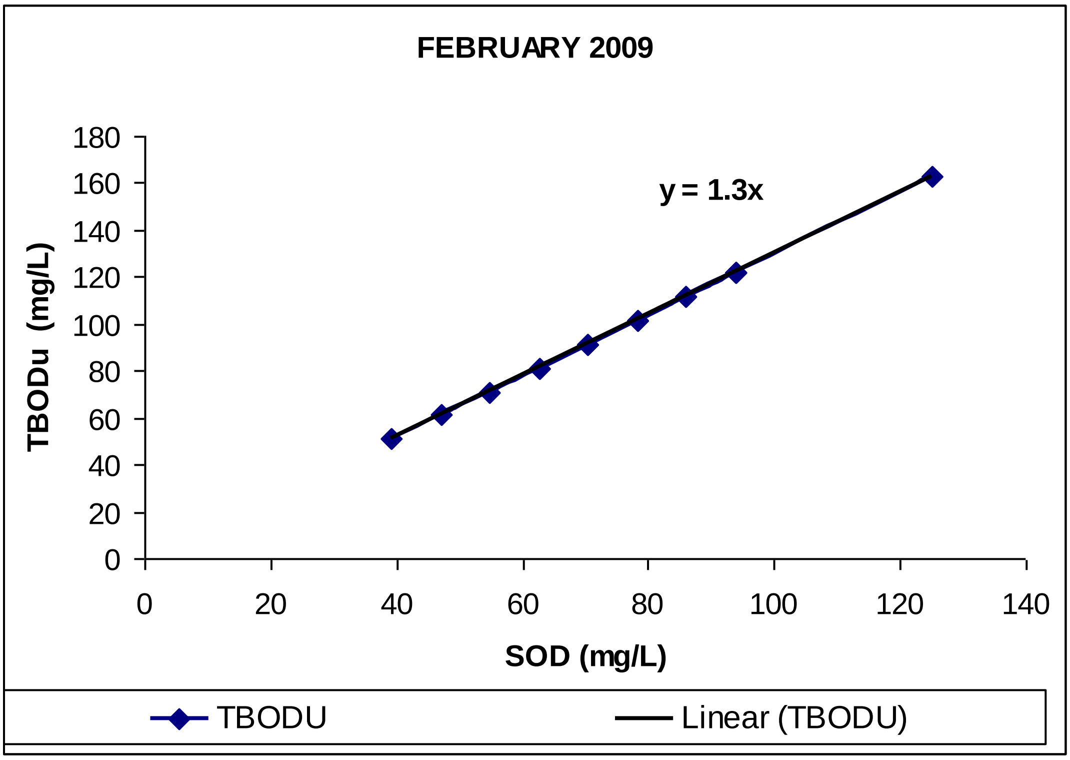


Figure 4.21: February 17, 2009 Atuwara River TBODu, Vs SOD Model Predictions

Table 4.14: February 17, 2009 Atuwara River Water Quality Model Loading Rates

Mean (H)	U	K_a	K_1	K_s	K_d	K_r
0.55	0.31	5.365	0.35	0.563636	0.958837	1.867928
0.49	0.32	6.481	0.35	0.653061	1.008132	2.02854
0.6	0.35	5.003	0.35	0.583333	0.923304	1.756637
0.67	0.35	4.239	0.35	0.522388	0.880128	1.626397
0.82	0.36	3.176	0.35	0.439024	0.806245	1.416001
0.93	0.36	2.629	0.35	0.387097	0.76338	1.301014
0.94	0.38	2.658	0.35	0.404255	0.759845	1.29176
0.76	0.4	3.751	0.35	0.526316	0.833277	1.491171
0.84	0.51	3.646	0.35	0.607143	0.797857	1.393095
0.74	0.48	4.277	0.35	0.648649	0.842977	1.518653
0.696	0.39	4.227	0.35	0.560345	0.865705	1.584096
0.78	0.3	3.125	0.35	0.384615	0.823936	1.464961
-	-	0.000	0.35	0	0	0
0.86	0.21	2.258	0.35	0.244186	0.789751	1.371146
0.94	0.27	2.241	0.35	0.287234	0.759845	1.29176
0.77	0.31	3.238	0.35	0.402597	0.828563	1.477913
1.55	0.28	1.078	0.35	0.180645	0.611587	0.934168

Table 4.15: March 18, 2009 Atuwara Rivers Model Water Quality Input Data

		Trace Organic Pollutants				Inorganic Water Pollutants									Heavy Metals				
Sample Code	**Relative Distance to STA-Atuara Upstream (km)**	**BOD_5**	**pH**	**Cond. (mS/cm^{-1})**	**DO**	**T.Hard.**	**Temp (°C)**	**T.Alkal.**	**TSS**	**TDS**	**COD**	**PO_4^{-}**	**Cl^-**	**NO_3^{-1}**	**Cad.**	**Pb.**	**Zn.**	**Fe.**	**Mn.**
FEPA STD		30	6.5 -8.5	**1000**	**4**	150	**20-33**		**30**	**500**	**80**	5	250	50	0.003	**0.01**	3	**0.3**	0.2
STA	0.00	21	6.7	7.3	7.03	6.2	26.6	47.6	14.45	136	73.8	1.17	4.04	3.6	0.006	0.29	<0.001	1.17	<0.002
STB	0.19	18	6.9	18.3	7.79	7.34	26.9	50.4	16.12	170	154	2.76	6	8.5	0.008	0.25	<0.001	1.46	<0.002
STC	0.24	23	6.85	4.1	7.24	7.62	26.8	49.2	17.6	161	121	1.55	5.57	8.5	0.005	0.24	<0.001	1.24	<0.002
STD	1.21	31	6.55	4.7	7.33	7.67	27.2	50.8	31.6	374	117	1.28	5.15	7.1	0.009	0.19	<0.001	7.03	<0.002
STE	1.26	19	6.5	48.1	2.18	7.2	33.8	55.2	32.8	410	91	0.81	7.43	6.5	0.006	0.23	<0.001	7.04	<0.002
STF	2.78	6	6.9	40.1	7.88	7.51	26.9	52.4	20.8	501	56	0.6	9.19	2.6	0.01	0.25	<0.001	1.47	<0.002
STG	2.83	30	6.85	2	6.66	7.78	26.9	63	19.8	128	65	2.49	5.51	4.4	0.009	0.29	<0.001	1.32	<0.002
STH	3.08	10	6.85	4.7	4.99	2.36	27	62	37.6	104	71	0.9	4.66	3.6	0.008	0.2	<0.001	1.56	<0.002
STJ	4.67	12	6.85	0.33	7.3	7.54	26.9	48	20.4	308	53	2.33	5.27	0.04	0.006	0.18	<0.001	1.54	<0.002
STK	7.94	9	6.95	2.01	7.78	8.89	26.9	61.2	56.4	256	181	0.32	6.31	2.4	0.017	0.13	<0.001	1.81	<0.002
STL	8.36	13	6.65	0.17	1.03	3.78	27.1	138.4	59	323	92	2.92	3.68	11.3	0.011	0.2	<0.001	6.36	0.038
STM	9.28	6	6.95	6.9	6.51	6.19	27	70.8	72.6	193	116	2.49	4.66	1.8	0.016	0.28	<0.001	1.77	0.037
STN	9.71	11	6.65	36.1	2.61	15.42	27.1	110.8	69	189	76	1.52	9.26	2.5	0.011	0.24	<0.001	2.37	0.071
STP	9.88	12	6.55	0.9	0.85	13.53	27	113.2	82	211	102	1.37	9.95	4.8	0.01	0.26	<0.001	3.48	0.127
STQ	9.88	10	6.7	25.5	4.2	12.2	27.1	112.6	89.8	242	51	1.08	7.73	3.7	0.004	0.01	<0.001	1.85	0.12
STR	10.71	17	6.85	1.8	5.32	11.75	27.1	111.2	826	204	42	2.18	6.25	5.2	<0.002	0.01	<0.001	1.365	0.041
STS	10.81	15	6.95	2.95	5.46	10.41	26.9	58.8	39.2	102	58	2.11	7.84	4.2	<0.002	0.01	<0.001	1.33	0.041

All parameters are in mg/L except where stated

Table 4.16: March 18, 2009 Atuwara Rivers Statistical Summary of Analytical Data

Parameters	Min	Max	Mean	Std dev	Range
BOD_5	6	31	15.5000	7.7115	6 - 31
Ph	6.5	6.95	6.7656	0.1502	6.5 - 6.95
Conductivity	0.17	48.1	12.6881	15.9338	0.17 - 48.1
Dissolve oxygen	0.85	7.88	5.4188	2.4938	0.85 -7.88
Total hardness	2.36	15.42	8.3113	3.4112	2.36 - 15.42
Temperature	26.6	33.8	27.3938	1.7144	26.6 - 33.8
Total alkalinity	47.6	138.4	74.8000	30.8157	47.6 - 138.4
Total suspended solids	14.45	826	91.6231	197.4755	14.45 - 826
Total dissolved solids	104	501	244.3750	111.4713	104 - 501
Chemical oxygen demand	42	181	91.3625	38.8645	42 - 181
Phosphate	0.32	2.92	1.6106	0.8129	0.32 - 2.92
Chloride	3.68	9.95	6.2913	1.9103	3.68 - 9.95
Nitrates	0.04	11.3	4.7838	2.9412	0.04 - 11.3
Cadmium	0.004	0.017	0.0085	0.0042	0.004 - 0.017
Lead	0.01	0.29	0.2031	0.0867	0.01 - 0.29
Zinc	0	0	0.0000	0.0000	0 - 0
Iron	1.17	7.04	2.6772	2.1280	1.17 - 7.04
Manganese	0.037	0.127	0.0271	0.0434	0.037 - 0.127

Table 4.17: March 18, 2009 Atuwara Rivers Field Measured Hydrogeometric Parameters

S/No	Way Points	Relative Distance to STA-Atuara Upstream (km)	Station Description	WIDTH(m)		DEPTH(m)				Sides Slope		Area (m^2)	Velocity (ms^{-1})	Flow(m^3s^{-1})	Manning's	Wetted Perimeter (m)	Oxygen Reaeration	Dispersion
				Top (B)	Bottom (B_o)	Left	Mid Stream	Right	Mean (H)	S_{s1}	S_{s2}	A_C	U	Q	n	P	K_a	E
1	STA	0.00	Atuara Upstream	9.2	8.16	0.49	0.65	0.55	0.56	0.69	0.78	5.15	0.34	1.751	0.035	9.635	5.468	2.825
2	STB	0.19	Abattoir	4.1	2.96	0.59	0.68	0.55	0.61	0.83	0.78	2.5	0.36	0.9	0.035	4.599	4.949	3.258
3	STC	0.24	Abattoir Downstream	6	4.73	0.68	0.83	0.59	0.72	0.96	0.83	4.32	0.35	1.512	0.035	6.712	3.806	3.740
4	STD	1.21	Sona Upstream	9.5	8.49	0.49	1.14	0.52	0.92	0.69	0.73	8.74	0.33	2.884	0.035	10.896	2.558	4.506
5	STE	1.26	Sona Discharge	8.8	7.66	0.59	1.42	0.55	0.85	0.83	0.78	7.48	0.4	2.992	0.035	9.944	3.172	5.046
6	STF	2.78	Ewupe Upstream	8.3	6.91	0.65	1.69	0.74	1.03	0.92	1.05	8.55	0.37	3.163	0.035	9.812	2.287	5.656
7	STG	2.83	Ewupe Discharge	8	6.27	0.68	1.6	1.05	1.11	0.96	1.48	8.88	0.36	3.196	0.035	9.578	2.016	5.930
8	STH	3.08	Ewupe Downstream	8.1	6.86	0.65	1.26	0.59	0.83	0.92	0.83	6.72	0.37	2.487	0.004	9.133	3.161	4.557
9	STJ	4.67	Afara Meje	13.4	11.06	0.77	1.05	1.57	1.13	1.09	2.22	15.14	0.43	6.511	0.004	14.742	2.145	7.212
10	STK	7.94	Ekusere	6.5	4.84	0.89	1.72	0.77	1.13	1.26	1.09	7.35	0.38	2.791	0.004	8.173	2.017	6.373
11	STL	8.36	Ekusere Down Stream	4.78	2.91	0.92	1.42	0.95	1.1	1.69	1.34	5.26	0.38	1.998	0.004	6.399	2.100	6.204
12	STM	9.28	Igboloye Upstream	5.7	4.1	0.65	0.71	0.95	0.77	0.92	1.34	4.39	0.3	1.316	0.004	6.348	3.186	3.427
13	STN	9.71	Igboloye Raw Effluents	-		-	-	-	-			-	-	0.02632				
14	STP	9.88	Igboloye Discharge	8.7	7.13	0.55	0.83	1.02	0.8	0.78	1.44	6.96	0.21	1.461	0.004	9.454	2.517	2.493
15	STQ	9.88	Igboloye 100m Down Stream	9.2	5.7	0.55	0.83	0.65	0.68	0.78	0.92	4.69	0.22	1.032	0.004	7.550	3.287	1.665
16	STR	10.71	Igboloye 600m Downstream	4.1	6.31	1.14	1.26	0.55	0.98	1.61	0.78	17.84	0.29	2.273	0.004	9.214	2.181	8.229
17	STS	10.81	Iju Water Works	6	9.82	2.62	1.39	1.36	1.79	3.7	1.92	24.7	0.29	7.163	0.004	16.808	0.884	17.719

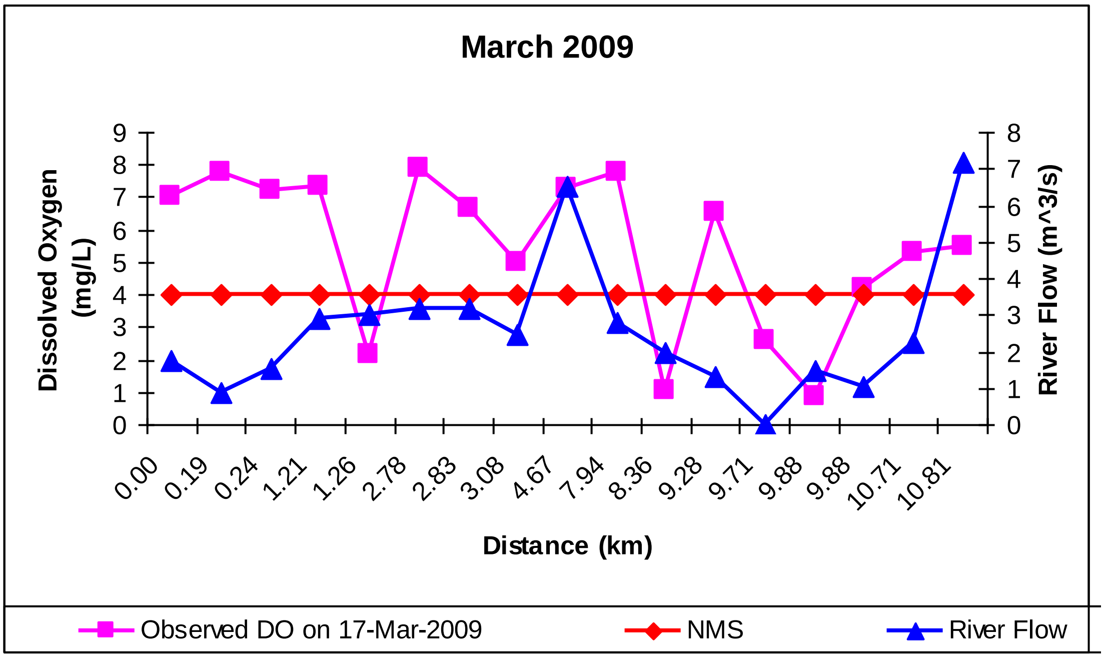


Figure 4.22: March 18, 2009 Atuwara River Dissolved Oxygen Vs River Flow Model Predictions

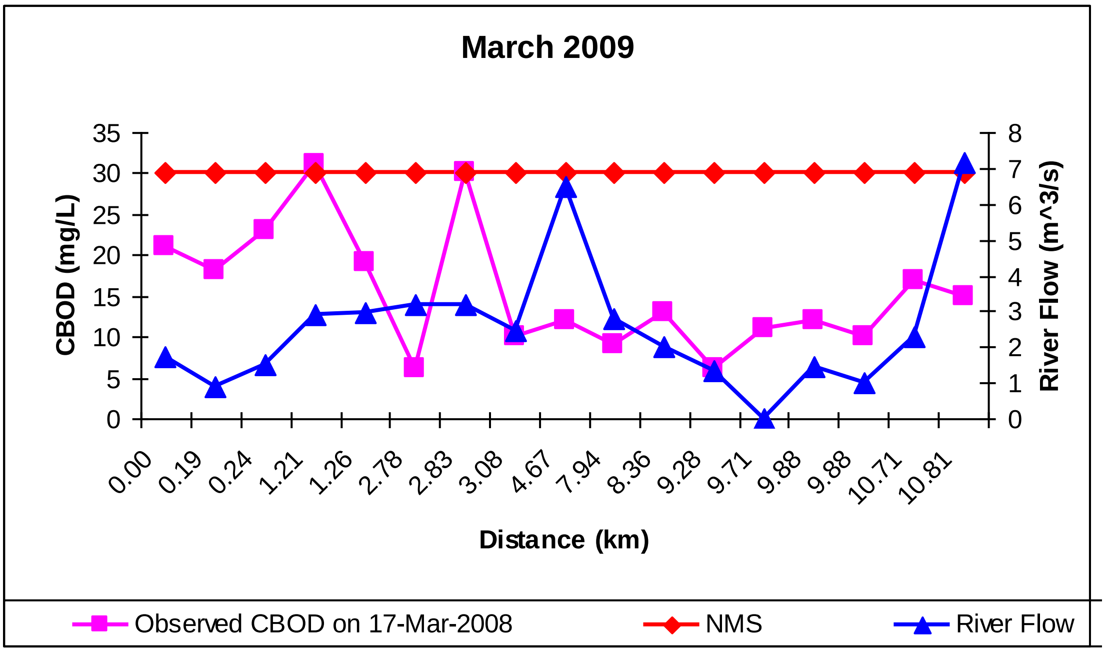


Figure 4.23: March 18, 2009 Atuwara River CBOD Vs River Flow Model Predictions

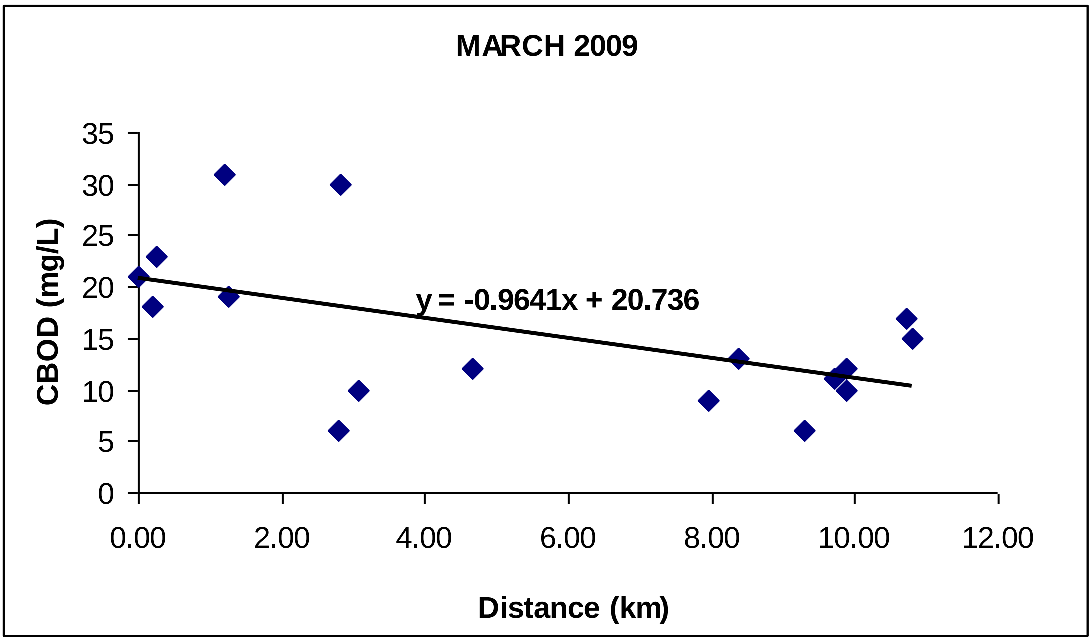


Figure 4.24: March 18, 2009 Atuwara River CBOD and Model Predictions

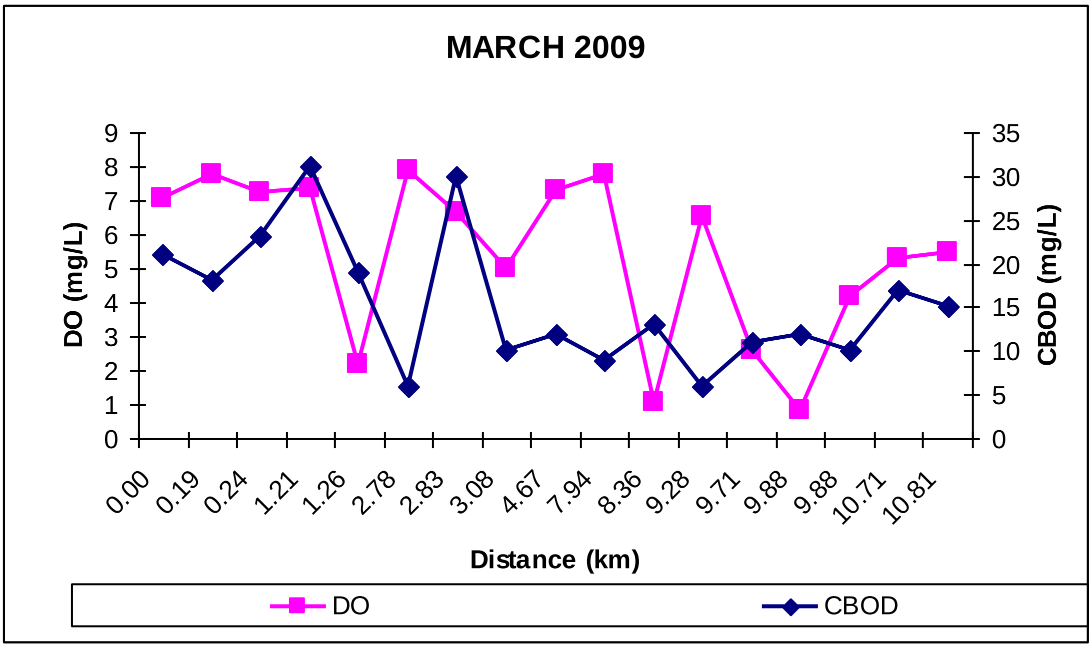


Figure 14.25: March 11, 2009 Atuwara River CBOD, DO and Model Predictions

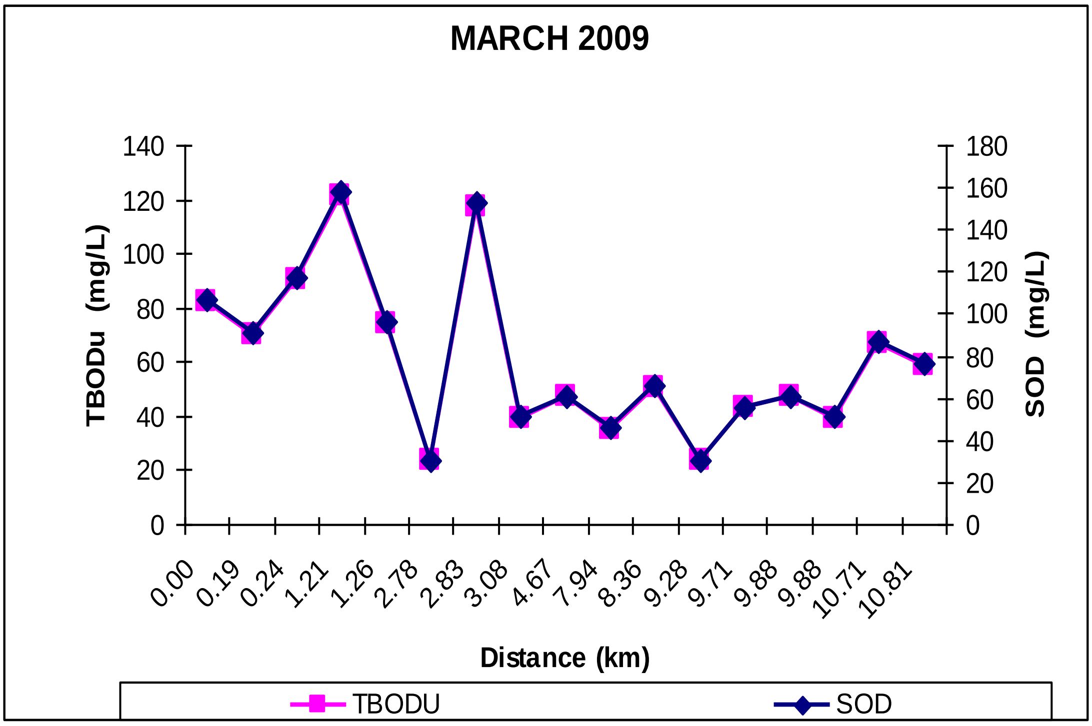


Figure 4.26: March 18, 2009 Atuwara River CBOD, Vs SOD Model Predictions

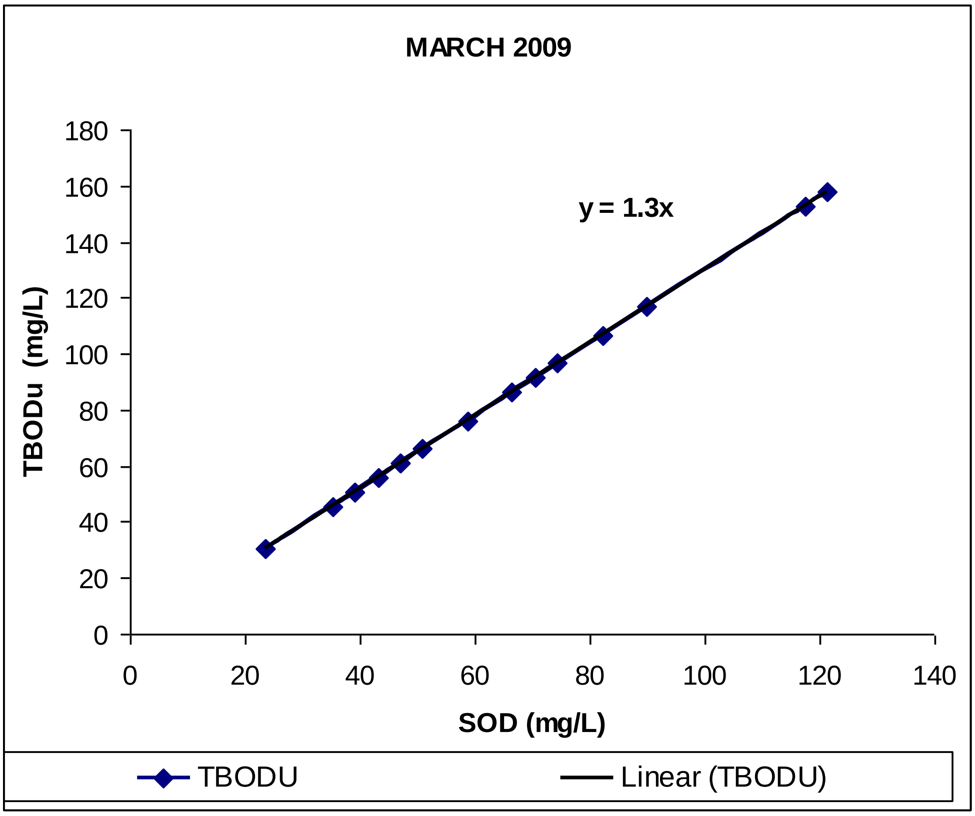


Figure 4.27: March 18, 2009 Atuwara River TBODu, Vs SOD Model Predictions

Table 4.18: March 18, 2009 Atuwara River Water Quality Model Loading Rates

Mean (H)	U	K_a	K_1	K_s	K_d	K_r
0.56	0.34	5.468	0.35	0.607143	0.951368	1.844226
0.61	0.36	4.949	0.35	0.590164	0.916704	1.736376
0.72	0.35	3.806	0.35	0.486111	0.853061	1.547505
0.92	0.33	2.558	0.35	0.358696	0.76697	1.310448
0.85	0.4	3.172	0.35	0.470588	0.79377	1.382005
1.03	0.37	2.287	0.35	0.359223	0.730283	1.215719
1.11	0.36	2.016	0.35	0.324324	0.706956	1.157406
0.83	0.37	3.161	0.35	0.445783	0.802015	1.404425
1.13	0.43	2.145	0.35	0.380531	0.701498	1.143976
1.13	0.38	2.017	0.35	0.336283	0.701498	1.143976
1.1	0.38	2.100	0.35	0.345455	0.709738	1.164283
0.77	0.3	3.186	0.35	0.38961	0.828563	1.477913
-	-	0.000	0.35	0	0	0
0.8	0.21	2.517	0.35	0.2625	0.814932	1.439932
0.68	0.22	3.287	0.35	0.323529	0.874487	1.609781
0.98	0.29	2.181	0.35	0.295918	0.746226	1.25643
1.79	0.29	0.884	0.35	0.162011	0.574545	0.853875

Table 4.19: May 11, 2009 Atuwara Rivers Model Water Quality Input Data

		Trace Organic Pollutants				Inorganic Water Pollutants									Heavy Metals				
Sample Code	**Relative Distance to STA-Atuara Upstream (km)**	**BOD_5**	**pH**	**Cond. (mS/cm^{-1})**	**DO**	**T.Hard.**	**Temp (°C)**	**T.Alkal.**	**TSS**	**TDS**	**COD**	**$PO_4^{-.}$**	**Cl^-**	**NO_3^{-1}**	**Cad.**	**Pb.**	**Zn.**	**Fe.**	**Mn.**
FEPA STD		30	6.5 -8.5	**1000**	**4**	150	**20-33**		**30**	**500**	**80**	5	250	50	0.003	**0.01**	3	**0.3**	0.2
STA	0.00	32	7.02	125	6.88	6.02	25.6	50	24.7	185	73	0.238	4.95	0.3	0.005	0.25	<.001	1.209	<.002
STB	0.19	28	7.16	139	6.63	7.14	26	48	26.6	236	102	0.216	7.35	0.2	0.006	0.21	<0.001	1.506	<.002
STC	0.24	20	6.84	142	5.86	8.16	25.9	42	31	219	101	0.231	6.82	0.15	0.004	0.2	<.001	1.281	<.002
STD	1.21	16	7.14	145	2.41	9.74	26.8	43	38	438	103	0.133	11.25	0.05	0.009	0.24	<.001	6.16	<.002
STE	1.26	16	6.52	152	1.02	13.2	32.6	51	56	544	198	0.242	6.45	0.1	0.006	0.2	<.001	6.128	<.002
STF	2.78	8	7.39	141	5.68	11.2	26.8	41	51	768	80	0.133	11.25	0.05	0.009	0.24	ND	1.51	<.002
STG	2.83	28	6.81	178	3.41	14.9	26.7	58	53	146	62	0.111	6.75	0.15	0.01	0.17	ND	1.361	<.002
STH	3.08	3	7.09	183	0.16	18.4	26.8	65	54	156	49	0.155	5.7	0.45	0.007	0.16	ND	1.601	<.002
STJ	4.67	4	6.85	198	3.06	23.1	26.7	42	228	465	73	0.259	6.45	0.18	0.005	0.15	ND	1.588	<.002
STK	7.94	14	6.41	136	1.06	15.3	26.8	48	241	358	45	0.287	9.3	0.13	0.013	0.11	ND	1.833	<.002
STL	8.36	28	6.63	187	0	17.2	26.9	73	255	392	163	0.199	4.5	0.28	0.01	0.17	ND	4.336	0.09
STM	9.28	12	6.83	193	1.41	10.8	26.8	63	276	255	78	0.132	5.7	0.38	0.015	0.24	ND	1.796	0.09
STN	9.71	3	6.52	141	0.9	11.4	27.7	136	305	231	137	0.288	14.7	0.3	0.01	0.2	ND	2.23	0.105
STP	9.88	20	6.76	149	0.82	7.13	26.8	121	344	243	62	0.092	12.2	0.28	0.009	0.22	ND	2.176	0.119
STQ	9.88	48	7.39	205	3.13	6.67	27.4	133	301	232	56	95	7.27	0.12	0.004	0.01	ND	1.741	0.113
STR	10.71	20	7.69	186	0.8	6.41	27.4	143	312	249	40	0.353	7.65	0.05	<.002	0.01	ND	1.405	0.1
STS	10.81	44	7.21	214	4.6	4.24	26.5	48	58	106	68	0.342	9.6	0.05	<.002	0.01	ND	1.369	0.1

All parameters are in mg/L except where stated

Table 4.20: May 11, 2009 Atuwara Rivers Statistical Summary of Analytical Data

Parameters	Min	Max	Mean	Std dev	Range
BOD_5	3	48	18.7500	12.1244	3 - 48
Ph	6.41	7.69	6.9406	0.3553	6.41 - 7.69
Conductivity	125	205	162.5000	26.3489	125 - 205
Dissolve oxygen	0	6.88	2.7019	2.3663	0 - 6.88
Total hardness	6.02	23.1	11.6731	5.0019	6.02 - 23.1
Temperature	25.6	32.6	27.1063	1.5618	25.6 - 32.6
Total alkalinity	41	143	72.3125	37.6505	41 - 143
Total suspended solids	24.7	344	162.2688	127.6606	24.7 - 344
Total dissolved solids	146	768	319.8125	166.5274	146 - 768
Chemical oxygen demand	40	198	88.8750	44.2476	40 - 198
Phosphate	0.092	95	6.1293	23.6990	0.092 - 95
Chloride	4.5	14.7	8.0181	2.9018	4.5 -14.7
Nitrates	0.05	0.45	0.1981	0.1216	0.05 - 0.45
Cadmium	0.004	0.015	0.0076	0.0037	0.004 - 0.015
Lead	0.01	0.25	0.1738	0.0744	0.01 -0.25
Zinc	0	0	0.0000	0.0000	0 -0
Iron	1.209	6.16	2.3663	1.6451	1.209 -6.16
Manganese	0.09	0.119	0.0386	0.0519	0.09 -0.119

Table 4.21: May 11, 2009 Atuwara Rivers Field Measured Hydrogeometric Parameters

S/No	Way Points	Relative Distance to STA-Atuara Upstream (km)	Station Description	WIDTH(m)		DEPTH(m)				Sides Slope		Area (m^2)	Velocity (ms^{-1})	Flow (m^3s^{-1})	Manning's	Wetted Perimeter (m)	Oxygen Reaeration	Dispersion
				Top (B)	Bottom (B_o)	Left	Mid Stream	Right	Mean (H)	S_{s1}	S_{s2}	A_C	U	Q	n	P	K_a	E
1	STA	0.00	Atuara Upstream	11.8	10.69	0.52	0.68	0.59	0.6	0.73	0.83	7.08	0.35	2.478	0.035	12.291	5.003	3.117
2	STB	0.19	Abattoir	4.2	2.86	0.65	0.74	0.69	0.69	0.92	0.98	2.89	0.38	1.101	0.035	4.787	4.227	3.891
3	STC	0.24	Abattoir Downstream	6.2	4.72	0.77	0.86	0.71	0.78	1.09	1	4.84	0.37	1.789	0.035	6.951	3.470	4.283
4	STD	1.21	Sona Upstream	14	12.46	0.74	1.79	0.8	1.11	1.04	1.13	15.54	0.36	5.594	0.035	15.666	2.016	5.931
5	STE	1.26	Sona Discharge	6.8	4.9	1.04	1.39	0.86	1.1	2.16	1.21	7.48	0.37	2.768	0.035	8.505	2.072	6.042
6	STF	2.78	Ewupe Upstream	9.2	7.75	0.77	2.09	0.68	1.18	1.09	0.96	10.85	0.37	4.016	0.035	11.108	1.865	6.479
7	STG	2.83	Ewupe Discharge	12.3	10.06	0.92	2.43	1.32	1.56	1.22	1.87	19.19	0.37	7.099	0.035	15.037	1.227	8.566
8	STH	3.08	Ewupe Downstream	12.8	11.2	0.89	2.31	0.71	1.3	1.25	1	16.64	0.36	5.99	0.004	14.990	1.591	6.946
9	STJ	4.67	Afara Meje	15.4	12.48	1.2	1.72	2.49	1.8	1.7	3.52	27.72	0.44	12.196	0.004	19.320	1.079	11.754
10	STK	7.94	Ekusere	9.1	6.57	1.54	2.24	0.99	1.59	2.18	1.4	14.47	0.39	5.642	0.004	11.882	1.224	9.202
11	STL	8.36	Ekusere Down Stream	6.9	4.74	1.45	1.69	0.71	1.28	2.05	1	8.83	0.37	3.268	0.004	8.808	1.651	7.030
12	STM	9.28	Igboloye Upstream	7.1	4.49	1.26	1.57	1.35	1.39	1.78	1.91	9.87	0.35	3.454	0.004	9.179	1.419	7.221
13	STN	9.71	Igboloye Raw Effluents	-		-	-	-	-			-	-	0.06908				
14	STP	9.88	Igboloye Discharge	7.5	4.75	1.8	1.08	0.95	1.28	2.55	1.34	9.6	0.29	2.784	0.004	9.143	1.461	5.510
15	STQ	9.88	Igboloye 100m Down Stream	10.9	9.08	1.17	1.51	0.65	1.11	1.65	0.92	12.1	0.27	3.226	0.004	12.436	1.746	4.393
16	STR	10.71	Igboloye 600m Downstream	8.8	7.35	1.14	1.35	0.31	0.93	1.61	0.44	8.18	0.25	2.048	0.004	9.997	2.191	3.454
17	STS	10.81	Iju Water Works	16.7	10.46	4.89	2.99	1.35	3.08	6.92	1.91	51.44	0.28	14.4	0.004	24.794	0.385	12.798

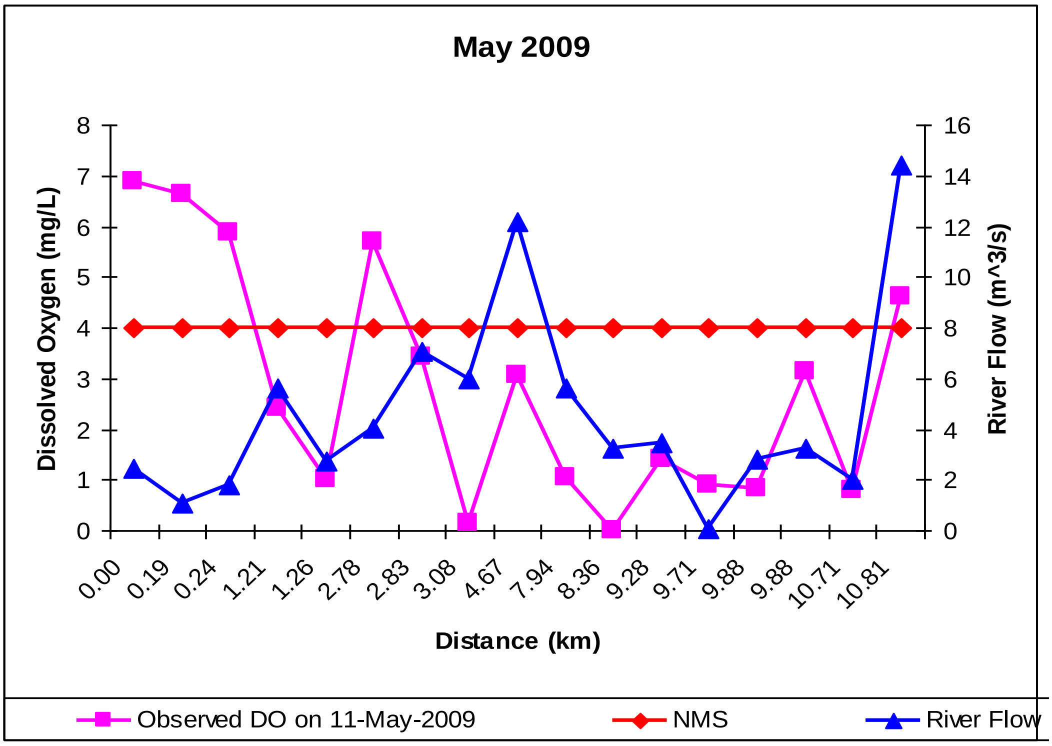


Figure 4.28: May 11, 2009 Atuwara River Dissolved Oxygen Vs River Flow Model Predictions

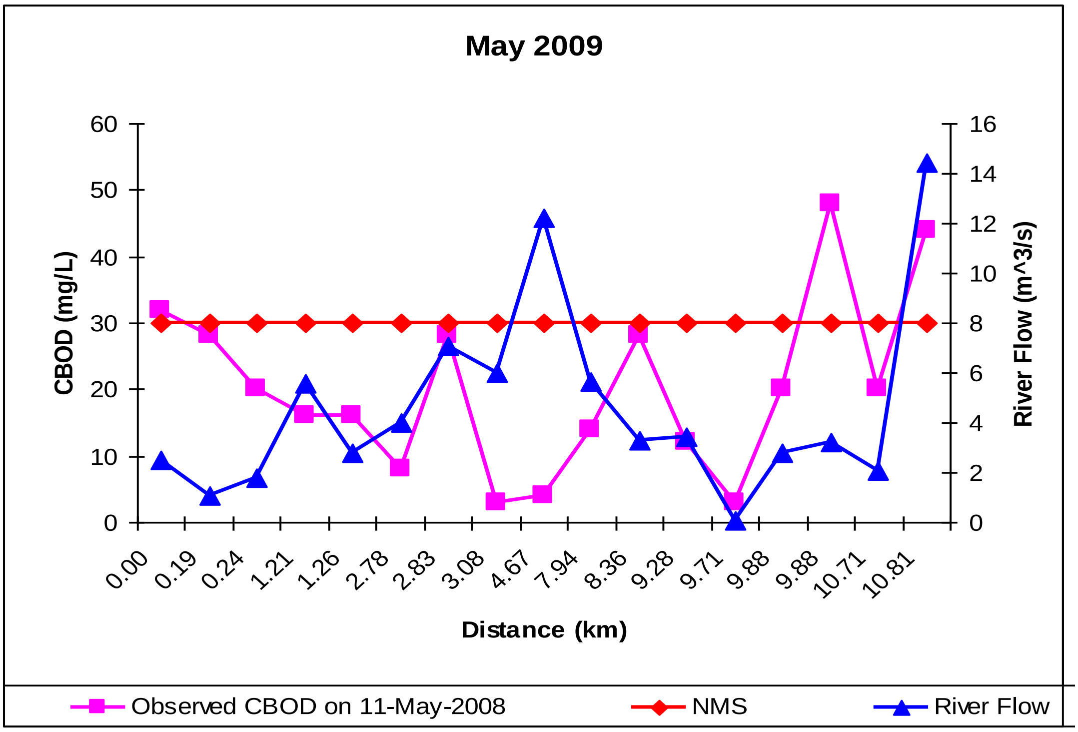


Figure 4.29: May 11, 2009 Atuwara River CBOD Vs River Flow Model Predictions

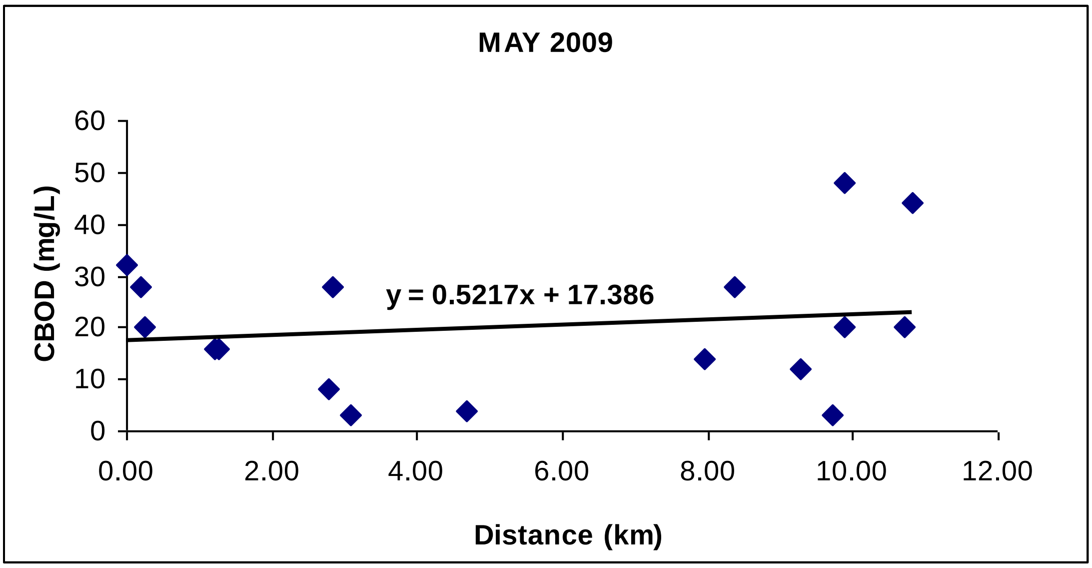


Figure 4.30: May 11, 2009 Atuwara River CBOD and Model Predictions

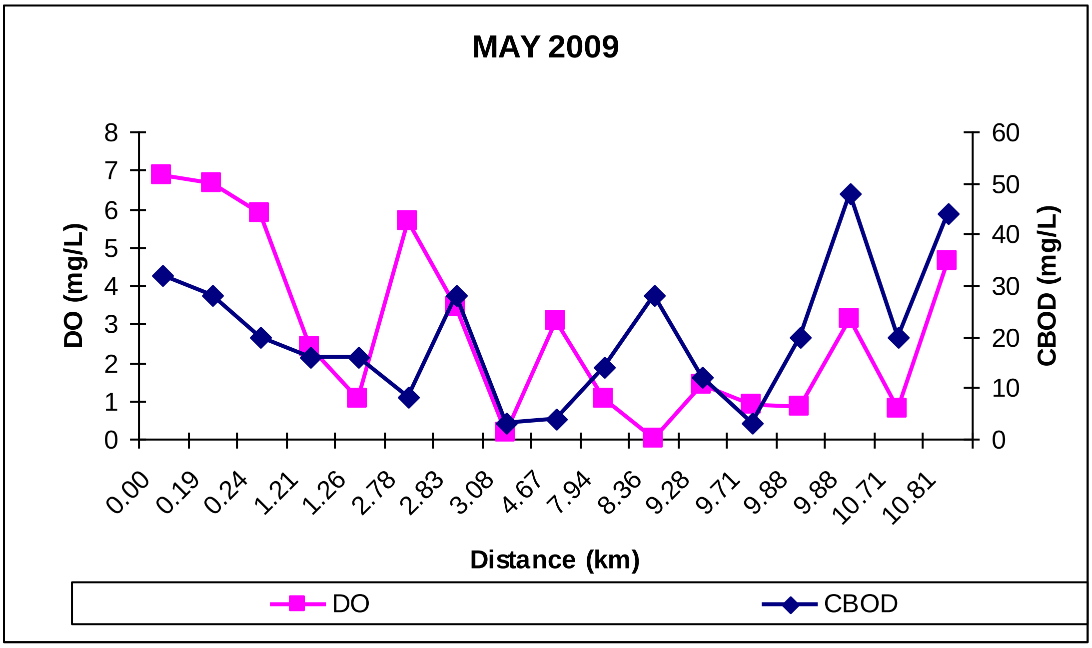


Figure 4.31: May 11, 2009 Atuwara River CBOD, DO and Model Predictions

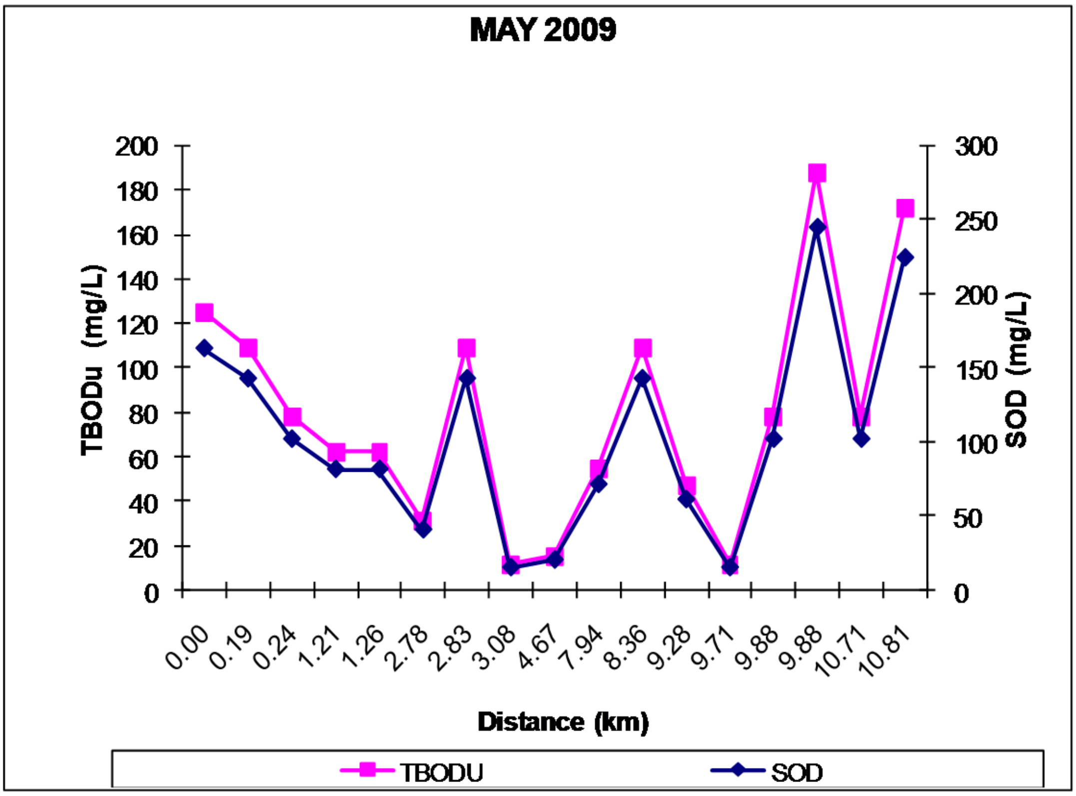


Figure 4.32: May 11, 2009 Atuwara River CBOD, Vs SOD Model Predictions

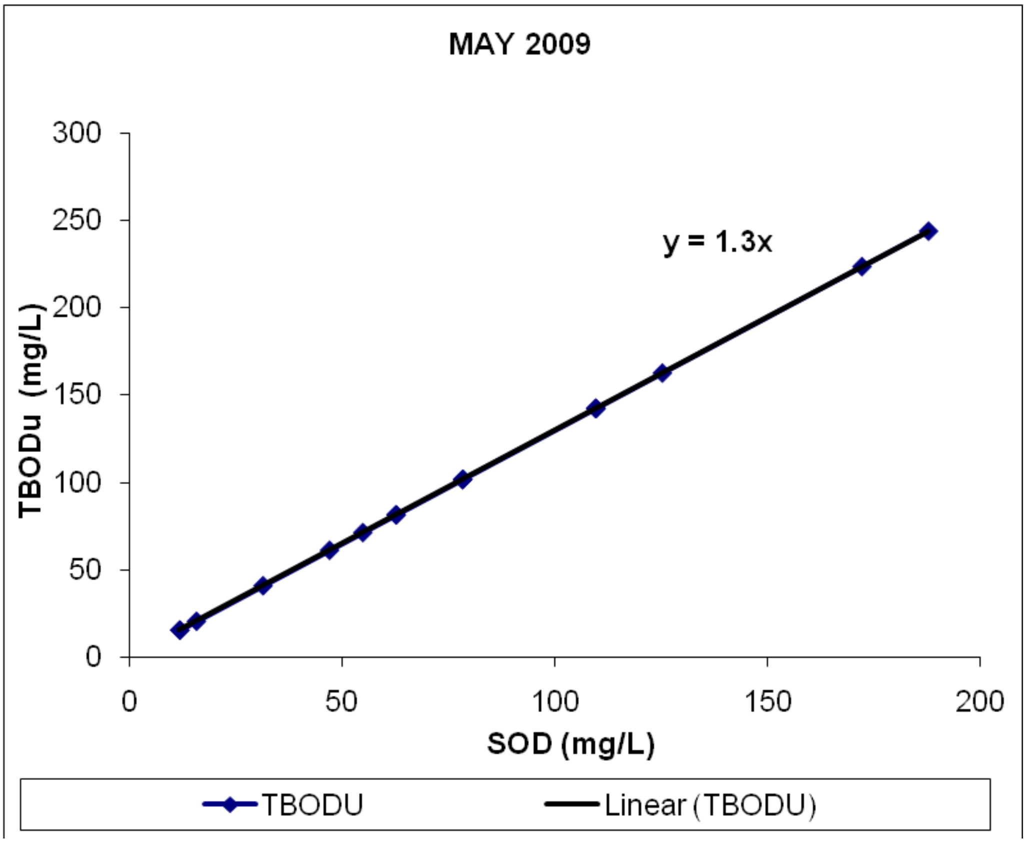


Figure 4.33: May 11, 2009 Atuwara River TBODu, Vs SOD Model Predictions

Table 4.22: May 11, 2009 Atuwara River Water Quality Model Loading Rates

Mean (H)	**U**	**K_a**	**K_1**	**K_s**	**K_d**	**K_r**
0.6	0.35	5.003	0.35	0.583333	0.923304	1.756637
0.69	0.38	4.227	0.35	0.550725	0.868964	1.593602
0.78	0.37	3.470	0.35	0.474359	0.823936	1.464961
1.11	0.36	2.016	0.35	0.324324	0.706956	1.157406
1.1	0.37	2.072	0.35	0.336364	0.709738	1.164283
1.18	0.37	1.865	0.35	0.313559	0.688439	1.112168
1.56	0.37	1.227	0.35	0.237179	0.609883	0.930395
1.3	0.36	1.591	0.35	0.276923	0.660102	1.044717
1.8	0.44	1.079	0.35	0.244444	0.573158	0.850935
1.59	0.39	1.224	0.35	0.245283	0.604862	0.919327
1.28	0.37	1.651	0.35	0.289063	0.664558	1.055183
1.39	0.35	1.419	0.35	0.251799	0.641201	1.000913
-	-	0.000	0.35	0	0	0
1.28	0.29	1.461	0.35	0.226563	0.664558	1.055183
1.11	0.27	1.746	0.35	0.243243	0.706956	1.157406
0.93	0.25	2.191	0.35	0.268817	0.76338	1.301014
3.08	0.28	0.385	0.35	0.090909	0.453974	0.616312

CHAPTER FIVE

5. EFFLUENT TREATABILITY STUDIES

5.1 INTRODUCTION

Several different alternatives, including steam stripping, activated carbon, advanced oxidation and anaerobic treatment, were considered to be used together with aerobic biological treatment. Among these, Fenton's oxidation, an advanced oxidation method, appeared to be the most promising method, in terms of cost-effectiveness and ease of operation. Recently, in a comprehensive review, Neyens and Baeyens (2003) indicated that Fenton's oxidation is very effective method in the removal of many hazardous organic pollutants from wastewaters. Fenton's oxidation can also be an effective pre-treatment step by transforming constituents to by-products that are more readily biodegradable and reducing overall toxicity to micro organisms in the downstream biological treatment processes .Fenton oxidation has led the way in the treatment of aqueous waste and is rapidly becoming the chosen technology for many applications.

Treatability studies were conducted under laboratory conditions with all chemicals (having COD varying from 900 to 7000 mg/L) produced in the factory in order to determine the operational conditions to utilize in the full-scale treatment plant. Optimum pH was determined as 3.5 and 7.0 for the first (oxidation) and second stage (coagulation) of the Fenton process, respectively. For all chemicals, COD removal efficiency was highest when the molar ratio of H_2O_2/Fe^{2+} was 150–250. At H_2O_2/Fe^2+ ratio of 155, 0.3 M H_2O_2 and 0.002 M $Fe^{2+,}$ provided 45–65% COD removal

The wastewater treatment plant that employs Fenton oxidation followed by aerobic degradation in Sequencing Batch Reactors (SBR), built after these treatability studies provided an overall COD removal efficiency of 98%, and compliance with the discharge limits. The efficiency of the Fenton's oxidation was around 45–50% and the efficiency in the SBR system which has two reactors each having a volume of 8 m^3 and operated with a total cycle time of 1 day, was around 98%, regarding the COD removal.

Fenton's oxidation is one of the best known metal catalyzed oxidation reactions of water-miscible organic compounds. The mixture of $FeSO_4$ or any other ferrous complex and H_2O_2 (Fenton's reagent) at low enough pH, results in Fe^{2+} catalytic decomposition of H_2O_2 and proceeds via a free radical chain process that produces hydroxyl radicals which have extremely high oxidizing ability and can oxidize hard to decompose organic compounds in a short time. The Fenton's reagent has not only oxidation function but also coagulation by the formation of ferric-hydroxo complexes and. the coagulation step acts as a polishing step, and removes the remaining after Fenton's oxidation.

The suggested overall reaction for Fenton's oxidation is given below:

$$2Fe^{2+} + H_2O_2 + 2H^+ \rightarrow 2Fe^{3+} + 2H_2O \qquad (5.1)$$

According to this equation, the pH value has to be in the acidic range to generate the maximum amount of hydroxyl radicals to oxidize organic compounds. However, pH value should not be too low since at very low pH values (<2.0) the reaction is slowed down due to the formation of complex iron species and formation of oxonium ion $[H_3O_2]^+$.

On the other hand, at high pH ($pH > 4$) the generation of hydroxyl radicals gets slower because of the formation of the ferric-hydroxo complexes. Therefore, the initial pH value has to be between 2 and 4 to generate the maximum amount of hydroxyl radicals to oxidize organic compounds.

5.2 Analytical methods

COD of the samples were measured according to an EPA approved reactor digestion method (for a COD range 0–1500 mg/L with a HACH DR2000 instrument). If a water or wastewater sample includes hydrogen peroxide, the standard COD test will be interfered since the dichromate ions react with H_2O_2 in an acidified solution. Because of this, COD measurements were performed only after the Fenton's coagulation stage. Since H_2O_2 is unstable in basic solution, after raising the pH above 7 for the initiation of Fenton's coagulation, it decomposes to give oxygen and water and lose its oxidation ability so that no interference is of importance.

pH measurements were performed using a pH meter (Model 2906, Jenway Ltd., UK) and a pH probe (G-05992-55, Cole Parmer Inst. Co., USA) as described by . Huseyin Tekin, et al. (2006).

The purpose of this research is to perform electro Fenton advanced oxidation method, and to put forward the applicability of the method by means of provided relevant data. In the experiments, optimization of doses of ferrous iron and hydrogen peroxide was carried out using a breweries wastewater sample. For that purpose, theoretical H_2O_2 doses required for Fenton oxidation of COD in wastewater theoretical have been calculated according to Equation 4.54

$$\begin{array}{cccc} H_2O_2 & \rightarrow \; H_2O & + & \frac{1}{2}O_2 \\ 34 & & & 32/2\left(=COD\right) \end{array} \qquad (5.2)$$

Theoretical H_2O_2 dose for one mole COD: 34/16 * COD = 2,125* 2810 = 5970 mg H_2O_2/l. During the electrolytic processes using iron electrode, the concentration of Fe^{2+} ions in electrolytic media increases depending on reaction time. The ions are diffused from iron anode and catalyze forming of hydroxyl radicals (•OH) in Fenton reaction can be seen from equation 4.55:

$$H_2O_2 + Fe^{+2} \rightarrow Fe^{+3} + \cdot OH + OH^- \tag{5.3}$$

Hydroxyl radicals (•OH) is the second strong oxidant after fluorine which standard oxidation potential (EO) is 2.87 volt. Hydroxyl radical has 2.33 volt standard oxidation potential.

5.3 Experimental Materials and Procedures

$FeSO_4 \cdot 7H_2O$, NaOH and H_2SO_4, which were used during experiments, were purchased from Merck KGaA (Germany). H_2O_2 solution of 50% was provided by the Plant, where H_2O_2 solution of 30% is used for producing their "product" H_2O_2. Ferric sulphate was added to the system in solid form.

Electro-Fenton oxidation of wastewater was conducted in an undivided reactor of 0.5 dm^3 volume. The overall experimental setup mainly consists of a cell unit, as shown in the following Figure 5.1. Iron plates as cathode and anode (thickness: 2.0 mm, length: 6.0 cm and width: 7.5 cm) were arranged in parallel.

Distance between electrodes was 6 cm. The total effective electrode area was 45 cm^2. The electrodes were connected to a DC power supply (KYSAN, DC Digital, 0-30 V, 0-3 A). Electrochemical treatment was conducted at 10V DC and 1.5 ampere (15 W). Electric current density was kept at 3.33 $A \cdot dm\text{-}^2$. All the experiments were made at room temperature. Before the process, the filled wastewater up was adjusted to pH=3. The study was performed for three different H_2O_2 doses (600, 1500 and 4500 mg/l which are equal to 10%, 25% and

75% of theoretical H_2O_2 dose, respectively). Electro-Fenton experiments were naturally realized until H_2O_2 residue in the solution does not exist. The measurement of H_2O_2 was made by permanganometric method (h2o2.com).

The pH was adjusted to 3 and 5 with 1N H_2SO_4 solution. Then H_2O_2 was added as 600, 1500 and 4500 mg/l for each experimental set-up. The current density was adjusted to the desired value; and electrolysis was started and maintained until all H_2O_2 was consumed. The analysis of H_2O_2 was done by the permanganometric method. The samples treated by the EF process were settled for 30 min after electro-oxidation reactions. In the study, all analyses were carried out on treated samples taken out of the limpid phase in the beaker. Merck analytical quality chemicals were used in the preparation of reagents. All the chemical analyses were carried out in accordance with the Standard Methods for Examination of Water and Wastewater.

A Jenway 3040 brand a pH-meter was used for pH measurements. Unit energy demands (UED) of the EF process were calculated from the following equation :(9) where UED for each m^3 of wastewater is the unit energy demand (kWh/kg COD removed); C_i is beginning COD concentration (kg/m^3); η is COD removal efficiency (%); t is the reaction time (h); A is the total current applied (A); V is the overall cell voltage (V). Unit energy demand of the electrolytic process were calculated from

$$UED_{(t)} = \frac{SEC_{(t)}}{C_{(t)} \times \eta_{(t)}} \times 100 \qquad (5.4)$$

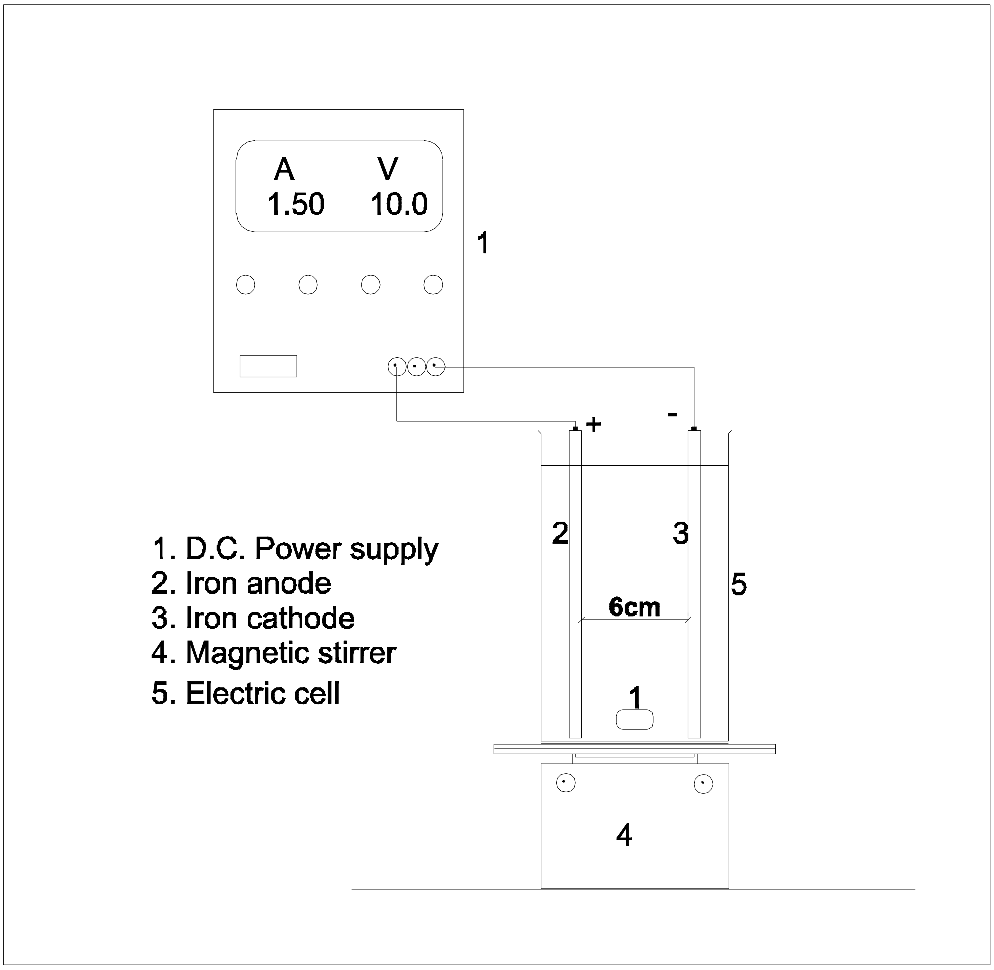


Figure 5.1 Electro –Fenton Experimental Set – up

Where UED is the unit energy demand (kWh/kg COD removed); C_i is the initial COD concentration, kg/m^3, η is COD removal percentage. Where SEC is the specific energy consumption (kWh/m^3) and calculated from

$$SEC_{(t)} = 10^{-3} \times J \times U \times t \qquad (5.5)$$

Where t is the time needed for the removal of a given pollutant, hour; J is the total current applied, Ampere; U is the overall cell voltage, Volt.

5.4 Experimental Results and Discussion

This experiment was organized and performed. The research considered the effluent samples having the most critical scenario in terms of volume of discharge and flow .The treatability study was to demonstrate the treatment and show that industries could optimally dispense of effluents that comply with the National Minimum Standards (NMS).Sample of effluents were obtained outside the discharge sewer of the factory with a two litre plastic bottle properly rinsed and this was immediately transferred to the laboratory the set up was shown in Plate XI ,Plate XII and Plate XIII. 250 ml Reagent bottles were prepared in different categories and listed A, B C and D Existence durations of residual oxidant in the solution determined for three different oxidant doses have been illustrated in Figure 5.1; as rounded, 15, 30 and 45 minutes for increasing dose order. These values give a suggestion for upper limit of electro-Fenton application time, for each dose.

PLATE XI Laboratory Bench Scale Electro –Fenton Experimental set - up

PLATE XII Running the Laboratory Bench – Scale Electro Fenton Experiment

PLATE XIII Measuring water quality parameters from Laboratory Bench- Scale Electro – Fenton Experiment

Table 5.1 Energy Variation of Electro-Fenton Experiments

Electrical current	15.0W,10V 1.5A 15mins	4.0W,5V 0.8A, 30mins	1.2W,3.4V0.35 A, 45mins	Oxidant doses& % of theoretical doses
A	25^{O}C 0.39A	0.16A 26.9^{o}C	0.11 A3.4V	600mg/L (10%)
B	9.6 V,0.35A	3.4V,0.10A	3.4V,0.11A	1500mg/L (25%)
C	10V,0.38A	5V,0.17A	3.4V,0.11A	4500mg/L (75%)

Table 5.2 Characteristics of effluents treatment by Electro- Fenton

Parameter	Units	Raw effluents	Treated effluents	% of Treatment
Temperature	^{o}C	53	32	
pH	-	3.3	4.6	
Suspended Solids	mg/L	271	195	28
TotalDissolved Solids(Inorganic)	mg/L	3850	2330	39.4
COD	mg/L	532	180	65.97
Cadmium	mg/L	0.27	0.002	99.25
Lead	mg/L	1.680	1.260	25

5.5 Uses of Activated Carbon for Effluents Treatment

In the research carried out by Adewumi (2006) the final AC product is either used in powdered AC (PAC), granular AC (GAC) or as shaped [palletized or Cartridge –type] AC the Cartridge AC usually consist of a cylindrical candle –type commonly used in micro filler units .The choice of AC mostly depends on the intended use to which it will be put.

Powdered AC is mostly used in fluidized bed reactor regimes to treat liquids waste. The PAC is mixed counter – current into the flow stream to the liquid medium or in a stirred reactor system and then filtered afterwards for disposal .Powdered AC is usually disposed after one use and is not regenerated. .This is used in packed beds reactor regimes such as columns for the treatment of water and other types of liquids or in gas masks or in under sink or flow through units for water refinement .Most liquid and water treatment requirements for AC use GAC which has the added possibility of being regenerated after exhaustion.

Laboratory experiments were conducted with the granulated AC BBC 945 with a stirring method. The GAC is calibrated in an electronic weigh balance for masses of 1 grammes, 2 grammes and 3 grammes, and these are in turn placed into the samples of effluents treated with Electro Fenton and each in turn set up in a beaker of 500 ml placed on a magnetic stirrer with a revolution of 1000 rpm for 5 minutes after which its allowed to settle for 30 minutes and then analyzed for the parameter used in the Electro- Fenton and the result is presented in the Table 4.10.

The sample was put into Poly-Ethylene containers and taken to the laboratory in one hour and protected at +4 °C during the experiments. The experimental set-up used in the present study is presented in Figure 5.1.

Experimental studies were performed in a batch laboratory reactor consisting of a 0.5 litre glass beaker equipped with a cathode and an anode, both made of iron and installed in parallel. The distance between the electrodes was 6.0 cm (dimensions of electrodes were 2.0 mm × 6.0 cm × 7.5 cm). Electrodes were plunged into the beaker containing tannery wastewater with a 0.5 litre working volume. The total effective electrode area was 45.0 cm^2. Ferrous ions acted as coagulation materials in the electro-chemical treatment. On the other hand, ferrous ions create hydroxyl radicals and catalyze the Fenton reaction. The electrodes were connected to a digital DC power supply (GW Instek, GPS 3030 DD, 0–30.0 V, and 0.0–3.0 A). All the runs were performed at an initial temperature of 20 °C and the temperature was increased up to 29 °C in 40 min. In each run, 400 cm^3 of wastewater was placed into the electrochemical cell, (Ugur Kurt, *et al*, 2007, Uğur Kurt *et al*, 2005, Hamdy Seif and Moheb Malak 2001.

Table 5.3 Specification of Quality and Use of Granular Activated Carbon

Article	WF – GAC 4 X 8		
Type	Granular Virgin Coal Base AC – Vapour Phase		
Description	WF –GAC 4 X8 is a granular AC made especially for use in a vapour application its particle size and pore structure have been specifically designed to provide the best adsorption of impurities from vapour steam with the least flow resistance. This product is manufactured to adsorb VOC'S and trace contaminants WF – GAC 4 X 8 is processed from selected seams of bituminous coal activated at high temperature with steam.		
Typical parameters	CCL_4 Adsorption	60 Minimum	ASTM – 3467
	Apparent Density	0.40- 0.46	ASTM 02854
	Moisture At Packed	3% Maximum	ASTM D- 2867
	Ash 1	12%	ASTM –D – 2866
	Hardness (Ball pan)	90 Minimum	
	Surface Area	950 – 1050	BET N_2
	Ignition Temperature	$400^{O}C$	ASTM – D - 3466

Table 5.4 Result of Effluents Treatment with both Electro - Fenton and GAC BBC 945

Sample ID	**Fenton reagent doses**	**COD mg/L**	**TSS mg/L**	**TDS mg/L**	**Temp ^{o}C**	**pH**	**Cd mg/L**	**Pb mg/L**
A0		532	271	3850	50	3.3	0.027	1.680
A1	600 mg/L10%	484	568	1960	30.5	4.1	0.002	0.910
A2		312	545	2330	30.5	3.9	<0.002	0.950
A3		396	558	2330	30.7	3.9	0.11	0.650
B1	1500 mg/L 25%	472	360	2330	30.7	2.6	0.023	0.950
B2		400	349	2330	30.6	2.2	0.019	1.490
B3		236	439	2330	30.8	2.5	<0.002	1.340
C1	4500 mg/L	180	395	2330	32	4.6	0.002	1.260
C2	75%	228	518	2380	30.8	2.6	0.025	1.130
C3		232	509	2340	29.9	4.2	0.020	0.860
D1	2 mg/L 10.2 V 0.38A, 600mg/L 15 min.	252	465	2450	29.0	6.4	<0.002	0.890
D2	3mg/L 10V 0.38A 1500mg/l 15min. 4	178	352	2560	29.1	5.8	0.006	0.360
D3	1mg/L 10V 0.45A 4500mg/L 15 min,	480	288	2850	29.5	5.7	<0.002	1.120

CHAPTER SIX

6. DISCUSSIONS OF RESULTS, SUMMARY AND FUTURE DIRECTIONS

6.1 Research Findings and Discussions

The development of hydrodynamics and QUAL2K model software for the River Atuwara has significantly advanced the process of examining water quality, as represented by Dissolved Oxygen and Biochemical oxygen demand within the watershed. The model was used to examine water quality scenarios that occurred between 14/10/2008 and 11/05/2009. Specifically, the model software was utilized to perform water quality studies on the Atuwara River. In addition, as Atuwara River watershed receives discharges and streamflow data made available, the model software simulation period can be extended further. The input parameters selected for the Atuwara River produced results for hydrodynamics and QUAL2K model software analysis. Water surface elevations and dissolved oxygen concentrations observed were compared with values of the Approved National Water Quality Standard. Potential improvements could be made to both the hydrodynamics and Water Quality inputs datasets as observed on the datasheets. However, a regimented sampling program would have to be established to make these improvements a reality.

To analyse the accuracy of the simulated results, errors in simulations were estimated as the difference between model software outputs and observed data at critical locations. The highest relative value for BOD was 56 mg/l which occurred in the month of October, that is, the peak of the wet season at the point of entry of the effluent discharged from combination of pharmaceutical effluents at Ewupe.

Differences between the observed values of DO were insignificant and with a good fit at all the study locations. Sona discharge was found to be the chief source of pollution in reach 1; it discharged 11.99 tonnes/day of loading, which is 58% of the total load (Table 4.7). Collective load of all the drains in reach 4 and 5 was negligible as compared to the other reaches. They contributed 19% and 7.4 % of the total load respectively. This additionally affected the water quality. Out of the 10.81 km segment of the River Atuwara under the current study, the highest observed DO level was 8.40 mg/l and this occurred upstream of Ewupe in the month of February which was the peak of the dry season (Figure 4.16). More than 7 discharge points along the river were found to be anoxic (i.e. DO = zero) after receiving loads from industries. This was the case so at Igboloye where the Effluents from IDL and M & B were being discharged into the mainstream of River Atuwara. The absence of any photosynthetic activity kept the DO at zero most of the time. However, replenishment of DO content was observed at about 150 m downstream from the headwater. Due to the huge pollution load from both the IDL and De – Real Industries Sewage Services which are discharged on daily basis (Plate 5.1), the DO concentration dropped down again to the anoxic state. The BOD concentration of the stream at the headwater peaked at 32 mg/l in the month of May and was least on February 2009 at 10 mg/l. Subsequent loading at Igboloye from IDL drain resulted in an increase in BOD level to about 56 mg/l. At the downstream of Sona Breweries, Combined (Nigeria –German, Fermex Mayer Nigeria.Plc) and other pharmaceutical drains culminated to a high BOD level of 48 mg/l from Ewupe discharge. The main tributaries discharged into the river at a distance of 1.84 km downstream of Ewupe discharge and this study confirmed that this was the main source of replenishment and buffered the assimilation capacity of river Atuwara.

The water quality of the river was found to correspond to class E, (Table 6.1) suggesting that the water could not be used for purposes of drinking, fisheries, bathing, and swimming (Figures 4.10, 4.16, 4.22 and 4.28).

Table 6.1 The surface water quality classification given by (CPCB) India

Parameter (mg/L)	Class				
	A	B	C	D	E
DO	>6	>5	>4	>4	<4
BOD	<2	<3	<4	<6	>6

Source: CPCB 1980 -81

A: Drinking watercourses without conventional treatment but after disinfection

B: Bathing Swimming and Recreation

C: Drinking water source after conventional treatment

D: Propagation of wild life, fisheries etc.

E: Irrigation, industrial cooling and controlled waste disposal

A comparison of DO and BOD levels just upstream and downstream of the discharged points showed the impact of various point loads on the river water quality. This is summarized in Tables 4.7, 4.11, 4.15 and 4.19. It was evident that Sona drain and IDL drains at Igboloye and combined effluents from the pharmaceuticals at Ewupe respectively had deleterious effects on the water quality parameters. BOD levels increased several folds from 12 mg/l to 56 mg/l whereas DO decreased to zero from 8.40 mg/l in the river. Impact of pollution load discharged through other sources did not showed significant effect as compared to IDL discharge. Only small rises in BOD were observed when other drains joined the river.

6.2 Summary of Hydrodynamics Model Results

QUAL2K showed significant sensitivity to boundary upstream (headwater boundary conditions) at the lower portion of the Atuwara River. The model did not show significant sensitivity to overland flow, instream flow, or Manning's roughness coefficients in the downstream direction. As a result, the boundary conditions govern the modelled water surface elevations in downstream portion of the Atuwara River.

For the upper portion of the model network, QUAL2K also showed significant sensitivity to boundary conditions. In addition, the model showed sensitivity to instream flow and Manning's roughness coefficients. Therefore, upstream model results were governed by the combination of elevations, instream flow, and Manning's roughness coefficients.

The simulation time period chosen for hydrodynamic calibration were 14/10/ 2008 through 11/05/ 2009. Modelled water datasets were compared with observed water surface elevations and results were obtained. A goodness-of-fit value of 0.749 was calculated using linear regression analysis. The period 18/03/2009 through 11/05/2009 was selected as the simulation time period for input parameter validation. Results were obtained and a goodness-of-fit value of 0.829 was calculated. Also, a goodness-of-fit value of 0.788 was determined for the entire simulation time period. As a result, QUAL2K proved to be an effective tool for reproducing hydrodynamic conditions within the Atuwara River.

6.3 Summary of QUAL2K Model Results

QUAL2K showed significant sensitivity to boundary BOD and DO concentrations, DO loading rates, and BOD removal rates in both the downstream and the upstream portions of the model network. The model did show significant sensitivity to segment dispersion coefficients. As a result, advective transport dominates BOD removal rates movement within the Atuwara River. In addition, the combination of boundary concentrations, loading rates, and BOD removal rates governs water quality results.

6.4 Treatability Studies Results

Literature data indicated COD reduction changes from 41% to 99% based on different variables such as effluent type, energy consumption, reaction time, etc. In this study, the efficiency of pollutant removal is evaluated for different variables such as oxidant doses, energy consumption, reaction time, etc.; The COD removal did not show any pattern of direct or inverse proportionality of the variables. For this reason, detailed laboratory treatment of a particular effluent would be required before the Electro - Fenton application.

Electro - Fenton treatability studies gave the best results of over 70% COD removal for pH 3.3. At a neutral pH, more than 60% COD removal was obtained. These results showed that, wastewater samples from breweries discharge could be treated up to the level of the minimum National (FEPA) discharge limit (COD 80 mg/l). The process under observation provided a solution in 15 min instead of long periods of chemical and biological treatments. With pH of 4.2, the 4500 mg/l oxidant dose and with power rating of 15.0 W, 76% COD removal was obtained in 15 min. During this process, 3.8 kWh/kg H_2O_2 was consumed. In acidic conditions, when readjustments are required, in the same conditions 72% COD removal was obtained with the energy consumption of 3.1 kWh/kg H_2O_2. However, the process requires acid consumption for a reduced pH and might make the system invulnerable to corrosion. For these reasons, it seems that it would be more convenient to perform the process at neutral pH.

If the lower energy consumption (with the energy consumption of 1.2 W) is the goal instead of reaching the sewerage discharge limit, consumption can be reduced until 0.5 kWh per COD removed per kg. But, due to the energy savings, the efficiency of COD removal turns out to be 35%. An additional treatment would be necessary due to the insufficiency of breweries effluent treatment. It was observed that energy consumed is used to decompose organic substances. The BOD tests showed that there were still biological degradable organic molecules in solution.

Consequently, the applicability of this process will increase since there are organic and toxic inorganic substances present in the breweries effluent and these substances have high resistance to biological degradation

The activated carbon application in effluent treatment showed a great improvement in the removal of trace and heavy metal. It was observed from the experimental result that the level of treatment showed a reduction from the initial value of 0.027 for Cd to less than 0.002 indicating about 45% reduction. For Pb, there was a reduction from initial concentration of 1.680 to as low as 0.360 when 3.0 g of granular AC BBC 945 was used indicating 79% treatment efficiency. With this result it can be concluded that the use of granular AC BBC 945 after Electro – Fenton oxidation will be an excellent treatment option for industrial effluent of varying pollutant combination in terms of energy consumption, time taken as well as the cost of treatment

6.5 Research Contribution to knowledge

The contributons to knowledge in this study are that:

- The successful application of developed water quality model softwares, QUAL2K to a tropical watershed is cost effective in the hydrodynamic and water quality simulation of BOD and DO within effluent receiving river.It will help others to study similar problems in watersheds in other parts of the country, where the climatic conditions, and the industrial pollution and effluent discharges are similar (e.g Kaduna River).
- Presentation of the applicability of existing model software in the determination of the assimilation and recovery capacity of streams to the impact of point discharge of untreated industrial effluents.
- The method used in the study can be adopted for examination of water quality in Nigeria waters.
- The study demonstrated the effectiveness of various options for treating industrial effluents using a bench scale experimental set up.The findings are particularly useful when considering the removal of excess heavy metals ,trace metals and other complex inorganic and organic compounds.
- The study showed that Electro – Fenton treatability process followed by Granular Activated Carbon (GAC BBC 945) is effective in the treatment of industrial effluents that contain heavy metals.
- The study elucidated the existing pollution and water quality problems on a river in a major industrial watershed in Nigeria.
- The results provide technical information on the dynamic nature of River Atuwara and its responses to pollution.
- The extensive data collected and analyzed will be very useful as baseline data for the environmental control agencies, such as FEPA/NESREA and researchers, for setting new water pollution standards and control guidelines, or improving on existing ones.

- The study provides a data base for the quality of effluents being discharged into Atuwara River by the various industries. It gives necessary information for the technical evaluation of the assimilative and recovery capacity of Atuwara River.

6.6 Future Directions in River Modelling in Nigeria

Current computer-based hydrodynamic model softwares allow the engineer or hydrologist to perform simulations in one two or three dimensions. Modellers have the capability of simulating instream velocities in the longitudinal, lateral, and vertical directions. If necessary, one can predict velocities associated with flow moving the length of the river, velocities associated with flow moving from the centre of the river to the banks or vice versa, and velocities associated with flow moving from the river bed to the water surface or vice versa. The same principles apply to current computer-based water quality models softwares.

Modellers have the tools necessary to simulate changing pollutant concentrations in one, two or three dimensions. A major consideration during model implementation is whether to develop a 3D model if a 2D or 1D model will provide similar results. This consideration is partially due to the fact that the data requirements for a 3D model are highly extensive and expensive. In addition, the time and money required to set up, calibrate, and validate a 3D model are typically greater than those necessary for 2- and 1-D models, especially if no data is available at the onset of model implementation. As a result, future research should examine the potential development of a parameter or series of parameters to be calculated before model implementation in order to determine the model dimensionality required for accurate river simulation.

With respect to River Atuwara, future research should explore the possible development and implementation of a two - or three - dimensional hydrodynamic and water quality model within the river system. As previously noted, WASP6.1 can be utilized for two - or three - dimensional water quality simulation. However, a new hydrodynamic model must be coupled with QUAL2K. One of the proposed hydrodynamic model software is the Environmental Fluid Dynamics Code (Total Maximum Daily Loads TMDLs), which was developed at the Virginia Institute of Marine Science (VIMS); this model had been utilized in numerous water quality studies with extensive use in tidal estuaries. Therefore, QUAL2K coupled with TMDL will be a good model for two - and three - dimensional hydrodynamic and water quality simulation within the river water.

CHAPTER SEVEN

7. RESEARCH CONCLUSIONS AND RECOMMENDATIONS

7.1 Research Conclusions

A number of different factors necessitated the selection and utilization of a one - dimensional hydrodynamic and water quality model for this research. The Atuwara River is relatively long, narrow, and shallow when compared with other tidally influenced rivers within the Ogun / Oshun river basin. As a result of the physical geometry present, a one - dimensional hydrodynamic and water quality model was adopted for use within the Atuwara River. In addition, lack of detailed bottom topography or bathymetry data within the area of interest hindered the development of a two - or three - dimensional model for this research. Computer-based model softwares can require a significant amount of time for set up, calibration, and validation. The amount of time required to set up, calibrate, and validate a one - dimensional hydrodynamic and water quality model is significantly less than that required for an equivalent two - or three - dimensional model. Due to huge cost of input demanded for the section of this study as well as the aforementioned arguments, a one - dimensional hydrodynamic and water quality model was chosen for simulation purposes.

7.1.1 The Model Software

After performing a detailed literature review, selected QUAL2K was selected as the model software for this research. Detailed arguments for this selection are presented in Chapter 2. In summary, QUAL2K was well matched computationally to the needs of this research and to the physical characteristics of the Atuwara River system. Data input requirements; particularly channel data also are compatible with the data currently available to this research. With the data available, results were obtained for hydrodynamic and water quality model calibration and validation. Therefore, QUAL2K proved to be quite effective in the hydrodynamic and water quality simulation of BOD and DO within the Atuwara River. As a result, the second objective of this research was achieved, which was to investigate the use of multiple models and select a moderate one in terms of cost to simulate river water quality. In addition, armed with the hydrodynamic and water quality background presented in Chapters 2 and 3 as well as with the newly developed model softwares, engineers and hydrologists can now investigate proposals for improving water quality within Nigeria river waters. Therefore, advancing the analytical process by which various proposals for improving water within the Nigeria Rivers waters could be examined and ultimately satisfying the primary objective of this research.

7.1.2 Location Description

The Atuwara river water shed is a sub basin of the Ogun/Oshun River Basin Authority. The investigated section of Atuwara watershed encompasses 10.808 km. This research practically covered seven reaches and seventeen sampling points in 2008/2009 seasons. This research effort defines the upper Atuwara watershed as approximately 8.162 km^2. Tributaries in the upper Atuwara watershed include; Afarameje, Balogun and Mosafejo rivers.

7.1.3 Water Quality Standard for all Assessment Units in this Research

All perennial reaches of River Atuwara and its tributaries are for domestic water supply, municipal water supply, irrigation, high quality fresh water fishery, livestock watering, wildlife habitat and secondary contact.

This research also concludes that in any single sample in the month of October 2008, electrical conductivity do exceed 1577 umhos at Ekusere where effluents from the combination of a Residential Secondary School, University and Food Processing Industry are discharged into the river. The pH ranges of 6.0 - 8.8. Temperatures were between 25.5 and 32.6^{o}C which was within the National Limit.

As shown in Tables 4.7, 4.11, 4.15 and 4.19. Priority pollutants occurred in Industrial food processing effluents at measurable concentration during the month of October. The total suspended solid (TSS) was 530.5 mg/L while the total dissolved solids (TDS) was 517.5 mg/L These far exceeded the Minimum National Standard. The COD of 360 mg/l and chloride of 393.8 mg/l exceeded the Minimum National Standard thereby posing a dangerous trend to both fauna and flora species around this section of the river at any period of the year. This was evidenced in the resulting value of the Dissolved Oxygen which were anoxic that is zero in almost all sampling station along the points of discharge of the industrial effluents.

Heavy metals occurred in all effluent tested some of which exceeded the minimum national standard as a result of the industrial discharge. This was also true for some of the priority organic pollutants. However, the hydrogeometric characteristics of river Atuwara as recorded in this study showed excellent recovery capacity because of the dilution power of river Atuara which receives discharge from Afara meje main tributary and other tributaries.

The river reach along Igboloye where the river receives industrial discharges from a large distillery firm is also of crucial consideration in all the months of the year. At Igboloye, the raw effluent sample analyzed showed, the values of BOD far exceeding the minimum national standard (MNS) which ultimately resulted into anoxic level for the Dissolved Oxygen indicating that there is no live in both the effluents and the river, at this discharge point in all the months sampled and tested. Other priority pollutants were tested and this showed that the water temperature was high with the effluents having travelled for a distance of more than 1km before it entered the river. Due to aeration effect, it would have cooled down before entering the river. The TDS, TSS, TS, Cl, COD, were very high specifically. The pH, in most samples from IDL indicated that they are highly acidic (values range from 5.2 – 6.7) the dilution effect of the river notwithstanding.

Heavy metals in the Igboloye reach were sampled and tested for pollutant and the result indicated that the water quality were grossly violated because majority of the priority heavy metal pollutants e.g. Cadmium, Lead and Iron exceeded the Minimum National Standard, thereby posing a great risk to both fauna and flora species living around the river reach, and ultimately to the municipal community which receives water directly below this reach. Heavy metals consumption and non- excretion or slow excretion from the human body are known to lead to cancer (carcinogenic or mutagenic (gene mutation) thus leading to abnormal behaviour and other behavioural patterns

Some of these pollutants cause different acute and chronic diseases such as skin burns and rashes, bone abnormalities lung and digestive system disorders in aquatic and surrounding land. A major source of worry as observed by this study was that majority of these industrial firms which are owned by multinationals with so much influence on the principals of the monitoring agency, a trend that is disadvantageous to everyone living in the surrounding communities.

The management of most of the industries often resisted impromptu visit or unnotified visit by the monitoring agency thereby allowing them to get away with the consequences of pollution into the environment by the government. Most often, diluted samples are taken for analysis and test. This study observed and confirmed that in most cases industries close-down operation to avoid agency from collecting correct in – situ samples, and even when in operation, some of them often discharge distilled water into the sampling point, to show that what they discharge is free of pollutants. In cases where short notice or no notice for monitoring was given to the firms, they prevented agents of the government from accessing their industrial premises, even when it had been proved that advanced notices were sent ahead of monitoring industrial visit.

Some of the industries give false claims to have treated their effluent to minimum National Standard which this study found otherwise. This was to avoid the expenses required and time spent to treat the effluent. The industries often indulge or bypass the required treatment. Even when some of the effluents were treated, this research effort observed that in terms of heavy metal only few firms had shown efforts of installed treatment facilities for heavy metal, by the process shown in figure 7.1 which applied modified and improved granular activated carbon bed recommended as treatment options.

7.1.4 Priority Pollutants along the Atuwara Watershed

Most of the industries located close to or along river Atuwara discharge directly or indirectly into the river. Sample analysis and tests indicated a violation of NMS in inorganic/trace organics. The following priority pollutants, BOD, COD, TDS, TS, TSS, Chloride conductivity, pH, and heavy metals such as Cadmium, Lead, and Iron were confirmed

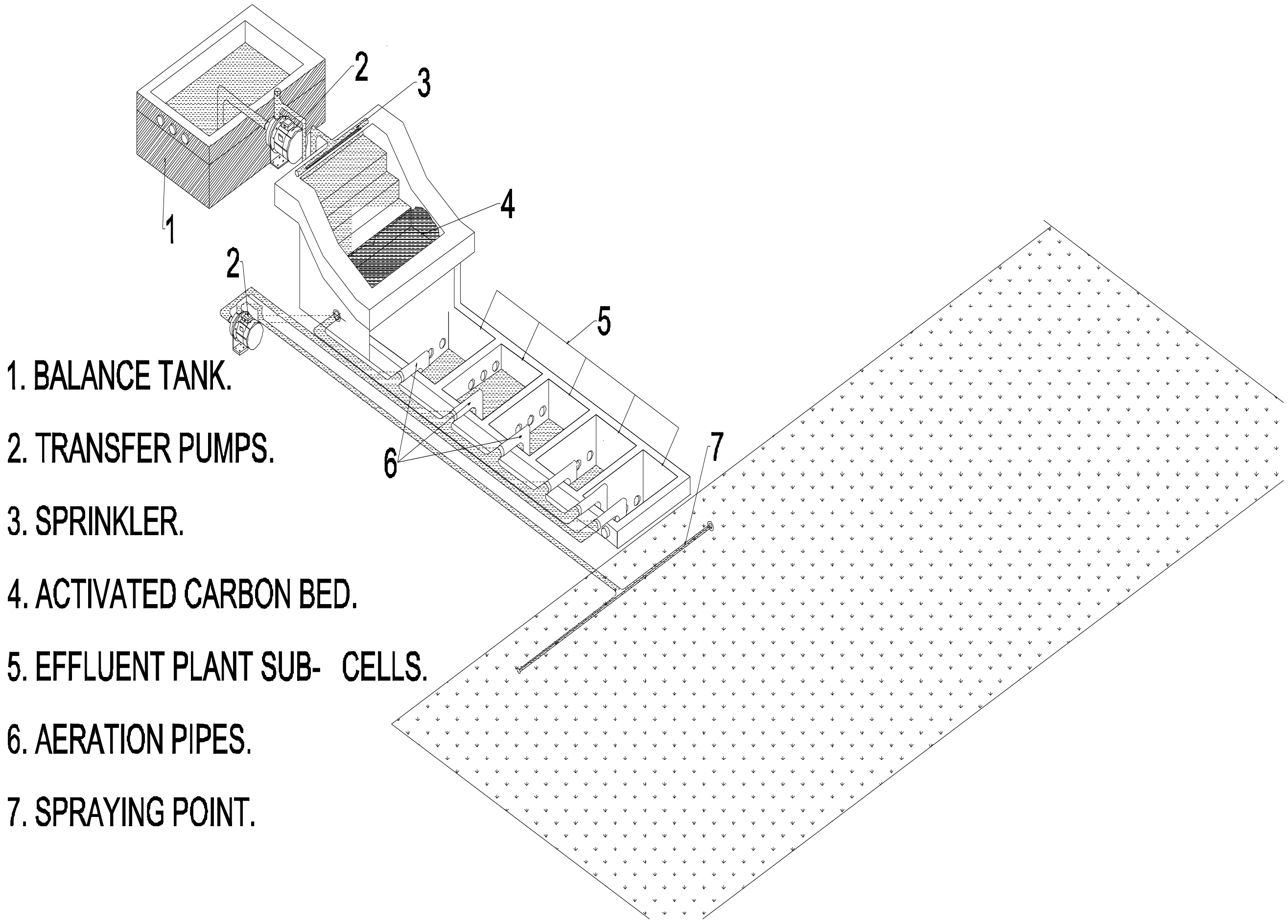


Figure 7.1: Improved activated carbon Bed

In any single sample: pH fell within the range of 5.42 – 7.92., temperature range of 25.2 to 33.8^{o} C. The upper river Atuwara watershed was intensively sampled during this study in the month indicated between 2008/2009. Water quality samples were collected during the wet season (14/10/ 2008 and 11/05/ 2009) and dry season (17/02/2009 and 18/05/2009).

Water quality monitoring stations were selected in this watershed to characterize water quality of the river reaches. Data set stations were positioned to evaluate the impact of tributary streams and to establish background conditions.

The result of the survey was summarized in a water quality survey report in Tables 4.7, 4.11, 4.15 and 4.19. More detailed physical, biological and chemical data were collected for this site using methods from the state environmental monitoring study. These data were collected in conjunction with the water quality survey and were used in the physical and biological assessment of this river segment. All temperature, chemical/physical and river sampling and assessment techniques are detailed and recorded in Tables 4.7, 4.11, 4.15 and 4.19.

As a result of the 2008/2009 monitoring process and subsequent assessment of results, exceedances of FEPA water quality standard for this river were documented. Accordingly these impairments will be made available to the state (OGEPA) for integration. This research applied each assessment unit by constituent (or pollutant) of the standard(s) which have been exceeded.

Table 7.1: Individual Reach Description: Summary of River Atuwara Watershed Impairment addressed in this research

Reach	Impairment	Delistings
1. Atuwara upstream including Abattoir.	BOD, TSS, TDS, TS, COD, Cadmium, Lead and Iron	Temperature
2. Sona Breweries Discharges	pH, DO, BOD, Temperature, TSS, TDS, TS, COD. Cadmium, Lead and Iron.	Stream bottom deposit, plant nutrients
3. Ewupe Discharge	DO, pH, BOD, TDS, TSS, TS, Cl. Cadmium, Lead and Iron.	Stream bottom deposit,
4. Afara meje	Chloride, Iron, Cadmium.	Temperature
5. Ekusere Discharges	pH, COD, DO, BOD, Cadmium, Lead, Chloride	
6. Igboloye Discharges	BOD, DO, pH, Temperature, TSS, TDS, TS, COD, Heavy metals.	Stream bottom deposit,
7. Water Corporation	pH, DO, Lead, BOD, TSS, Iron	

7.2 Recommendations

The model and softwares was further applied to determine strategies that would help to shore up the water quality of the river to an acceptable limit. The simulations were performed to explore how the water quality would change with changes in loads as well as environmental modifications i.e., flow augmentation to the river. The scenario helped to visualise the effectiveness of approaches intended to prevent pollution before their actual implementation.

The following recommendations are hereby given:

1. With respect to governmental agency monitoring and control of industries there should be legislation that all Local, State and Federal Government should establish an independent and enforceable monitoring unit for industries. In this regard this agency should be allowed unhindered access to any factory or industry with or without advance notices.
2. The government should also empower the monitoring agencies to enforce the law by arming their task force with legal teeth so as to prevent their being manhandled by the security services of the industrial outfits. A mobile industrial court should be established to give instant enforcement and punish or charge firms which may violate or contravene environmental laws. Some industries are fond of engaging the services of environmental consultants who more often than not produce doctored analytical results to the governmental monitoring agencies periodically. This is a case of he who pays the piper dictate the tunes.
3. Calculated worst scenario on 14/10/ 2008 as: (56 mg/L of BOD from source – 25 mg/L BOD from headwater) X (4.477 m^3/s or 4.477 X 10^3 L /s) of flow X (3600 s) X (24 hrs) = 11.99 tonnes/day The scenario was generated in order to achieve water

quality of the river corresponding to class C as indicated in Table 6.1, i.e., achieving DO of more than 4 mg/L and BOD of less than 30 mg/L every where in the river..The BOD and DO levels of all the point sources were set at 30 mg/L and 4 mg/L respectively. These are in lieu of the permissible levels for discharging effluents to surface water from any point outlet. This may be achieved by providing proper wastewater treatment to all the drains. In addition, headwater quality was restricted to a BOD level of 4 mg/L

4. Government should mandate the contribution of certain percentage of Firms' profit after tax to provide alternative source of water supply to communities where their surface water had been polluted as a result of their activities such as deep borehole.
5. It is recommended that the mainstream flow rate should be 7 m^3/s of fresh water from upstream of industrial discharge. This implied that water of about 10 m^3/sec would flow through the river, even after the withdrawal for Iju water-works, It was noteworthy that this exercise could be achieved, the desired DO levels will be attained but the targeted BOD levels (of less than 4 mg/L) could not be achieved. Further simulation was carried out by curtailing flow of some of the major drains in order to achieve BOD levels below 4 mg/L at all locations. The above generated scenario suggested that achieving the water quality of the river corresponding to the class C is a major challenge. But in order to maintain desired water quality in this stretch the following approaches would be helpful:

   i. All the effluent discharges should be given adequate treatment. Waste water discharge from all the Industrial outlets should be treated to achieve the BOD and DO levels of 30 mg/L and 4 mg/L respectively.

ii. Flow curtailment from industrial discharge: Discharge rate of some of the industries is very high which may be curtailed from entering into the river to maintain its quality.

iii. As specified by Central Pollution Control Board, to maintain river water quality of Class C. through covered pipelines where further treatment could also be provided (NEERI, 1996), flow augmentation to the river must be improved and flow after Sona discharge contributed by waste discharges from drains should be strictly monitored. Thus, a flow of 10 m^3/s in the river should be maintained.

iv. Artificial aeration is also deemed necessary as DO levels in the river are less then 1mg/L at specific stretch of the river reaches, which presents constraint for biological degradation of organic load.

v. Common Effluent Treatment Plants (CETP) are indispensable, especially for all small-scale industries, who cannot afford to treat their effluents; both small scale industries and large industrial establishment must adopt the possibility of installing Electro – Fenton Oxidation process followed by granular activated carbon and other contemporary high technology treatment processes.

vi. Sewage treatment facilities should be expanded in the city to guard against untreated domestic waste being discharged into the river;

vii. Adopt rain water harvesting, which may increase natural recharge capacity of the river to provide sufficient flow.

REFERENCES

Adelegan, J. A. (2002). Environmental policy and slaughterhouse waste in Nigeria. 28th WEDC Conference on Sustainable Environmental Sanitation and Water Services.

Ademoroti, C. M. A. (1985). Case studies of industrial waste treatment. In P. O. Sada & F. O. Odemerho (Eds); Environmental Issues and Management in Nigeria; Chapter 19. Ibadan: Evans Nig Ltd.

Adeniji, F. A. (2006). Wastewater management and use: the Nigerian situation. Project proposal on Towards Greening Grey Water for Urban and Peri-Urban Agriculture in Nigeria.

Adenuga, A. O.; Ogunjiuba, K. and Ohuche, F. K. (2003). Sustainability of the environment and water pollution in Nigeria: problems, management and policy options, in African Institute for Applied Economics. Enugu, Nigeria: AIAE.

Adewumi .I. K (2006) Optimization and Specification of Activated Charcoal Produced from Palm Kernel Shells. A Thesis Submitted in Partial Fulfilment of the Award of the Degree of Doctor of Philosophy in Civil Engineering Obafemi Awolowo University Ile Ife Nigeria

Adewumi I.K and Ogbiye A.S (2009) Using water hyacinth (Eichhornia Crassipes) to treat Wastewater of a Residential University. Toxicological & Environmental Chemistry Vol. 91, No. 5, pp. 891–903

Aka, M. K.; Oyewo, E. O. and Sylvia, S. T. (2002). Management of municipal sewage in sub-Saharan Africa through appropriate technologies, working group on Regional Africa Project Proposal on Pollution, The Gambia.

Ambrose, R. B. (1987). Modelling volatile organics in the Delaware Estuary. American Society of Civil Engineers. Journal of Environmental Engineering. Vol.113 No.4 pp. 703-721.

Ambrose, (Jr.) R. B.; Wool, T. A.; Connolly, J. P. and Schanz, R. W. (1988). WASP4: a hydrodynamic and water quality model—model theory, user's manual, and programmer's guide. United States Environmental Protection Agency. Athens, GA. EPA /.600 /.3-87 - 039.

Ambrose, (Jr.) R. B.; Wool, T. A. and Martin, J. L. (1993). The water quality analysis simulation programme, WASP5: part A: model documentation. United States Environmental Protection Agency, Athens, Georgia. 202.

APHA (1998) Standard Methods for the Examination of Water and Wastewater, 20th Ed., American public Health Association, American Water Works Association, Water Environmental Federation, Washington D.C..

Ayoade J.O (1975) Water Resources and Their Development In Nigeria .Hydrological Science Bulletin –des Sciences Hydrologic xx,

Azeez, L. O. (1972). Rural water supply in the basement complex of Western State of Nigeria. Hydrological Science Bulletin. Vol.17 No.7, pp. 110.

Badawy M. I. and Ali – M. E. M (2006) Fenton’s Peroxidation and Coagulation Process for the Treatment of Combined Industrial and Domestic Waste water Research Centre. Water Pollution Department Doleki Cairo Egypt.

Bedford, K.; Findikakis, A.; Larock, B. E.; Rodi, W. and Street, R. L. (1998). Turbulence modelling of surface water flow and transport. Journal of Hydrology Engineering. Vol.114, No.9, pp. 970-1073.

Beck, M. B. and Finney, B. A. (1987). Operational water quality management: problem context and evaluation of a model for river quality. Water Resource Research. Vol.23 No. 11 pp. 2030-2042.

Birgrand, Franccois (2003). Evaluation of QUAL2E. Southern Cooperative Series Bulletin. North Carolina State University.

Bowei .G.L. Mills W.B, Pervella, D.B..Campbell,.C.L.Johnson K.M,Chan .P.W.H,Ghenini.S.A and Chamberlin .C.E,(1985) Rates Constants and Kinetic Formulation in Surface Water Quality Modelling US Environmental Protection Agency ORD Athens GA ERL.EPA/6003-85040

Brown, L. C. and Barnwell, T. O. (1987). The enhanced stream water quality models QUAL2E and QUAL2E-UNCAS: Documentation and user manual. United States Environmental Protection Agency, Athens, GA. EPA/.600 /.3.-87-007.

Canale, R. P.; Owens, E. M.; Auer, M. T. and Effler, S. W. (1995). The Validation of a Water Quality Model for the Seneca River. New York Journal of Water Resources Planning Management.Vol. 121, No.3, pp. 241-250.

Carrondo, M. J. T.; Lester, J. N. and Perry, R. (1979). An investigation of a flameless atomic absorption method for determination of aluminium, calcium, iron and magnesium in sewage sludgeAtalanta.. 257-290, 26. 929-933.

Casman and Linker, (1994). Response of the Chesapeake Bay Water Quality Model to Loading Scenarios. Chesapeake Bay Programme Technology Transfer Report CBP/TRS. 101/.94.

Chanshang H.E (2003) Integration of Geographic Information System and Simulation Model for Watershed Management ELSEVIER Science Ltd.

Chapra, S. C. (1997). Surface Water Quality Modelling. Series in Water Resource and Environmental Engineering. New York: McGraw-Hill Companies Inc. New York.

Chapra S. C. and Reckhow, K. H. (1983), Engineering approaches for lake management. Butterworth Woburn, MA: 2 Mechanistic Modelling

Chaudhry, M. H. (1993). Open-channel flow. Prentice Hall: Englewood Cliffs, New Jersey. 483.

Chow V.T. (1959) Open Channel Hydraulics Mc Graw Hill New York.

Claire M. S. (1999). Environmental Technology and Economics, Sustainable Development in Industry Global Environment Alert.

Congalton, Ohoebe (1998) Leaf litter and Organic Soil – quality and Decomposition across an Urban Rural land use gradient < http: 11 Courses. Mbl. Edu/ SES/data/project/1998/ Conglaton. pdf > Accessed April 2003.

Cowan, J. L. W.; Boynton, W. R. (1996). Sediment-water oxygen and nutrient exchanges along the longitudinal axis of Chesapeake Bay: seasonal patterns, controlling factors and ecological significance. Estuaries 19,. 562–580.

Cowan, J. L. W.; Pennock, J. R.; Boynton, W. R. (1996). Seasonal and interannual patterns of sediment-water nutrient and oxygen fluxes in Mobile Bay, Alabama (USA): regulating factors and ecological significance. Material Ecology Programme Series. 141 :.229-245.

Connolly, J. P. and R. V. Thomann (1985). WASTOX: a framework for modelling the fate of toxic chemicals in aquatic environments. Part 2: Food Chain. United States Environmental Protection Agency. Gulf.

CPCB (1983) Central Pollution Control Board. Assimilation Capacity of Point Pollution Load Cups/12 CPCB Delhi India.

CPCB (2000) Water Quality Status of the Ilamuna River ADSORBS/32 Central Pollution Control Board Delhi India.

Deininger, R. A. (1965). Water quality management: the planning of economically optimal control system proceedings of the first annual meeting of the American Water Resources Association.

Dickinson WT (1967) Accuracy of Discharge Determinations Hydrology paper 20, Colorado State University Fort Collins. Co.

Di Toro, D. M. and Connolly, J. P. (1980). Mathematical models of water quality in large Lakes. Part 2: Lake Erie. United States Environmental Protection Agency. EPA-600/3-80-065.

Di Toro, D. M. and Matystik, W. F. (1980). Mathematical models of water quality in large Lakes, Part 1: Lake Huron and Saginaw Bay. United States Environmental Protection Agency. EPA. 600 /.3 -. 80 - 056.

Di Toro, D. M.; O'Connor, D. J. and Thomann, R. V. (1971). A dynamic model of the Phytoplankton population in the Sacramento San Joaquin Delta. Advanced Chemical Services. 106, American Chemical Society. Washington, DC.131-180.

Di Toro, D. M.; J. J. Fitzpatrick and Thomann, R. V. (1983). Water quality analysis simulation programme (WASP) and model verification programme (MVP)-Documentation. Hydro Science Inc. 206 Westwood, NY, for United States Environmental Protection Agency, Duluth, MN, Contract No. 68-01-.3872.

Eckenfelder, W. W. (1987). Industrial water pollution control. New York: McGraw-Hill Book.

Emmanuel, M. K.; Oyewo, O. and Sylvia, S. Tenu (1999) Management of municipal sewage in sub-Saharan Africa through appropriate technologies.

Falconer, R. A. (1990) Engineering problems and the applications of mathematical models relating to combating water pollution in Municipal Engineering. December 7. 281-291.

Federal Environmental Protection Agency (1988). Decree No. 58 National Interim Guidelines and Standards for Industrial Effluent, Gaseous Emission and Hazardous Wastes Management in Nigeria..

Federal Environmental Protection Agency (1991). Guidelines and Standards for Environmental Pollution Control in Nigeria.

Federal Environmental Protection Agency (1991). National Environmental Protection (Effluent Limitation) Regulation. S. I. 9 National Environmental Protection (Pollution Abatement in Industries and Facilities Generating Wastes).

Federal Environmental Protection Agency (1992). Decree No. 59. Environmental Impact Assessment.

Fischer, H. B.; List, E. J.; Koh, R. C. Y.; Imberger, J. and Brooks, N. H. (1979). Mixing in inland and coastal waters. New York: Academic Press.

Ghosh N. C (1996) Application of QUAL2E for water quality modeling of Kali River (U. P) Indian Journal of Environmental Health .38 (.3):. 160 – 170.

Giblin, A. G.; Hopkinson, C. S. and Tucker, J. (1997). Benthic Metabolism and Nutrient Cycling in Boston Harbor, Massachusetts. Estuaries. .20 : 346-364.

Gupta R. S (1989) Hydrology and Hydraulic Systems Pentice Hall Englewood Cliff. NJ.

Hager, W. H. (2003). Fargue founds of experimental river engineering Journal of Hydraulic Research. BBC .10 - .03-07 - 001.

Hamdy Seif and Moheb Malak (2001) Textile Wastewater Treatment Sixth International Water Technology Conference, IWTC, Alexandria, Egypt

Hammond, A. J. (2004). Hydrodynamics and Water Quality Simulation of Feacal Coliforms the Lower Appomattox River Virginia. Masters Thesis. Virginia Polytechnic Institute and State University.

Henderson (1996) Open Channel Flow. Boston: Pitman.

Hodges, (1973). Environmental pollution. 2nd Edition. New York: Holt, Rinehart and Winston, 233-234.

Huseyin Tekin , Okan Bilkay, Selale S. Ataberk ,Tolga H. Balta ,I. Haluk Ceribasi ,F.Dilek Sanin, Filiz B. Dilek ,and Ulku Yetis(2006) Use of Fenton oxidation to improve the biodegradability of a pharmaceutical wastewater. Journal of Hazardous Materials Vol.136 Issue 2 Pp 258 – 265.

Hydroscience (1971) Simplified Mathematical Modeling of Water Quality

prepared for the MITRE Corporation and the USEPA Water Programs Washington D.C.

Imevbore, A. M. A. (2000). Industrial overview of the contribution of industry to sustainable development in Nigeria. EU Integrated Product Policy.

IPP (2003) Integrated Pollution prevention and control (Northern Ireland) A presentation Guide Edition Department of the Environment www.europa.eu.int/comm/environment/IPP,Visited.

Iwugo, K. O.; Brian, D. A. and Robert A. (2003). Aspect of land based pollution of an African coastal: megacity of Lagos. Diffuse Pollution Conference, Dublin.

James, R. T.; Martin, J.; Wool, T. and Wang, P. F. (1997). A sediment re-suspension and water quality mode of Lake Okeechobee. *Journal of American Water Resource Association.* 33: 661-680.

Jiang, B. (1998). The least squares finite element method: theory and application in computational fluid dynamics and electromagnetic springer Verlag.

Jolankai, G. and Berlin, Heidelberg Y. (1997). Basic river water quality models, International Hydrological Programme IHP-V/Technical Documents in Hydrology. 13. Paris: UNESCO, Paris.

Kaliakin V. N. (2002). Introduction to approximate solution techniques: numerical modelling and finite element methods. Machel Decker. Inc. NY. 243-301.

Kazmi A.A. (2000) Water Quality Modeling of River Yamuna. *Journal of Institute of Engineers*. India, 81, .17 – 22

Keith, L. H. (1988). Environmental Sampling: a Summary. Environmental Health and Technology. Vol.24, No.5, pp. 610-617.

Kemp, W. M.; Smith, E. M.; Marvin Dipasquale, M. and Boynton, W. R. (1997). Organic carbon balance and net ecosystem metabolism in Chesapeake Bay. Mar. Ecological Programme Series. 150 : 229-248.

Krantz, D. and Kifferstien, B. (2001). Water pollution and society with Netscape. Navigator Gold.

Lahlou N. Shoemaker, L.Chaudhury S. Elmer, R.Hu A. Manguetta H Parker, A (1998) BASINS V. 2.0 User’s Manual US. EPA office of water Washington DC EPA - 823 B - 98- 006.

Linping, K. and Verstraete, W. (1997). Autotrophic Denitrification of domestic wastewater to meet the new discharge limits in Flanders in the 3rd Ph.D. symposium. Universiteit Gent.

Lung, W. S. (1993). Water quality modelling. III. Application to Estuaries. Boca Raton, Florida: CRC Press. 1 -. 4.

Macpresse, (2001) Interim Report Submitted to the Pollution Control and Environmental Health Federal Ministry of Environment on Industrial Effluent Waste Treatment Facilities in Lagos State

Mamood, K. and Yevjevich, V. (1975). Unsteady flow in open channels. Fort Collins, Colorado: Water Resources Publications.

Markotsky, M. and Harleman, D. R. F. (1973). Prediction of water quality in stratified reservoirs. American Society of Chemical Engineers; Journal of the Hydraulics Division. Vol.99 No. 5, pp. 729-745.

Martin, J. L. and McCutcheon, S. C. (1999). Hydrodynamics and transport for water quality modelling. Boca Raton, Florida: CRC Press.

Monod, J. (1949). The growth of bacterial cultures. Annual. Review. Microbiology.. 3: 371-394.

Montes, S. (1998). Hydraulics of Open Channel Flow. American Society of Chemical Engineers.pp. 20-22.

MPCA (1999). Disposal of Industrial Wastewater and Alternatives. Minnesota Pollution Control Agency. UICP /.8 -0.2.

Neyens .E and J. Baeyens, (2003), A review of classic Fenton's Peroxidation as an Advanced Oxidation Technique, J. Hazard. Mater. Vol.**98** pp. 33–50

O’Connor D.J,(1988c) Models of Sorptive Toxic Substances in Freshwater Systems III Streams and Rivers “Journals of Environmental Engineering Vol.114, No.3, pp. 552-574

O'Connor, D. J. and Thomann, R. V. (1972). Water Quality Models, Chemical Physical and Biological Constituents. in Estuarine Modeling: An Assessment. Environmental Protection Agency. Water Pollution Control Research Series 16070 DZV. Section 702 No.71, Pp.102-169.

O’Connor, D. J. (1967). The temporal and spatial distribution of dissolved oxygen. In Streams Water Resources. Vol.3, No.1, pp. 65-79.

O’Connor D. J. and Dolbins W. E. (1958) Mechanisms of Reaeration in Natural Streams, Transactions of the American Society of Civil Engineers Vol.123, pp. 641 – 684.

Ogunfowokan, A. O.; Okoh, E. K.; Adenuga, A. A. and Asubiojo, A. I. (2005). An assessment of the impact of point source pollution from a university sewage treatment oxidation pond on a receiving stream. A preliminary study: Journal of Applied Sciences. Vol.5, No.1, pp. 36-43. ISSN 1607-8926.

Ojo, M. S. (1996). Environmental degradation in Lagos. Technical paper at Lagos State Environmental Action Plan Workshop, Victoria Island, Lagos.

Oluwande, P. A. (1975). Environmental development in Nigeria (some engineering aspects). Paper presented at the National conference of Nigerian Society of Engineers.

OMOE, (1990). St. Clair River Municipal-Industrial Strategy for Abatement Pilot Site Investigation. Draft Technical Findings and Appendices, St. Clair River Pilot Site Team, G. Johnson ed. Ontario Ministry of the Environment, ISBN #0-7729-6304-5. 3 Volumes.

Organization of Economic Cooperation and Development (1980). Water Management in Industrialized River Basins. Paris.

Orlob, G. T. (1982). Mathematical modeling of water quality. CHichester: Wiley.

Orlob, G. T. and Selna, L. G. (1970). Temperature variations in deep reservoirs. American Society of Chemical Engineers; Journal of the Hydraulics Division. Vol.96, No. 2, pp. 391-410.

Pakulski, J. D.; Benner, R.; Whiteledge, T.; Amon, R.; Eadie, B.; Cifuentes, L.; Ammerman, J.; Stockwell, D. (2000). Microbial metabolism and nutrient cycling in the Mississippi and Atchafalaya River plumes estuaries. Vol.50, pp. 173-184.

Paliwal, R., Sharma, P., Kansal A., (2006). Water quality modelling of river Yamuna (India) using QUAL 2E-UNCAS. Accepted in Journal of Environmental Management.

PDER (1981) simplified method for determining point source effluent limitations for discharges to free – flowing streams. Developed by Pennsylvania Department of Environmental Resources and U.S Environmental Protection Agency. December 14 http://www.dep.state.parces/dep/depatate/watermgt/wap/WQ standard/ Legacy/Simpli.Method.pdf

Pink Daniel, H. (2006). Water pollution investing in tomorrow's liquid gold. From the free Encyclopedia. http://en.wikipedia.org/wiki/water_pollution.

Pomeroy, L. R.; Blanton, J. O.; Paffenhöfer, G. A.; Damn, K. L. V.; Verity, P. G.; Windom, H. L. and Lee, T. N. (1993). Inner shelf processes. In D. W. Menzel, (Ed.). Ocean Processes: United States Southeast Continental Shelf. 9-43.

Rahman, M. (1988). The hydrodynamics of waves and tides, with applications. Topics in Engineering. 4. Southampton, United Kingdom: Computational Mechanics Publications.

Radwan, M. P.; Willens, A. El-Sadem and Berlamont, J. (2003). Modelling of dissolved oxygen and biochemical oxygen demand in river water using a detailed and a simplified model. International Journal of River Basin Management.Vol. 1, No.2, pp. 97-103.

Rauch, W. M.; Henze, L.; Koncsos, P.; Reicher, P.; Shanahan, L. Somlyody and Valarolleghem, P. (1998). River water quality modelling I: State of the Art. In IAWQ Biennial International Conference, Vancouver British Columbia Canada. ;.21-26.

Rauch, W. and Harremoes, P. (1996). The importance of the treatment plant performance during rain to acute water pollution. Water Science Technology.Vol. 34, No.3-4, pp. 1-8.

Reichert, P. and Wanner, O. (1991). Enhanced one-dimensional modelling of transport in rivers. Journal of Hydrology Engineering. Vol.117, No.9, pp. 1165-1183.

Ritu, P. and Prateek, S. (2004). Application of QUAL2E for the River Yamuna to assess the impact of point loads and to recommend measures to improve water quality of the river. Yamuna Action Plan National River Conservation Directorate, Ministry of Environment and Forest, New Delhi

Runkel R. L. Bencala K.E, Bronchears R.E, and Chapra S.C. (1996) Reactive Solute Transport in small streams I, Development of an Equilibrium Based Simulation Model. Water Resource Research.

Shanahan, P.; Henze, M.; Koncsos, L.; Rauch, W.; Reinhert, P.; Somlyody L. and Vanrollegem, P. (1998). River water quality modelling II: problems of the art. IAWQ Biennial International Conference, Vancouver British Columbia, Canada.

Shifrin, N. H. (2005). Pollution management in the twentieth century. In American Society of Chemical Engineers; Journal of Environmental Engineering. ISBN: 0733-9372.. 131 : 676.

Simachaya, W. (2002). Water quality monitoring and modelling: application in Thailand. Paper presented to the Third World Water Forum session on the present situation and partnership in the future at the United Nations University Centre, Tokyo, Japan. October 16-17.

Simpson, M. J. and Clement, T. P. (2003). Comparison of finite difference and finite element solutions to the variably saturated flow equation. Journal of Hydrology. 27:. 49-64.

Sukanda J, Ake B and Anak P (2004), Wildlife, human and domestic animal use of buffer Zone area.Consequences for management strategies Huzi kha kaeng wildlifesanctuary Thailand Master Theses No 36 Swedish Biodiversity Centre

Standard Methods (1995). Standard methods for the examination of water and waste-water (19th edition). Jointly published by the American Public Health Association, American Water Works Association and Water Pollution Control Federation. Washington DC.

Steele, J. H. (1962). Environmental control of photosynthesis in the sea. Limnol Oceanography.Vol. 7 :.137-150.

Streeter, H. W. and Phelps, E. B. (1925). A study of the pollution and natural purification of the Ohio River. Factors concerned in the phenomena of oxidation and reaeration. United States: 209 Public Health Service. Public Health Bulletin. Vol.146 No.75. Reprinted by United States DHEW, PHA, 1958.

Terry, L. A. (1996). Water Pollution Environmental Law Practice.Vol. 4, No.1,pp. 19-29.

Thomann, R. V. and Fitzpatrick, J. J. (1982). Calibration and Verification of a Mathematical Model of the Eutrophication of the Potomac estuary. Prepared for the Department of Environmental Services, Government of the District of Columbia, Washington DC.

Thormann, R. V. and Sobel, M. J. (1964). Estuarine Water Quality Management and forecasting. American Society of Civil Engineers; Journal of San. Engineering Division.Vol. 90, No SA5, pp 9-36.

Thomann, R. V.; Winfield, R. P.; Di Toro, D. M. and O’Connor, D.J. (1976). Mathematical modelling of phytoplankton in Lake Ontario. 2. Simulations using Lake 1 Model. United States Environmental Protection Agency. Grosse Ile, MI. EPA-600/3-76-065.

Thomann. R. V and Mueller J. A (1987) Principle of Surface Water Quality Modeling and Control. Harper Collings Publishers Inc. New York. NY.

Thormann, Robert V, James Collier, Athur Butt, Elizabeth Casman and Levis Lunker (1994) Response of the Chesapeake Bay Water Quality Model to loading Scenarios. Chesapeake Bay Program Technology Transfer Report. CBP/TRS 101/94

Truong, P.; Truong, S. and Smeel, C. L. (2003). Application of the Vetiver system in computer modelling for industrial wastewater disposal Proceedings. Third International Vetiver Conference; Guagliou, China.

Try, P. M. and Price, G. J. (1995). Sewage and industrial effluents.

Uğur Kurt, Ömer Apaydin, M. Talha Gönüllü (2005) A Research on treatability of leather industry wastewater by using electro-fenton process 34349 Besiktas/İstanbul/Turkey ukurt@yildiz.edu.tr .

Ugur Kurt, Omer Apaydin and M. Talha Gonullu (2007) Reduction of COD in Wastewater from an organized tannery industrial region by Electro-Fenton process .Journal of Hazardous Materials Vol. 143, Issue 1 – 2, Pp 33 – 40.

United States Environmental Protection Agency (1997). Benefits due to improved water quality. In water quality survey. New York Harbor. New York City Department of Environmental Protection. Pp.55-56.

United States Environmental Protection Agency (1995). QUAL2E Windows interface user's guide. United States Environmental Protection Agency.

EPA/823/B/95/003. Also at http://www.epa.gov/OST/BASINS/ bsnsdocs.html.

United States Geological Survey (2007). Water use in the United States: water science for schools. http://ga.water.usgs.gov/edu/wateruse.html.

United States Geological Survey (2007). Water Science and Water Quality. Url.http://ga.water.usgs.gov/edu./water quality.

USEPA (1993) United States Environment Protection Agency Manual; Nitrogen Control. EPA/625/ R_ 93 / 010. Office of Research and Development Washington D.C.

UN (1993) United Nations Conference on Environment and Development (UNCED) The Earth Summit Agenda for change Published by the centre for Our Common Future, 52 rue des paquis 1201 Geneva, Switzerland.

Velz, C. J. (1970). Applied stream sanitation. Interscience. New York: Wiley.

Velz C.J(1947) Factors Influencing Self – Purification and their Relation to Pollution Abatement. Sewage Works Journals Vol. 19, No.4, pp.629 – 644

Velz C.J (1938) Deoxygenation and Reoxygenation “Proceedings of American Society of Civil Engineers Vol.65, No.4 pp. 677 - 680

Vision 2010 Report (2003). Charting in the future development of Nigeria on ecology and environment.

Vandleeghem, P.; Bordart, D.; Henze, M.; Rauch, W.; Reichert, P.; Shanahan, P. and Solmlyody, L. (2000). River water quality model. 1. (RWQM1).

Wang, P. F.; Martin, J. and Morrison, G. (1999). Water quality and eutrophication in Tampa Bay, Florida. Estuarine, Coastal and Shelf Science.Vol. 49, pp 1-20.

Water Pollution Control Federation (1982). Sewer charges for wastewater collection and treatment. Jointly with APWA and ASCE. Washington.

Walton, R. and Webb, M. (1994). QUAL2E simulations of pulse loads. Journal of Environmental Engineering. Vol.120, NO.5, Pp.1017-1031.

Wang, H. F. and Anderson, M. P. (1982). Introduction to groundwater modelling, finite difference and finite element methods. New York: W. H. Freeman and Company. 233.

West, L. (2006). World water day: a billion people worldwide lack safe drinking water. Http://en.wikipedia.org/wiki/water_pollution.

Wlosinski, J. H. and Minshall, G. W. (1983). Predictability of stream ecosystem models of various levels of resolution. In Dynamics of Lotic Ecosystems; T. D. Fontaine and S. M. Bartell (ed.); Ann Arbor Science, Chelsea, MI, USA. Pp.69-86.

Wood, Tamara M. (2001) Sediment Oxygen Demand in Upper Kolamath and Agency Lakes Oregon 1999, U.S, Geological Survey Water Resources Investigations Report 01 – 4080 pp13.

Wool, T. A.; Ambrose, R. B.; Martin, J. L. and Comer, E. A. (2003). Water quality analysis simulation programme. WASP version 6.0 Draft; User’s manual. United States Environmental Protection Agency. Region IV Atlanta GA 26 1PP.

World Bank (2004). Environment at a glance: Nigeria. World Bank Environment Department. Washington D.C; 20433 USA, AQUASAT.

World Health Organisation (1984). Guideline for drinking water quality, health criteria and other supporting information (2nd edition). Geneva.

Wouter, G. and Verstraete, W. (1997). Nitrogen removal from sludge reject water with a membrane assisted bioreactor in the 3rd Ph.D. Symposium. Universiteit Gent.

Zheng, L.; Chen, C. and Zhang, F. Y. (2004). Development of water quality model in the Satilla River Estuary, Georgia. Ecological modelling. Vol.178 No. 457 pp482 - 465.

<http://ogunstate.gov.ng/index.asp>OgunState.gov.ng,(2010) <http://en.wikipedia.org/wiki/local government area of Nigeria Ado Odo /Ota from Wikipedia the force encyclopedia>(Wikipedia.org,(2010)

APPENDIX A

WATER QUALITY COMPONENTS

The mathematical expression for the internal sources or sinks (Si,I=1,8) of the quality variables sown in equation A2 are given as follows. Ci (I = 1,8) were corresponding to the concentrations of dissolved oxygen, phytoplankton, carbonaceous chemical oxygen demand, ammonium nitrogen nitrate, and nitrite nitrogen, ortho-phosphorous, organic nitrogen and organic phosphorous, respectively.

A.1 Dissolved oxygen (DO)

$$S_1 = k_{r1}\theta_{r1}^{(T-20)}\left(C_s - C_1\right) - k_{d1}\theta_{r1}^{(T-20)}\frac{C_1C_3}{K_{BOD}+C_1} - \frac{32}{12}k_{r2}\theta_{r1}^{(T-20)}C_2 - \frac{32}{14}2k_{ni}\theta_{ni}^{(T-20)}\frac{C_1C_4}{K_{NITR}+C_1}$$

$$+G_P\left[\frac{32}{12}+\frac{48}{14}a_{nc}\left(1-P_{NH_4}\right)\right]C_2 - \frac{SOD}{D}\theta_{SOD}^{(T-20)} - k_{r3} \qquad (A.1)$$

A.2 Phytoplankton (PHYT)

$$S_2 = G_P C_2 - D_P C_2 - \frac{\omega 2S}{D}C_2 \qquad (A.2)$$

A.3 Carbonaceous Biochemical Oxygen Demand (CBOD)

$$S_3 = a_{oc}\left(k_{par}+k_{grz}\right)C_2 - k_{dl}\theta_{dl}^{(T-20)}\frac{C_1C_3}{K_{BOD}+C_1} - \frac{\omega 3S\left(1-fD3\right)}{D}C_3 - \frac{5}{4}\ X\ \frac{32}{12}$$

$$X\ \frac{12}{14}k_{dn}\theta_{dn}^{(T-20)}\frac{C_5K_{NO_3}}{K_{NO_3}+C_1} \qquad (A.3)$$

A.4 Ammonium Nitrogen (NH_4)

$$S_4 = a_{nc}D_P\left(1-f_{on}\right)C_2 + k_{m1}\theta_{m1}^{(T-20)}\frac{C_1C_7}{K_{mpc}+C_2} - a_{nc}G_PP_{NH_4}C_2k_{ni}\theta_{ni}^{(T-20)}\frac{C_1C_7}{K_{mpc}+C_1} + B_1 \quad (A.4)$$

A.5 Nitrate and Nitrite Nitrogen (NO3)

$$S_5 = k_{ni}\theta_{ni}^{(T-20)}\frac{C_1C_4}{K_{NITR}+C_1} - a_{nc}G_P\left(1-P_{NH_4}\right)C_2 - k_{dn}\theta_{dn}^{(T-20)}\frac{C_5K_{NO_3}}{K_{NO_3}+C_1} + B_2 \qquad (A.5)$$

A.6 Ortho- Phosphorous (OPO4)

$$S_6 = a_{pc}D_p\left(1-f_{op}\right)C_2 + k_{m2}\theta_{m2}^{(T-20)}\frac{C_2C_8}{K_{mpc}+C_2} - a_{pc}G_PC_2 + B_3 \qquad (A.6)$$

A.7 Organic Nitrogen (ON)

$$S_7 = a_{nc}D_P f_{on}C_2 - k_{m1}\theta_{m1}^{(T-20)}\frac{C_2C_7}{K_{mpc}+C_2} - \frac{u7S\left(1-fD7\right)}{D}C_7 \qquad (A.7)$$

A.8 Organic Phosphorous (OP)

$$S_8 = a_{pc}D_P f_{op}C_2 - k_{m2}\theta_{m2}^{(T-20)}\frac{C_2C_8}{K_{mpc}+C_2} - \frac{\omega 8S\left(1-fD8\right)}{D}C_8 \qquad (A.8)$$

Where the definition for each parameters used are in the above equations is given in Table A. The aeration rate k_{rl} is chosen as the maximum value of flood – induced reaeration and wind – induced reaeration (O' Connor, 1983). Dissolved oxygen saturation concentration, Cs is determined as a function of salinity (s) and temperature (t) via the following equation (Alpha, 1985):

$$\ln C_s = \left\{\begin{matrix} -139.34+\left(1.5757\times10^{5}\right)T^{-1}-\left(6.6423\times10^{7}\right)T^{-2}+\left(1.2438\times10^{10}\right)T^{-3}-\left(8.6219\times1011\right)T^{-4}-0.5535\times \\ S\left(0.031929-19.428T^{-1}+3867.3T^{-2}\right) \end{matrix}\right\} \qquad (A.9)$$

The growth rate of phytoplankton G_p is determined by the ambient temperature, incident irradiance intensity, and nutrient availability. It can be expressed as:

$$G_P = k_{gr}\theta_{gr}^{(T-20)} f_1\left(N\right) f_2\left(I\right) \qquad (A.10)$$

Where f_1(N) is the nutrient limitation factor that is assumed to follow the Michaelis-Menten function i.e.

$$f_1(N)=\min\left(\left(C_4+C_5/\left(K_{mN}+C_4+C_5\right),\left(C_6/K_{mP}+C_6\right)\right)\right)$$

And f_2(I) is the light limitation factor.

The reduction rate of phytoplankton included its endogenous respiration, death rate due to the effect of viral lysis, and grazing by zooplankton was expressed as:

$$D_P=\left(k_{r2}+k_{par}+k_{grz}\right)\theta_{gr}^{(T-20)} \qquad (A.11)$$

During phytoplankton growth both NH_4 and NO_3 were available for uptake .For physiological reasons the preferred form for phytoplankton uptake was NH_4

The ammonium preference form was given as:

$$P_{NH_4}=\frac{C_4C_5}{\left(K_{mN}+C_4\right)\left(K_{mN}+C_5\right)}+\frac{C_4K_{mN}}{\left(C_4+C_5\right)\left(K_{mN}+C_5\right)} \qquad (A.12)$$

APPENDIX B

THE RESEARCH QUESTIONNAIRES

COVENANT UNIVERSITY

College of Science and Technology

Department Of Civil Engineering

Canaan Land, Otta, Ogun State.

RESEARCH QUESTIONNAIRE

PROGRAMME**:**

PhD CIVIL ENGINEERING

NAME OF RESEARCHER:

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PROJECT TITLE

POLLUTION PROBLEMS AND AN ENGINEERING APPROACH TO THE MANAGEMENT AND CONTROL OF INDUSTRIAL EFFLUENTS IN OTA NIGERIA.

AIM OF RESEARCH

Determination of the dilution power and self- recovery ability of a purposively selected

River in Ado –Odo Ota District after receiving industrial effluents and

assessment of the industrial waste management capability of the facilities of selected

industries.

Important Notice

This research work takes ethical considerations seriously and pledges anonymity and confidentiality of respondents and interviewees in line with the requirements of the *Covenant University* in research matters.

Please return answered questionnaire through email: aogbiye@yahoo.co.uk

INDUSTRIAL ASSESSMENT FORM

The objective of this survey is to assess the quantity and quality of the effluent being generated and disposed in your industry with a view to developing a modeling tool for appropriate treatment. We shall appreciate your giving us all available information, and assisting us in going round your facilities and also allowing us to collect the required effluent samples. The information collected shall be treated with utmost responsibility and confidentiality.

1.0 Industrial Identification

1.1 Name and Address: ---

1.2 Type of Industry by Products e.g. Food Processing, Breweries e.t.c--------------
----

1.3 Are there any off- site factory (warehouses, processing Units, Farms etc.) that fall under the direct control of your plant Management

1.4 If yes list the off- site locations and their functions. -------------------------------
----

1.5 List the sections or department under your operations -----------------------------
----

1.6 Year of Establishment / Commencement of Production-----------------------

1.7 Do you operate shift system? Yes ☐ No ☐

1.8 If yes, specify shift periods ---

1.9 Number of employees: - please kindly complete the table below.

Employees	No. Of Permanent	No. Of Non-Permanent	No. Of Casual	No. Of Skilled	No. Of Semi-skilled	No. Of Unskilled	Total
Management							
Administrative							

Technical							
Others please specify							

2.0 General Sanitation of The Premises

2.1 How often do you clean your surroundings? (a) Once a week (b) Fortnightly,

(c) Monthly, (d) Yearly (e) Others (please specify) ---------------------------------------

2.2 How do you keep the floor of your facility free from spent oil/ lubricant and grease? --

----

2.3 How frequent is the landscape managed? (a) Once a week (b) Fortnightly, (c) Monthly, (d) Yearly (e) Others (please specify)---

3.0 Materials

3.1 Raw Materials: -, Please kindly list the raw materials used in the industry

----

3.2 Please kindly complete the table below indicating the raw materials details

List all materials including industrial chemicals	Average quantities used per day (kg/T, L/m, etc)	Average quantities stored (kg/T, L/m, etc)	Storage conditions (containerized, open storage, specific Temp. Humidity etc. Please specify
--------------------------------------- ---------------------------------------	----------------------------- -------------------------------	--------------------- --------------------	-- --

3.3 Products: Please kindly complete the table below for the product details

List all bye products	Average quantities produced per day (kg/T, L/m, etc)	State the Percentage Recycled	State the Percentage Rejected
--------------------------------------- --------------------------------------	----------------------------- -----------------------------	--------------------------- ------------------------------	---------------------------------- --------------------------

3.4 Bye Products: Please kindly complete the table below for the bye - product details

S/No	List of all Products	Average quantities produced per day (kg/T,L/m,etc)	Percentage accepted	Percentage rejected	Remark

3.5 Waste Products: Please kindly complete the table below for the waste product details

List of all waste products	Average quantities produced per day (kg/T,L/m,etc)	State the percentage recycled	State the percentage disposed.
-- --	------------------------- -------------------------	------------------ ------------------	------------------------------------- -------------------------------------

4.0 Installation of Pollution Abatement Equipment

4.1 List all types of pollution abatement equipment installed in your facility. -----------------

Uses of Water.

4.1 Please complete the table below on water procurement

Type of water supply	Source of Water supply	Average quantity supplied per day m^3/day	Average quantity Utilized per day m^3/day	Method of treatment applied	Storage capacity m^3/day
Deep Well					
Municipal Water Supply					
Borehole					

Others, please Specify					

5.2 Please complete the table below on Water Use.

Type of Water Use	Volumes used per day m3/day	Volume disposed per day m3/day	Volume recycled per day m3/day	Volume Stored per day m3/day	Others, please specify
Process					
Boiling					
Cooling					
Washing/Sanitation					
Others. please Specify					

5.3 Please give a brief description of the production process that involves the use of water.

5.0 Waste Water

6.1 Please complete the table below on Waste water Details

Sources of Waste water	Method of waste water collection and storage	Volumes of wastewater		Discharge Outlets m^3/day
		Quantity recycled m^3/day	Quantity disposed m^3/day	

6.2 What are the various ways by which wastewater are collected in your factory?.

a) Combined for all effluents------------------------------------m^3/day

b) Process water-- m^3/day

c) Domestic water-- m^3/day
d) Rain run –off-- m^3/day
e) Others please specify-- m^3/day

6.3 Do you treat your wastewater? Yes ☐ No ☐

6.4 If yes please outline the steps undertaken by your firm in the treatment of

Wastewater before discharge--

6.5 If no give reasons. --

6.6 Please indicate the volume (m^3/day) and methods of disposal of treated/untreated wastewater

a) Into general sewers.-- m^3/day
b) Into receiving waters. -- m^3/day
c) Land. -- m^3/day
d) Recycle. -- -----------------m^3/day
e) Reuse.--- m^3/day
f) Others please specify.-- m^3/day

6.7 Please briefly comment on the quality of the receiving stream before or after

discharged. ---

6.8 Do your firm carry –out the analysis of sample in the receiving stream before or

after discharges. ---

6.9 Please indicate the frequency of sampling and analysis

a) Weekly
b) Fortnightly
c) Monthly
d) Others please specify

6.10 Please indicate which effluent monitoring methodology is used and attach your effluent analysis log sheet

a) Federal Environmental Protection Agency (FEPA) Federal Ministry of Environment (FEM)
b) Ogun State Environmental Protection Agency (OGSEPA)
c) International Oceanographic Commission (IOC)
d) World Health Organization (WHO)/Global Environment Monitoring System (GEMS)
e) United Nations Environmental Protection (UNEP)
f) Others, please specify

6.0 Solid Waste

7.1 At what point along your production process do you generate solid waste?.--

7.2 Do you have any waste segregation, Sorting mechanism or plants in your firm ?.

Yes ☐ No. ☐

7.3 What is the average amount of industrial solid waste generated by your firm in

Kg /day. --

7.4 Indicate from the following the management method(s) adopted by your firm
a) Compression/ Compaction ---Kg
b) Recovery from sorting. --- Kg
c) Incineration. -- Kg
d) Store/ Buried within the premises.-- Kg
e) Others please specify. -- Kg

7.5 What disposal method do your firm operate?.--
7.6 Where is the final waste disposal site?.--
7.7 How does your firm treat and dispose of any toxic, corrosive, flammable or radioactive waste materials? --
7.8 How do you treat and dispose of your expired raw materials and / or products? --

7.9 Describe the method of collection and the disposal of leachate from your dump? ------ --

7.0 Gaseous Waste.

8.1 List the major gases emitted from your facilities. --

8.2 Indicate the type of gaseous emissions abatement equipment provided by your firm (Filter, Scrubber, Electrostatic Precipitator, Others). ---------------------------------------

8.3 State your firm’s Maintenance Schedule if any? ---

8.4 State how you discharge the gaseous effluent. --

8.0 **Spent Oil/ Grease and Lubricants**

9.1 List the type of power generating used in your firm. ---------------------------------------

9.2 What is the power rating of the sets? ---KVA

9.3 State the efficiency with respect to:

a) Oil/Fuel consumption ---m^3/day

b) Noise level--- m^3/day

c) Smoke emission ---Db

d) Others please specify--- Specify Level

9.4 What quantity of spent oil / grease does your firm generate? ----------------------------

9.5 How do you manage the spent oil/grease? ---

10.0 Health and Safety

10.1 Do you have an in- house environmental pollution- monitoring unit?

Yes ☐ No ☐

10.2 When last did your firm carry out an environmental audit of your facilities? ----------- --

10.3 Are there jobs, tasks or areas where respiratory protective equipment (e.g. Dust

Masks Charcoal respirators, air supplied respirators etc) are required?

Yes ☐ No. ☐

Is noise protection (e.g. muffs, earplugs) required any where in the premises?

Yes ☐ No ☐

10.4 Is there a routine programme for periodic measurement of levels of employee exposure to air –borne chemicals, noise, heat or radiation?

Yes ☐ No. ☐

10.5 State the type of safety warning signs put in place by your firm. -------------------------

10.6 List the types of safety wears provide for your staff. ---------------------------------------

10.7 How do you enforce the use of the listed safety wears?.------------------------------------

10.8 What impact do the activities of your industry have on the immediate environment? -- ---

10.9 What is your firm’s future plan with respects to the production and plant capacity? ---- ---

______________________________ ___________________________

Officer Providing Information. Date of Information

APPENDIX C

TABLES UTILIZED FOR MODEL SELECTION

Table C.1 Water Quality Model Comparison Matrix

Model Name	Model Developer Agency	Model Contact Information	Model Availability Information
Water Quality Analysis Simulation WASP6.1	US EPA	CEAM 706-355-8400 US EPA	Downloadable from US EPA website
Enhanced Stream Water Quality Model QUAL2E	US EPA	Gerald D Laveck 202-260-7771 US EPA	Downloadable from US EPA website
Three-Dimensional Hydrodynamic-Eutrophication Model HEM-3D Hydrodynamic Model Code EFDC	VIMS	VIMS	Availability Subject to question
Tidal Prism Water Quality Model \TPWQM	Albert Y. Kuo VIMS	Albert Y Kuo VIMS 804-642-7212	None Specified

Two Dimensional, Laterally Averaged, Hydrodynamic and Water Quality Model CE-QUAL-W2	US ACE-WES	WQCMB 601-634-3785 US ACE- WES Scott Welss Civil Engineering Portland State University	Downloadable from Portland State University CEE website
CE-QUAL-ICM Three Dimensional Eutrophication Model **CE –QUAL -IM** (Chesapeake Bay Estuary Model) Proposed Hydrodynamic Model: CH3D	US ACE - WES	WQSMB 601-634-3785 US ACE-WES	Currently for US ACE use only

Table C.1 Water Quality Model Comparison Matrix (Contd.)

Model Name	Model Dimension Capability 1-D ,2-D ,3-D.	Coupled or Uncoupled Model	Steady State or Unsteady State Model
Water Quality Analysis Simulation WASP6.1 Proposed hydrodynamicDYYNHYD5 RIVMOD- H EFDC	1-D 2-D 3-D	Uncoupled water quality model	Unsteady and Steady – State Model
Enhanced Stream Water Quality Model QUAL2E	1-D	Coupled Water Quality and Hydrodynamic Model	Steady – State Model
Three-Dimensional Hydrodynamic-Eutrophication Model HEM-3D Hydrodynamic Model Code EFDC	1-D 2- D 3- D	Coupled Water Quality and Hydrodynamic Model	Unsteady Model
Tidal Prism Water Quality Model \TPWQM	1-D	Coupled Water Quality and Hydrodynamic Model	Steady – State Model
Two Dimensional, Laterally Averaged, Hydrodynamic and Water Quality Model CE-QUAL-W2	1-D 2-D (Literally Averaged)	Coupled Water Quality and Hydrodynamic Model	Unsteady Model
CE-QUAL-ICM Three Dimensional Eutrophication Model **CE –QUAL -IM** (Chesapeake Bay Estuary Model) Proposed Hydrodynamic Model: CH3D	1-D 2 –D Depth Averaged 3- D	Uncoupled Water Quality Model	Unsteady Model

Table C.1 Water Quality Model Comparison Matrix (Contd.)

Model Name	Water Quality Kinetic Source Code	Simulation Time Frame Continuous /Discrete	Minimum simulation time step
Water Quality Analysis Simulation WASP6.1	Potomac Eutrophication Model (PEM)	Continuous will model more than 1 tidal cycle	No Minimum Specified Model can Autostep
Enhanced Stream Water Quality Model QUAL2E	QUAL II	None specified	No Minimum Specified
Three-Dimensional Hydrodynamic-Eutrophication Model HEM-3D Hydrodynamic Model Code EFDC	TPWQM CE- QUAL- ICM	Continuous will model more than 1 tidal cycle	No Minimum Specified
Tidal Prism Water Quality Model \TPWQM	CE- QUAL- ICM	Continous model utilises an average tidal range for calculation	No Minimum Specified
Two Dimensional, Laterally Averaged, Hydrodynamic and Water Quality Model CE-QUAL-W2	Developed by USACE -WES	Continuous will model more than 1 tidal cycle	1 Second Minimum Model can Autostep
CE-QUAL-ICM Three Dimensional Eutrophication Model **CE –QUAL -IM** (Chesapeake Bay Estuary Model) Proposed Hydrodynamic Model: CH3D	Developed by USACE -WES For application to Chesapeake bay	Continuous will model more than 1 tidal cycle	No Minimum Specified Model Can Autostep

Table C.1 Water Quality Model Comparison Matrix (Contd.)

Model Name	Model Computer Requirements	Model Application of Tidal Estuaries	Specific Feacal Coliform Routine
Water Quality Analysis Simulation WASP6.1	Pc compartible system	Yes when coupled with a hydrodynamic model	Yes
Enhanced Stream Water Quality Model QUAL2E	PC Compartible System	Yes for rivers /estuaries that are well- mixed	Yes
Three-Dimensional Hydrodynamic-Eutrophication Model HEM-3D Hydrodynamic Model Code EFDC	PC Compartible System	yes	Yes
Tidal Prism Water Quality Model \TPWQM	PC Compartible System	Yes for estuaries that are well mixed	Yes
Two Dimensional, Laterally Averaged, Hydrodynamic and Water Quality Model CE-QUAL-W2	PC Compartible System	Yes for estuaries that are well mixed	Yes
CE-QUAL-ICM Three Dimensional Eutrophication Model **CE –QUAL -IM** (Chesapeake Bay Estuary Model) Proposed Hydrodynamic Model: CH3D	PC Compartible System	Yes when coupled with a hydrodynamic model	No will model first order decay

Table C.1 Water Quality Model Comparison Matrix (Contd.)

Model Name	Finite Element or Finite Difference Model	Model Handling of Watershed Loading Inputs	Water Quality Model Output
Water Quality Analysis Simulation WASP6.1	Finite Difference Model	Model can be linked to HSPF for watershed loading inputs	Time – Variable water quality constituent Concentrations
Enhanced Stream Water Quality Model QUAL2E	Finite Difference Model	None Specified	Steady –State Water Quality Constituents Concentrations
Three-Dimensional Hydrodynamic-Eutrophication Model HEM-3D Hydrodynamic Model Code EFDC	Finite Difference Model	None Specified	Time – Variable water quality constituent Concentrations
Tidal Prism Water Quality Model \TPWQM	Finite Difference Model	None Specified	Steady –State Water Quality Constituents Concentrations
Two Dimensional, Laterally Averaged, Hydrodynamic and Water Quality Model CE-QUAL-W2	Finite Difference Model	Watershed loading are handled as time varying boundary inputs	Time – Variable water quality constituent Concentrations
CE-QUAL-ICM Three Dimensional Eutrophication Model **CE –QUAL -IM** (Chesapeake Bay Estuary Model) Proposed Hydrodynamic Model: CH3D	Finite Difference Model	More can be linked to HSPF for watershed loading inputs	Time – Variable water quality constituent Concentrations

Table C.1 Water Quality Model Comparison Matrix (Contd.)

Model Name	Model Developer Agency	Model Contact Information	Model Availability Information
Water Quality Analysis Simulation WASP6.1	US EPA	CEAM 706-355-8400 US EPA	Downloadable from US EPA website
Enhanced Stream Water Quality Model QUAL2E	US EPA	Gerald D Laveck 202-260-7771 US EPA	Downloadable from US EPA website
Three-Dimensional Hydrodynamic-Eutrophication Model HEM-3D Hydrodynamic Model Code EFDC	VIMS	VIMS	Availability Subject to question
Tidal Prism Water Quality Model \TPWQM	Albert Y. Kuo VIMS	Albert Y Kuo VIMS 804-642-7212	None Specified

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APPENDIX D

SECTORAL GROUPING OF ADO ODO /OTTA INDUSTRIES

Sector A: Food, Beverages & Tobacco

S/N	Company’s Name	Business Address/ Company’s Address	Company’s Product
1	Allied Atlantic Distilleries	Km 40 Lagos – Abeokuta Expressway Sango Otta	Extra Neutral Alcohol
2	Coca Cola Nigeria Limited	Ilogbo Road Sango Otta	Coca- Cola Concentrates
3	Danico (W.A) Limited	Km 40 Lagos – Abeokuta Expressway Sango Otta	Suntop, Orange And Black Currant Fruit Drink ,Fruit Juice
4	De-United Foods Industries Ltd.	Km 4 Otta Idi-Iroko Road Otta	
5	Dil Maltex Nigeria Plc	Agbara Industrial Estate Agbara	Maltex (Malt Drinks)
6	Intercontinental Distilleries Ltd.	Km 15 Otta – Idiroko Road Otta	
7	Kerlin Products Limited	10 Ilo Awela Road Sango Otta	Wine & Alcoholic Drink
8	Newage Industries Ltd	Plot 2 Medina Industrial Estate Igbesi Agbara	Fruit Juice
9	Nutri Food Nigeria Ltd	3 Igbesa Road Agbara Industrial Estate Agbara	Food Items
10	Nestle Nigeria Plc	Agbara Industrial Estate Agbara	Maggi Cubes, Nido, Golden More,Nutrend,Cerelac,Maize & Wheat,Beance,Miillo,Chocomilo,Nescafe
11	National Suit Company Plc	Ijoko Road Sango Otta	Salt
12	Nigeria Distilleries Ltd	Km 40 Lagos-Abeokuta Express Way Sango Otta	Schnapps ,Tonic Wine Coconut Liquored Gin, Brandy
13	Sona Breweries Plc	Km 40 Lagos-Abeokuta Express Way Sango Otta	Beer & Miltonic
14	Unilever Nigeria Plc	Km 32 Badagry Express Way, Agbara Industrials Estate Agbara	Food Beverages’
15	Vita Malt Plc	Agbara Industrial Estate Agbara	Vita Malt Drinks

Sector B : Chemical & Pharmaceuticals

S/N	Company's Name	Business Address/ Company's Address	Company's Product
16	Ault & Wibong Nigeria Ltd	Km 38 Lagos –Abeokuta Express Way Sango Otta	Printing Hikes
17	Decross Ltd	Oyindamola Close Ijoko Road Sango Otta	Music Cassette &Tape
18	Dye Chem. Nigeria Ltd	Otta Industrial Estate Otta	Dyes & Chemicals
19	Evans Medical L T D	Agbara Industrial Estate Agbara	Pharmaceuticals
20	Farmex Meyer L T D	Km 38 Lagos Abeokuta Express Way Sango Otta	Pharmaceuticals'
21	Fine Chemical Ltd	Km 40 Lag .Abeokuta Express. Way Sango Otta	Chemical For Paint
22	Fids On Health Care Ltd	Km 40 Lagos Abeokuta Express Ways	
23	Fumman Nigeria Ltd	Ijoko Road Sango Otta	Chemical
24	Falcon Chemicals Ltd	Km 40 Abeokuta Express Way Sango Otta	Chemicals
25	Leady Pham A Industrial Ltd	Plot 3 & 4 Tomori Industrial Estate Sango Otta	Pharmaceutical
26	Metropolitan Batteries Ltd	Old Tarmac Road Sango Otta	Automotive Batteries
27	Nigeria –German Chemical Plc	Km 38 Lagos Abeokuta Express Way Sango Otta	Pharmaceuticals Agric Medicine
28	Glaxo –Smith Clive Nigeria Plc	Agbara Industrial Estate Agbara.	O.T.C Medicine
29	Nycil Ltd	Otta Industrials Estate Otta	Oral Nutrition Health Drinks
30	Olympic Hills Ltd	Km 38 Lagos –Abeokuta Express Way Sango Otta.	Printing Hills & Industrial Coating.
31	Purechem Industries Limited	Km 38 Lagos-Abeokuta Express. Way Sango Otta	Chemicals
32	President Paints Nig. Ltd	Km 15 Ota-Idiroko Road Iju Otta	Textile Chemicals
33	Pharma-Deko Plc	Agbara Industrial Estate	Pharmaceuticals
34	Petralpha Limited	Km 38 Lagos-Abeokuta Express. Way Sango Otta	Drinks
35	Reckitt Benckiser Nigeria Limited	Agbara Industrial Estate	Cleaning/ Washing Liquids
36	Sren Chemicals Limited	Lynsan Chemical Close Igbala Sango Otta	Printing Inks And Chemicals

S/N	Company's Name	Business Address/ Company's Address	Company's Product
37	Samfad Industries Limited	9/11 Old Tarmac Road Sango Otta	Cosmetics & Fruit Juice
38	Savel Pharmaceuticals	Plot Iv, Block Iv Otta Industrial Estate	Pharmaceuticals
39	Unique Pharmaceuticals Limited	Km 38 Lagos-Abeokuta Express. Way Sango Otta	Intravenous Liquid
40	Universal Gases Limited	Ijoko Road Sango Otta	Industrial And Domestic Gases
41	Unilever Nigeria Limited	Agbara Industrial Estate	Detergents, Soap Foods, Oral,7 Personal Care Products, Cosmetics.
42	Vego Products Limited	Otta Industrial Estate, Otta	Cosmetics

Section C: Domestic & Industrial Plastics, Rubber & Foam

S/N	Company's Name	Business Address/ Company's Address	Company's Product
43	Ars Nigeria Limited	Km 38 Lagos-Abeokuta Express. Way Sango Otta	Plastics
44	Aftrade Nigeria Limited	Km 38 Lagos-Abeokuta Express. Way Sango Otta	Plastics
45	Combined Chemicals Limited	Km 40 Lagos-Abeokuta Express. Way Sango Otta	Plastic Bottles/Chemicals
46	Diversified Packaging Industries Limited	Km 38 Lagos-Abeokuta Express. Way Sango Otta	Plastics
47	Enkay Plastics Limited	Km 38 Lagos-Abeokuta Express. Way Sango Otta	Jerry Cans, Cosmetics Containers, Yoghurt Containers
48	Fasraj Nigeria Limited	Plot 5, Tomori Industrial Estate, Sango Otta	Plastics And Water Pipes
49	Geepee Industries Limited	Km 38 Lagos-Abeokuta Express. Way Sango Otta	Plastics And Water Containers
50	Homus Industries Limited	Otta Industrial Estate, Otta	Plastic And Nylon
51	Jid-Bod Industries Limited	Plot 2, Tomori Industrial Estate, Sango Otta	Polyethylene & Nylon
52	Lovleen Toys Industries Limited	Km 39 Lagos-Abeokuta Express. Way Sango Otta	Toys
53	Lombardy Plastics Limited	Otta-Idiroko Road Otta	Pipes

S/N	Company's Name	Business Address/ Company's Address	Company's Product
54	Lotus Plastics Limited	Agbara Industrial Estate	Plastics
55	Mercury Mills Limited	Km 38 Lagos-Abeokuta Express. Way Sango Otta	Plastic/ Nylon
56	Mike-Emman Agro Allied Bagging Limited	25/27 Agro Road Otta Ogun State	Polypropylene Woven Sacks, Polypropylene Bags
57	Salient Rubber Products Limited	Km 38 Lagos Abeokuta Express. Way Sango Otta	Rubber Parts
58	Shonghai Packaging	Km 38 Lagos Abeokuta Express. Way Sango Otta	Plastic Packaging
59	Synthetic Rope Limited	Km 36 Lagos Abeokuta Express. Way Sango Otta	Nylon
60	Veepee Industries Limited	Km 38 Lagos Abeokuta Express. Way Sango Otta	Nylon/Plastics Flexible Packaging Materials

Sector D: Basic Metal, Iron, Steel & Fabricated Metal Products

S/N	Company's Name	Business Address/ Company's Address	Company's Product
61	Avon Crown Caps & Containers Nig. Plc	Km 38 Lagos Abeokuta Express. Way Sango Otta	Crown Caps Metal Container Rcpp Caps & Tin Lets
62	All Seasons Industries Limited	Plot 3 & 4 Blk V Otta Industrial Estate Ota	Roofing Sheets
63	Aluminum Rolling Mills	Otta Industrial Estate Otta	Aluminum Roofing Sheets
64	Associated Metal & Allied Limited	Otta Industrial Estate Otta	Metal Bowls- Enamel Wares, Aluminum Wares
65	Electrode Nigeria Limited	Block XI Plot 3-10 Ota Industrial Estate Ota	Arc-Welding Electrode
66	Federated Steel Mills Limited	Block XI Plot 3-10 Otta Industrial Estate Otta	Reinforcing Steel Rod, Angle Iron
67	Homan Industries Limited	Plot 15-16 Block XIII Otta Industrial Estate Otta	Steel Pipes For Furniture Construction, Galvanized Pipes, Angle, Z-Purling
68	Kolorkote Nigeria Limited	Otta Industrial Estate Otta	Painted Aluminum Sheets, Steel Straps In Coil Form

S/N	Company's Name	Business Address/ Company's Address	Company's Product
69	Minl Limited	Plot 5-8 Block XIII Otta Industrial Estate Otta	Aluminum Rolled Embossed Coils, Aluminum Corrugated Roofing Sheets & Aluminum Alloy Ingots
70	Nigerian Foundries Limited	Km 38 Lagos Abeokuta Express. Way Sango Otta	Abrasion Resistance Heat Resistance Alloyed Castings: Water Fillings & Municipal Castings
71	Orzburn Aluminum Limited	Ilo Awela Road Off Lagos Abeokuta Exp. Way Sango Otta	Corrugated Aluminum Roofing Sheets
72	Precise Saviour Limited	1 Abigail Oyindamola Close Ijoko Road Sango Otta.	Copper Ingots, Aluminum Ingots, Lead Ingots, Zinc And Metal Ingots, Cables Of Copper And Aluminum
73	West African Building Materials	Block XIII Plot 11-12 Otta Industrial Estate Otta	Corrugated Galvanized Iron Sheets Galvanized Steel Pipes.
74	Sun And Sand Industries Limited	Plot 1-3 Block XVI Otta Industrial Estate Otta	Material Ingots And Alloys

Sector E: Pulp Paper & Paper Products; Printing & Publishing

S/N	Company's Name	Business Address/ Company's Address	Company's Product
75	Eagle Package Printing Ltd	Eagle Package Rd Off Idiroko Road Otta	Printing Of Light Packages & Labels

Sector F: Electrical and Electronics

Sector G: Wood & Wood Products Furniture

S/N	Company's Name	Business Address/ Company's Address	Company's Product
76	A& Y Enterprises Limited	Plot 5-6 Block X Otta Industrial Estate Otta	Particle Board
77	Chitra Knitting & Manufacturing. Ltd	Otta Idiroko Road Otta	Imitation Leather & Knitting Garments

Sector H: Non Metallic Mineral Products

S/N	Company's Name	Business Address/ Company's Address	Company's Product
78	Beta Glass Plc	Km 32, Lagos Badagry Express. Way Agbara	Hollow Wares Beer Minerals, Malts & Pharmaceutical Bottles & Cosmetic Jars
79	Imperial Mineral Products Limited	Km 38 Lagos Abeokuta Express. Way Sango Otta	Asbestos Flat Sheets, Corrugated Sheets & Roofing Ceilings

APPENDIX E

INDUSTRIAL EFFLUENT DATA

Table E1: Water Quality Analysis of Selected Industries in Ado – Odo Otta

	Trace Organic Pollutants																					
							Inorganic Water Pollutants							**Heavy Metals**					**Trace Metals**			
SAMPLE CODE	**pH**	**Cond. mS/cm-l**	**T.Solids**	**DO**	**T.Hard.**	**Temp °C**	**T.Alkal.**	**TSS**	**TDS**	**COD**	**Phos.**	**Chlo.**	**NO3**	**Pb.**	**Zn.**	**Fe.**	**Mn.**	**Cr.**	**Ca**	**Cu**	**Mg**	**Ni**
Kolokote Nig. Ltd.	6.84	7850	3970		60	27	232	28	3942	120		750.5		ND	0.13	1.88	0.12	ND		ND		ND
Purechem Ind Ltd.	7.14	100.5	897		18	32	24	47	850	5		28.79		ND	0.33	ND	0.03	ND		ND		ND
Homus Ind Ltd.	6.64	86.2	91		32	32	18	41	50	102		26.73		ND	0.28	0.86	0.05	ND		ND		ND
Homan Ind Ltd	7.12	162	212		40	27	32	76	136	145		48.32		ND	0.97	5.82	0.06	ND		ND		ND
May & Baker Nig. Plc	6.09	1577	1348		42	29	56	530.5	817.5	360	0.09	393.3		ND	0.028	0.81	0.014	ND	16.9	0.024		ND
Enjels Nig. Ind Ltd	7.05	87.3	656		24	29	34.72	583.5	725	290	0.04	39.5		ND	0.97	0.75	0.024	ND	9.4	0.015		ND
IDL	6.7	387	1532		74	26	151.2	24.5	1507.5	230	0.02	1523.8		ND	0.028	0.69	0.019	ND	29.4	0.028		0.065
Ecomed Pharm.Ltd	7.05	243	1224		-	27	-	871.5	352.5	272	0.06	20.4		ND	0.041	12.83	0.032	ND		0.063	6.03	ND
Sandtex Ptl Paints	6.45	579	506		250	28	368.48	156	350	402	0.11	76.3		ND	ND	1.3	0.018	ND	101	ND	3.2	ND
Drugfield Pharm.Nig.Ltd	7.63	124.9	248		52	28.5	39.2	7	248	330	0.18	54.5		ND		1.17	0.048	ND	21	0.016	10.5	7.14
Nycil Nig. Ltd.	5.95	6320	4878		=	31	262.03	255.5	4622.5	250	0.15	2505.5		1.09	0.005	3.03	0.129	0.05		0.059		0.104

	Trace Organic Pollutants						Inorganic Water Pollutants							Heavy Metals					Trace Metals			
SAMPLE CODE	**pH**	**Cond. mS/cm-l**	**T.Solids**	**DO**	**T.Hard.**	**Temp °C**	**T.Alkal.**	**TSS**	**TDS**	**COD**	**Phos.**	**Chlo.**	**NO3**	**Pb.**	**Zn.**	**Fe.**	**Mn.**	**Cr.**	**Ca**	**Cu**	**Mg**	**Ni**
Ease- Hon.Int.Ltd	7.24	120.4	416		-	28	-	53.5	362.5	420	0.09	88.5		ND	0.013	0.66	0.078	ND		ND	5.9	ND
Sona Breweries	8.07	7420	1315	8.20		32	98	348	917	418	0.142	45.60	0.09	0.28	0.282	0.702	0.568	ND			7.4	
Pardee Foods	6.27	606	1143	0.80		26	82	810	333	220	0.114	13.20	1.31	0.18	ND	5.223	0.697	ND				
Fermex Meyers	6.30	980	792	1.20		26	96	251	541	240	0.132	15.20	1.06	0.31	ND	53.86	2.82	ND				
FEPA LIMITS.	**6.5-8.5**	**1000**			**150**	**20-33**		**30**	**2000**	**80**	**5**	**600**	**50**	**0.01**	**0.3**	**0.3**	**0.2**	**0.05**	**200**	**1**	**0.20**	**0.02**

Table E2: Water Quality Analysis of Selected Industries in Ado – Odo Otta and Lagos

Industry Name	**Sector**	**BOD**	**PH**	**Cond.(mS/cm)**	**Turd. FTU**	**D.O**	**Temp (C)**	**Sal (%)**	**M.B.D**	**T.D.S**	**O&G**	**C.O.D**
Kolokote Nig. Ltd.	Painted Aluminum Sheets, steel strapin coil forms	66.0	6.84	7850	NS	NS	27	NS	NS	3942	NS	120
Purechem Ind Ltd.	Pharmaceuticals	2.75	7.14	100.5	NS	NS	32	NS	NS	850	NS	5
Homus Ind Ltd.	Plastic & Nylon	56.1	6.64	86.2	NS	NS	32	NS	NS	50	NS	102
Homan Ind Ltd	Plastic & Nylon	79.75	7.12	162	NS	NS	27	NS	NS	136	NS	145
May & Baker Nig. Plc	Food Beverages	198	6.09	1577	NS	NS	29	NS	NS	817.5	NS	360
Enjels Nig. Ind Ltd		159.5	7.05	87.3	NS	NS	29	NS	NS	72.5	NS	290
Intercontinental Distilleries	Distilleries	126.5	6.7	NS	NS	NS	26	NS	NS	1507.5	NS	230
Ecomed Pharm.Ltd	Chemicals & Pharmaceuticals	149.6	7.05	243	NS	NS	26	NS	NS	352.5	NS	272
Sandtex Ptl Paints	Paints	221.1	6.45	579	NS	NS	27	NS	NS	350	NS	402
Drugfield Pharm. Nig. Ltd	Chemicals & Pharmaceuticals	181.5	7.63	124.9	NS	NS	28.5	NS	NS	248	NS	330
Nycil Nig. Ltd.	Health Drinks	137.5	5.95	6320	NS	NS	31	NS	NS	4622.5	NS	20
Ease- Hon. Int. Ltd		147	7.24	120.4	NS	NS	28	NS	NS	362.5	NS	420
Niger Biscuits	Food Processing	38.00	8.90	0.18	59.00	4.58	21.00	0.00	12.00	246.00	382.00	28.00
Nigeria Breweries Plc	Breweries	56.70	8.95	0.39	162	0.05	34.80	0.01	80.10	328.0	185.00	1318.00
Nigerite	Asbestos	6.00	10.90	10.00	1.00	1.10	33.00	0.01	NT	NT	NIL	1.00

Industry Name	Sector	BOD	PH	Cond.(mS/cm)	Turd. FTU	D.O	Temp (C)	Sal (%)	M.B.D	T.D.S	O&G	C.O.D
Pfizer	Pharmaceuticals	6.00	9.30	0.16	1.00	0.50	33.00	0.60	30.00	394.00	233.00	56.00
Super Engineering	Steel works	30.00	10.70	0.21	24.00	6.00	30.00	0.00	172.00	36.00	214.00	2.00
Tower Extrusions	Metal fabrication	37.7	10.10	0.485	6	6.83	28.4	0.02	12.00	582.00	6.00	117.00
Universal Associates		562.00	9.02	0.62	115.00	4.13	25.70	0.02	274.00	570.00	425.00	24.00
Vitabiotics	Pharmaceuticals	563.00	10.40	0.56	23.00	5.60	35.00	0.00	294.00	556.00	204.00	1669.00
WAMCO	Dairy	22.00	10.80	0.25	8.00	2.80	40.00	0.00	30.00	258.00	132.00	17.00
WEMABOD Effluent	Waste Management	544.00	9.90	0.83	18.00	1.10	38.00	0.00	500.00	518.00	464.00	
Woolen & Synthetic Ltd	Textiles	354	9.15	0.226	129	3.18	39.2	0.00	220.00	274.0	8.00	13.00
FEPA Standard		50	6-9				<40		30	2000	10	80

Table E3: Water Quality Trends in Selected Receiving Water Bodies from 1980 – 1997

Parameters		**pH**	**Temp °C**	**TSS**	**TDS**	**Tub NTU**	**BOD**	**DO**	**C0D**	**O&G**	**Cond**	**Ca**	**Cu**	**Fe**	**Mg**	**Mn**	**Zn**	**Pb**	**Cn**	**Total Coliform**
Atuara	2008																			
River	2009																			
Odo-Iya	1980	-	36	73	165	10	80	**NIL**	330	153	15	1.1	0.12	4.9	2.5	0.04	NDL	0.06	NS	7.5×10
Alaro Stream	1997		28.4	166	114		70	**0.8**	216		10	1.25	ND	ND	0.71	ND	ND	ND	ND	
Shasha-G	1980	6.5	366	43	165	NS	230	NIL	**750**	NS	NS	3.6	0.24	4.8	5.1	0.16	NS	0.2	NS	**1.1×10**
	1997	9.2	30.9	132	652	125	158	.28	204	57	0.94	5.75	ND	2.81	2.55	ND	0.1	ND	ND	
Eric Moore	1980	6.1	NS	50	1.141	60	10.4	NS	150	NS	155	18	NS	1.5	.30	0.25	NS	NS	NS	NS
canal	1997	10.10	33.7	250	1.98		259	1.67	21	31.98	4.7	ND	ND	1.75	12.15	ND	.10	ND	.001	1.1×10
FEPA Limit		6-9	35-40	30	2000		50	Not <2	80	10		200	<1	20	200	50	<1	<1	0.1	400

All parameters are in mg/L except where stated

Courtesy: Federal Ministry of Environment, (2002) Pollution Control and Environmental Health

Table E4: Industrial Sub-Sectoral Types, Raw Materials, Products & Waste Characterization

Industries	Raw material	Products	Waste characterization
Food & Beverages **7UP Bottling Co.** Oregun Ikeja **Nigerian Bottling Co.** Agidingbi, Ikeja.	Sugar, Treated water, Liquid Carbon dioxide, $FeSO_4$, Caustic soda HTH Chlorine, Soda ash, Lubricant, P37, Diesel (AGO), Engine Oil, Washing additive Fe CI_2, Hypo chlorate, Diokem	7UP, Pepsi, Mirinda Club Soda, Coca Cola, Fanta, Orange, Fanta Lemon, Eva water, Schweppes, Fanta Tonic .	Liquid Effluent Suspended solid, Caustic soda, Soluble carbohydrate, Detergent wastes
Flavoring & Spices **Cadbury Nig. Ltd** Agindingbi, Ikeja **West African Seasoning Company**, Apapa **Union Dicon Salt**, Apapa	Cocoa powder, Grains, Milk powder, Bulk salt, Monosodium Glutamate, BOPP	Maggi, Vedan, Knorr, Royco, Jumbo, Ajinomoto Food Seasoning, Edible Salt.	Liquid Effluent; BOPP waste
Flour, Grains & Millings **Lisabi Mills** Nig, Ltd, Ikeja	Cornstarch, Sugar, Cocoa, Wheat, Guinea corn, Millet, Sorghum, Chemical additives	Custard, Yam flour, Banana Custard, Gold Chocó meal, Flour	Liquid Waste; Oily waste, bran middling and offal,
Edible Oil, Fat & Margarine **Real Oil Mills** Ltd. Ikorodu Rd **Lever Brothers** Nig. Ltd, Dockyard Road, Apapa	Phosphoric acid, Bleaching earth SPO, Oil palm fruit, Groundnut, Soya beans, Melon seed, Coconut fruit, Vitamins, Flavorings Additive, Benilseed and Sunflower	Blue Band Margarine, Defined bleached deodorixide palm oil, Palm olein, Palm Stearine.	Liquid Waste Containing detergent, Grease and Oil

Industries	Raw material	Products	Waste characterization
Starch &Starch Products **Lewis Agro-Allied** Services Nig. Ent. **Lisabi Mills** Nig Ltd, Ikeja	Sorghum, -FF, -FK, Maize-Flint, dent, Formalin, Lime Phostosine	Malted Sorghum, Maize, Corn Mill, Corn Semolina	Liquid Waste Soluble materials, Nitrogen compounds, Carbohydrate, Organic acid, Minerals, Protein, Suspended sold, Fibres, Fat & Oil
Beer Stout **Nigeria Breweries** Plc, Iganmu **Guinness** Nigeria Plc, Oba Akran way, Ikeja	Sorghum, Barley, Maize, Sugar & Syrups, Yeast brewing, Water, Isin glass, Finings, Hops, Caustic soda, Ascorbic acid, Filtering aids, Enzymes & Additives	Star, Gulder, Harp, Heineken, Guinness Stout, Legend Beer	Liquid Waste Effluent containing Fermented Starches, Suspended Solids, Organic Solids, Micro organisms, Oily water, Detergent, Phenol & Lubricants
Tea Coffee & Beverages **Cadbury Nig** Plc, Agindingbi, Ikeja **Lever Brothers** Nig, Ltd, Plc Apapa **Nigercafe Food** West Africa Ltd, Ikeja **Nestle Foods** Nig Plc, Ilupeju	Cocoa powder, Grains, Milk powder, Crown roasted coffee beans, Tea leaves, Tea bags, Lemon, paper sacks, rolled dry chicory	Bournvita, Lipton tea, Nescafe, Milo	Liquid Waste Liquid effluent containing organic matters, Micro organism (Salmonella, Listeria Escherichia coli) Oil & Grease

Industries	Raw material	Products	Waste characterization
Chemical/Pharmaceutical: Paint, Vanishes & Allied Products **Berger Paints**, Oba Akran, Ikeja **DN Meyer** Plc, Mobolaji Johnson, **Regency** (Overseas) Co. Ltd Abebe Village Road, Iganmu. **Peggy Chemical** Ltd.Jumoke Babalola Crescent, Badagry Expressway, Km 6	Trioxide, PVA, Calcium carbonates Kaolin, ALKYD Resin, and DAK. Kerosene, Xyhlene, Pigments, Toluene Water	Emulsion paints, Gloss paints, Industrial paints, Dulux, Star, Luxol, Fire retardants, Texcote protection, Adhesive, Putties, Wood finishes, Textured coatings Marine &Heavy duty coatings, Industrial Adhesive, Nigalux, Nigatex, Body filler, Sandrex, Authomotive paints, Decorative floor polishing, Gloss finish & House coating	Liquid Waste Wastewater containing poly-chlorinated biphenyls, Hydrocarbon pigments, Suspended solids, Fe & Fi, Oil & Grease.

Industries	Raw material	Products	Waste characterization
Soap & Detergent **Lever Brothers** Nig, Ltd Dockyard Apapa. **PZ** Ind, Ltd, Ikorodu **Remonic**, Ogba Ijaiye. **Henkel Chemical**, Isolo Expressway. **Cybele Cosmetics** Ltd, Ladipo, Mushin	Caustic soda & potash, Cocoanut oil (cocheen) Palm oil, Palm Kernel, Olive oil, Detergent paste perfume, dyes, Resin, water, stream free, Steam free, Steric acid, Sulphur, Sodium silicate, Calcite, Packaging materials Water, Oleum sodium, Dodecyl benzene, Sulphur acid, Tetra propylene, Linear alkyl benzene, Aluminum chloride, Sulphuric acid, Sodium hydroxide, Carcoxymethyl, cellulose (SCMC), Sodium tripoly phosphate (STTP), Ethanol, Fecl$_3$, HCl, Sodium toluene sulphonate	Joy, Elephant, Imperial, Leather, Premier, Duck Canoe soap, Laundry soap, Bar soap, toilet &Liquid soap & Bleaching. Industrial detergent, disinfectant cleaning agent, detergent-washing powder, Industrial degreasers, Washing up Liquid & Scouring powder, Automotive liquid detergent.	Liquid Waste Wastewater containing soap, Suspended solids, Acetate, Glycerol, Oleate & Stearates Presence of foams in receptor wastewater containing Surfactants with increasing BOD.

Industries	Raw material	Products	Waste characterization
Foam **Vita Foam** Nigeria Ltd. Oba Akran Avenue, Ikeja **Mouka Foam**, Awosika Avenue, Ikeja **Beta Foam** Ltd, Oregun, Ikeja **Vono Products**, Agege Motor Rd, Mushin	Flomo-trichlolmethane, Dimelthyl ethylamine, Polyol, Toluene, Disocynate, Silicone-oil, Colour-ing pigment, melthylchloride, Dioctyl phthalate, Stannous octate, Fluorocarbon, Dropoil, Kraft paper, Polyethylene cover textile and thread.	Mattress, Foam, Cushions, Upholstery sheeting	
Dairy & Confectioneries Products **Nabisco Biscuits**, Oba Akran Ikeja **Niger Biscuits**, Creek Road, Apapa **Nutra Foods**, Mobolaji Johnson Avenue, Oregun **Fast Foods**, Creek Road, Apapa **WAMCO**, Ikeja **Foremost Diary**, Mushin	Flour, Sugar, Sault, Sodium Bicarbonate Sodium Meta- Sulphite, Ammonium Bicarbonate, Flavours, Fat, Yeast, LPFO, Cellophane, Gum base Glucose, Glycerin, Cocoa butter, Milk powder, Colouring, Meat, Spices, Preservatives, Eggs Fresh Milk, Soya Milk Vitamins Butter Oil.	Cabin Biscuit, Ball Gum, Mint fruit, Gem, Zoo, Jenka, Nabisco Biscuit, Sausage, Snacks, Bread, Evaporated Peak Milk, Dried Powder Milk Yoghurt, Lolly Ice cream	Liquid Waste: Containing nutricants carbohydrates, Fat/Grease, Colloidal organic compols, Micro-organisms very high in BOD

Industries	Raw material	Products	Waste characterization
Distillery and Blending of Spirit **West Africa Distilleries** Ltd, Ikeja **Ozde Distileries** Nig Plc, Ajao Estate, Oshodi	Lime, Lemon, Orange peels, Yeast, Matted Bailey, Palm wine, Flavour concentrate , Potable & Technical ethyl alcohol, caramel, Caustic soda, Hydrochloric acid Fermented mash, Bitter almonds & Juniper berries	Brandy, Whisky, Dry Gin, SCHNAPPS, Rum, Cognac Table wines, Tonic wines & Cherries	Liquid Waste: Waste water containing carbohydrates, Protein & Fat, Alcohol, Suspended solids, powder plant effluent & Alcohol vapour.
Toiletries & Cosmetics **Doyin** Industries, Badagry Exp Way, Coker **Johnson Products** Nig Ltd. Ikosi Rd, Oregun **Eleganza** Industries Ltd, Mobolaji Johnson Avenue Ikeja **Procter & Gamble**, Lagos	Glycerine, Sorbital, Petrol- Jelly, Menthol, Camphol, Peppermint oil, Student, Whit mineral; oil, Stearic acid, Caustic soda, Disodium EDTA, Peg 150, Lanolin, Paraffin wax, Microcrystalline wax, Sodium laureth sulfate, Ethyl alcohol, Large quantity of water, Chemical pulp.	Dento Clean Toothpaste, Wasrub, Menthrob, Chinese Balm, Hair straightener, Hair conditions, Hair shampoo, Hair lotion, Hair protein conditioners, Cream lotion, body cream, Sanitary pad & Toiletries.	Liquid Waste Wastewater containing suspended solids, Settleable fire particles mainly, Fibres, Clays, Titanium dioxide, Deinking sludge, Dissolved wood, Sugars, Lignin Tannin Resin acid soap
Basic Industrial Chemicals **Nigerian-German Chemical** Plc, Oba Akran way, Ikeja **Water Ford** Ltd, 9, Kolex Avenue, Ajao Estate	Vinyl Acetate Monomer Butyl acrylate, Pigment powder, Alkyl Benzene sulphuric acid, Stearin monomer, acrylic acid, Cassava starch, white crystal sugar, mono ethylene Glycol, urea, Pal kernel oil, para formaldehyde.		Liquid Waste Waste water containing oily sludge, H2 SO4 & Hot Water from the cooling water

Industries	Raw material	Products	Waste characterization
Dry Cell Battery **Associated Battery** Mfg Nig Ltd, Ikeja	Carbon black, Sulphuric acid, red lead (Pb3 O4), Litharge (PbO), Adhesive lead pasted plate, Graphite, Mercuric zinc.		Liquid Waste Wastewater containing carbon black Nickel, Sulphuric acid, Lead Cadmium, Manganese.
Printing Ink Manufacturer **Eleganza Ball Point**, Ikeja **Phototech**	Carbon black, Litto Red R, Litho yellow, Plotline, Eosin, Resin, Toners, Aluminum & Copper, Titanium dioxide, Bitumen solution, Sulfatant petroleum solvent Furnace black, Lamp black		Liquid Waste Spills containing petroleum products into public drains and receiving water and soil
Petroleum Products **Agip/ Elf Joint Venture** Fuel Depot **Texaco**	Leaded petrol, Kerosene, Naphtha, Heavy oil, Diesel, Grease	Pms, AGO, DPR, HHIC, Lubricant oils Bitumen	Liquid Waste Spills containing petroleum products into public drains and receiving water and soil.

Industries	Raw material	Products	Waste characterization
Textile Wearing Apparel **AfPrint** Nigeria Plc,Eric Moore, Iganmu **Nichemtex**, Ikorodu **Ijora Textile** Mills **Haffa** Ind Co, Ltd, Mushin	Cotton, Jute, Wool, Silk, Viscose, Rubber Acetate, Triacetate, Polyester, Acrylic, Polypropylene, Waste yarn, Caustic soda, Soda ash, Sodium, Sulphide, Sodium silicate, Ammonium sulphate, Sulphuric acid, Acetic acid, Alum, Wetting, Hydrogen peroxide, Sodium chloride, Sodium sulphate Synthetic Resin	African prints, Dress print, Staple fabrics, Brocades, Wax prints Embroidery thread.	Liquid waste Liquid effluent highly colored water from dye house, hot water from boiler room, wastewater containing suspended solids, colloids, Proteins, Soap, Oils Phosphate of sodium & Calcium, Dyestuff, Starch, Alikatils, Hypochlorite, Gelatin
Paper Pulp & Publishing **Printex** Nig, Ltd, Isolo **Bell Papyrus** Ltd., Oregun Ikeja **Papersack** Nig, Ltd, Moore, Iganmu	Ink , Toluene, Caustic soda, Metal potash, Paper, Sponges, Alum, Polymin HTH, Carvaflex, Amvimusol, Glue, Stereo rubber, Seniode tape, Sack Kraft Ltd	Jumbo Reels, Labels for Beer/ Stout bottles, Cigarette packets, Bank note wrappers, paper sacks	Liquid waste Effluent water containing very high of suspended solids, white streak in stream of titanium dioxide, fatty acids, Resins acids, Black liquor, Zinc hydrosulphite, Sodium Sulphide, Starch, Lignin.

Industries	Raw material	Products	Waste characterization
Basic Meal, Iron & Aluminum **Eldorado** Nig Ltd **Nigeria Foundries** Ltd. **Aluminum** Mfg, Co, Nig, Plc **Nigeria Enamelware** Plc.	U. Beenis, Steel, Plate Electrodes, Stainless steel scrap, Ferro chrome, Silicon, Molybdenum, Graphite, Macroplast, Methylene chloride, Solubum oil, Enamel frit, Potassium carbonate, Sulphuric acid, Sodium carbonate, Oxides, Steel coil	Tanks, Trailer, Steel structures, cast iron, Alloyed Iron Product, plain carbon & alloyed steel, Aluminum doors, soup finger bowl	Liquid waste Wastewater from coolant containing chloride or sulphur bearing vapours,Cyanide, CO, CH, Metallic oxides, O3 Be, Cd, Pb, Hs from paints fluorides, A1 mg, Cr Trichloroethylene, Trichloroethylene, Ammonia, Gas, Acid mist

Table E5: Volume of Wastewater Produced by Some Industrial Sector

Industry Sector	Volume in Litres/Day	Percentage of Total Volume
	Total L/Day	%
Bulk fuel terminal	120000	0.370
Cement bagging	100000	0.31
Dairy	70000	0.22
Distilleries	100000	0.31
Fertilizer	0	0.00
Fisheries	0	0.00
Food Processing	1600000	4.98
Glass	180000	0.56
Grain Milling	28000	0.09
Industrial Chemicals	6120000	19.07
Malt &Liquor (Brewery)	6000000	18.69
Metal Fabrication	1470000	4.58
Oil Exploration & Production	0	0.00
Oil Servicing Industry	0	0.00
Paints	80000	0.25
Pharmaceuticals	2000000	6.23
Plastics	1400000	4.36
Printing & Publishing	1440000	4.49
Pulp &Paper	860000	2.68
Refinery	0	0.00
Soaps & Detergent	1770000	5.51
Soft Drink	720000	2.24
Solid Mineral Mining		
Steel Works	160000	0.50
Tanneries	0	0.00
Textiles	7360000	23.93

Industry Sector	**Volume in Litres/Day** **Total L/Day**	**Percentage of Total Volume** **%**
Tubes &Tyre	30000	0.09
Vegetable Oil Mills	220000	0.69
Total	**31828000**	**100**

(Macpresse, 2001) Interim Report Submitted to the Pollution Control and Environmental Health

Federal Ministry of Environment on Industrial Effluent Waste Treatment Facilities in Lagos State

The General Food and Beverages Industry

This sector is very large encompassing more than 11 sub-sectors in a very wide range. Processes differ but the raw materials and products are mostly organic in origin. Wastewater is usually high in BOD, suspended solid, oils and greases leading to depletion of dissolve oxygen and eutrophication in receiving aquatic systems. Typical wastewater concentrations for these industries are given in table 4.01 below.

Table E6: Characteristic of Typical Brewery and Distillery Wastewater

Parameter (mg/1)	**Brewery**	**Brewery**	**Brewery**	**Distillery**	**Distillery**
	1[*]	2[†]	3[‡]	A	B
PH	10.7	8.8	4.6	4.7	4.1
Total Solids	550	3500	2530	23390	23415
Suspended Solids	154	616	804	1102	722
Settleable Solid	76	256	311	397	400
Dissolved Solids	396	2884	2219	22290	22630

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[*] Brew house Effluent

[†] Hourly composite Sample

[‡] Grab Sample of Combined Effluent: A- 1st Sample: B – 2nd Sample

Parameter (mg/1)	**Brewery**	**Brewery**	**Brewery**	**Distillery**	**Distillery**
	1[*]	2[†]	3[‡]	A	B
Alkalinity		125			
Conductivity	960	810	1340	4200	5300
Sodium	21.5	160	40	500	240
Potassium	8.0	120	28	87.5	51.2
Calcium	1.1	42.0	9.0	2.5	1.8
Magnesium	1.3	1.5	7.6	1.3	1.2
Chloride		1.0			12.0
Phosphate		1.7		3.1	1.2
BOD$_5$	250.4	2400	1250	20944	21450
COD		3100		44350	45220
Zinc	0.09	0.12	1.7	0.03	0.04
Copper	0.02	0.06	0.2	0.02	0.05
Manganese	0.09	0.16	0.5	0.13	0.23

Source: **Federal Environmental Protection Agency (FEPA)**

Generation of Liquid Wastes in Industries

Liquid wastes are defined as unwanted ,non- solids, non- gaseous materials which are consequently discharged into the environment ;like spent lubricants, paints, solvents etc. which may be held in containers and may not be channeled directly into the wastewater which itself may amount to 99.95 % of the total amount of liquid waste (Pollutech,1998) Pollutech ,1998, Industrial Pollution Policy Investment Study in Nigeria (Macpresse, 2001) Interim Report Submitted to the Pollution Control and Environmental Health Federal Ministry of Environment on Industrial Effluent Waste Treatment Facilities In Lagos State.

The sources of wastewater are;

- Excess used process water
- Wash water (for reaction vessels)
- Wastewater from kitchens bathrooms and toilets
- Rain water run

These sources may be combined but may be channeled separately .The volume of wastewater discharge is important because the total liquid pollution load and exposure risk is dependent on the characteristics and concentration of the pollutants entrained in the wastewater and therefore an effort is made to determine the volume of wastewater produced by typical industrial sectors as shown in Table E7 below

Table E7: Volume of Wastewater Produced by Some Industrial Sector

Industry Sector	**Volume in Litres/Day** **Total L/Day**	**Percentage of Total Volume** **%**
Bulk fuel terminal	120000	0.370
Cement bagging	100000	0.31
Dairy	70000	0.22
Distilleries	100000	0.31
Fertilizer	0	0.00
Fisheries	0	0.00
Food Processing	1600000	4.98
Glass	180000	0.56
Grain Milling	28000	0.09
Industrial Chemicals	6120000	19.07
Malt &Liquor (Brewery)	6000000	18.69
Metal Fabrication	1470000	4.58
Oil Exploration & Production	0	0.00
Oil Servicing Industry	0	0.00
Paints	80000	0.25
Pharmaceuticals	2000000	6.23
Plastics	1400000	4.36
Printing & Publishing	1440000	4.49
Pulp &Paper	860000	2.68
Refinery	0	0.00
Soaps & Detergent	1770000	5.51
Soft Drink	720000	2.24
Solid Mineral Mining		
Steel Works	160000	0.50
Tanneries	0	0.00
Textiles	7360000	23.93

Industry Sector	**Volume in Litres/Day** **Total L/Day**	**Percentage of Total Volume** **%**
Tubes &Tyre	30000	0.09
Vegetable Oil Mills	220000	0.69
Total	**31828000**	**100**

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Generation of Hazardous Wastes

Hazardous (Liquid) wastes are defined by the following characteristics:-

- Liquids with a flash point below 60 ^{o}C
- Aqueous wastes with pH less than or equal to 2.0 or equal to or greater than 12.5
- Liquid waste capable of corroding steel at a rate greater than 0.035 cm per year

The major sources and types of hazardous wastes most of which are liquids in nature are listed in Table E8 below.

Table E8: Source and Types of Hazardous Waste in Some Industries

Industry	Hazardous Waste Sources
Plastics/Rubber/Polymer Product	– Monomers used in polymerization (e.g. alkynes, alkenes, phenols, aldehydes, vinyl chloride, phthalate esters plasticizers', filler, extenders, reinforcing reagents, anti oxidants and pigment
Textiles	– Solvents for bleaching, desizing, scouring, mercerizing and dyeing – Lubricants, antistatic agents, dyes (nitroso compounds, nitrophenols, azo compounds, triarylmethane compounds, aromatic amines, sulphur compounds)
Leather	– Tannins and various metal salts (e.g. cone. Solution of lime, sodium sulphydrate), chromium (+3) salts, sodium forrmate and soda ash
Soaps & Detergent	– Sodium hydroxide, sulphuric acid and other chemicals for saponification, sulphonation, etc.
Petroleum Refining	– Slop-oil emulation solids, API separator sludge, leaded tank bottoms, kerosene, toluene, turpentine, spent catalyst material, heat exchanger bundle sludge, dissolved air floatation
Metal Fabrication	– Cyanides for electroplating, chelating agents e.g. NTA, EDTA
Steel Works	– Phenols, benzene, toluene, sulphuric acid, hydrofluoric acid, hydrochloric acid for picking, dewatered air waste from scrubbers, spent picking liquor, sludge from lime treatment of spent picking liquor etc.
Pulp &Paper	– Phenols, aldehydes in resins, sodium hydroxide and sodium sulphide pulping
Paint	– Resins and volatile solvents, paint pigments and drying agents
Industrial Chemicals	– ink pigments, flammable solvents corrosive acids and alkalis, reactor bleaches/oxidizer, toxic heavy metals, pesticides, oils, phenols, abrasives etc.

Industry		Hazardous Waste Sources
Pharmaceuticals	–	organic solvents, resins, dyes, heavy metals (e.g. mercury, zinc)
Battery Manufacturer	–	use of corrosive sulphuric acid and toxic lead metal