# DEVELOPMENT OF MATHEMATICAL MODEL FOR pH ASSESSMENT OF A SEWAGE TREATMENT PLANT EFFLUENT
## (*A CASE STUDY OF NICON HILTON HOTEL, ABUJA*)

**BY**

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# CERTIFICATION

This is to certify that this research project 'development of mathematical model for pH assessment of a sewage treatment plant effluent' is the original work of Umoffia, Anietie Patrick, carried out wholly by her under supervision and submitted to the Department of Chemical Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Minna.

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## DECLARATION

I, Umoffia, Anietie Patrick, hereby declare that this project, titled 'development of mathematical model for pH assessment of a sewage treatment plant effluent', carried out by me is my original work, and has not been submitted, to the best of my knowledge, elsewhere.

Umoffia, Anietie Patrick

31/10/03

Date

# DEDICATION

This project work is dedicated to the woman I appreciate most;

Who by her strength; has taught me to be strong,

Who by her lifestyle; has taught me integrity,

And who by her love has directed me, yet enabling my liberty.

My teacher, my friend, my mother...

Mrs. Dorcas P. Umoffia.

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# ABSTRACT

The aim of this work is to develop a mathematical model for pH assessment of a sewage treatment plant effluent. To accomplish this, the interaction of individual parameters with pH are determined and used to generate an expression of pH as a function of these parameters.

The Least Squares Method is then used to generate a series of equations solved by a computer programme written in Java and the results obtained are substituted into the generated pH equation to give the model equation.

The model equation is then used to simulate pH results for the 1998 experimental data that was used to construct it and for data for the year 2000. The simulated results are then compared to the experimental (real) values and average percentage errors of 1.6 and 8.96 are obtained respectively, thereby proving the validity of the developed model equation.

# CHAPTER ONE

## 1.0 INTRODUCTION

Water may be polluted at its source by excreta or sewage which is almost certain to contain pathogenic microorganisms and cause illnesses by draining into an improperly protected and treated surface or ground water supply.

The pH is a measure of acidity or alkalinity. The bactericidal, virucidal and cysticidal efficiency of chlorine as a disinfectant increases with a decrease in pH and the germicidal activity is greatly reduced at a pH level above 8.0. Consequently, the pH of water affects the quality of water.

The pH values of natural water range from about 5.0 to 8.5 and are acceptable except when viewed from the standpoint of corrosion; corrosion is associated with pH levels below 6.5 to 7.0. A guideline value of 6.5 to 8.5 is suggested for potable water.

Mathematical modeling is a comprehensive process of representing real-world phenomena in terms of mathematical equations and extracting from them useful information for understanding and prediction.

Models can be used for exploration, communication, testing and making predictions. A good model is accurate enough to reflect the important details, but simple enough to avoid confusion. (David Benyon, 1990)

The purpose of modeling is to develop an information system which takes measurements of some phenomenon as its input and produces data messages i.e. data elements more usefully structured, and related to other data elements, as its output. This output can then be used as an aid to decision making i.e. in making choices among alternatives with the purpose of exercising control, subject to uncertainty in the system.

## 1.1 OBJECTIVES

The aim of this research work is to develop a mathematical model to assess the pH of a sewage treatment plant effluent by investigating the dependence of pH on some measured water quality parameters, and thus enhance the prediction of the behaviour of the system.

## 1.2 SCOPE AND LIMITATION

This project focuses on the results of sewage effluent analysis carried out from January - December 1998. The many impurities present in wastewater upon dissociation directly or indirectly affect pH by causing a change in the hydrogen ion concentration of the water.

These impurities are represented in the form of chlorides, sulphides, nitrites, nitrates, hardness ($Ca^{2+}$ and $Mg^{2+}$ concentrations), alkalinity ($CO_3^{2-}$, $HCO_3^-$, $OH^-$), etc. but due to the limited scope of the experimental data available, pH is studied in this research project as a function of the following measured water quality parameters: temperature, chloride, total alkalinity, total alkalinity content and hardness. These parameters all influence pH and are interrelated but they do not add up to give the pH value.

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

### 2.1 POLLUTION

Pollution is the contamination of the environment by man-made substances or energy that has adverse effects on living or non-living matter. This contamination of air, water, or soil materials interferes with human health, the quality of life, or the natural functioning of ecosystems. In simple terms, pollution can be seen as the wrong substance in the wrong place in the wrong quantities at the wrong time. This implies that harm is caused to the environment, and if the same substance is present at levels too low to cause harm, then it can be considered as contamination. Many substances that can be pollutants also occur naturally, in which case they are not classified as pollution. However, other pollutants result entirely from human activity, such as most toxic organic compounds and artificial forms of radioactivity, particularly from nuclear waste.

The main types of pollution are:

1 Air Pollution (Atmospheric pollution)
2 Water Pollution (Freshwater and sea pollution)
3 Land pollution (Solid Waste Disposal)
4 Noise pollution

However, transfers can occur in both directions between the atmosphere, water, and the land, with consequences for both the spread of pollution and its effects. For example, the emission of sulphur dioxide-caused by the combustion of fossil fuels such as gas, petroleum, and coal-into the air can result in the acidification of soils and lakes when it reaches the Earth's surface as acid rain.

Pollution can be classified on the basis of the type of pollutant, such as pesticides and other persistent toxic organic compounds, heavy metals, radioactivity, human and animal effluent, and toxic gases. The most familiar forms of pollution result from the chemical properties of the substances concerned, but the physical properties may also be important, for example ionizing radiation, noise pollution, and excessive heat.

### 2.1.1 Water Pollution

Water pollution arises from the discharge of industrial, agricultural, and human wastes into freshwaters, estuaries, and seas. This may result in the poisoning of aquatic organisms or the depletion of oxygen owing to excessive growth of microorganisms (anthropogenic eutrophication), which makes less of the water habitable for fish. Metal pollution and toxic organic compounds are of concern for human and environmental health as a result of discharges to water, air, and the terrestrial environment.

Water Pollution is the contamination of water by foreign matter such as microorganisms, chemicals, sewage, and industrial or other wastes. Such matter deteriorates the quality of the water and renders it unfit for its intended uses.

The major pollutants of water are the following:

- Sewage and other oxygen-demanding wastes (largely carbonaceous organic material, the decomposition of which leads to oxygen depletion)
- Infectious agents
- Plant nutrients that can stimulate the growth of aquatic plants, which then interfere with water uses and, when decaying, deplete the dissolved oxygen and produce disagreeable odours

• Exotic organic chemicals, including pesticides, various industrial products, surface-active substances in detergents, and the decomposition products of other organic compounds

• Petroleum, especially from oil spills

• Inorganic minerals and chemical compounds

• Sediments consisting of soil and mineral particles washed by storms and floodwater from croplands, unprotected soils, mine-workings, roads, and bulldozed urban areas

• Radioactive substances from the wastes of uranium and thorium mining and refining, from nuclear power plants, and from the industrial, medical, and scientific use of radioactive materials

Heat may also be considered a pollutant when increased temperatures in bodies of water result from the discharge of cooling water by factories and power plants.

#### 2.1.1.1 Effects of Water Pollution

Notable effects of water pollution include those involved in human health. Nitrates (the salts of nitric acid) in drinking water can cause a disease in infants that sometimes results in death. Cadmium in sludge-derived fertilizer can be absorbed by crops. If ingested in sufficient amounts, the metal can cause an acute diarrhoeal disorder and liver and kidney damage. The hazardous nature of inorganic substances such as mercury, arsenic, and lead has long been known or strongly suspected.

Lakes are especially vulnerable to pollution. One problem, eutrophication, occurs when lake water becomes artificially enriched with nutrients, causing abnormal plant growth. Run-off of chemical fertilizer from cultivated fields

may trigger this. The process of eutrophication can produce aesthetic problems such as bad tastes and odours and unsightly green scums of algae, as well as dense growth of rooted plants, oxygen depletion in the deeper waters and bottom sediments of lakes, and other chemical changes such as precipitation of calcium carbonate in hard waters.
Another problem, of growing concern in recent years, is acid rain, which has left many lakes in northern and Eastern Europe and North-Eastern North America totally devoid of life.

#### 2.1.1.2 Sources and Control

The major sources of water pollution can be classified as municipal, industrial, and agricultural.

Municipal water pollution consists of wastewater from homes and commercial establishments. For many years, the main goal of municipal sewage disposal was simply to reduce its content of suspended solids, oxygen-demanding materials, dissolved inorganic compounds (particularly compounds of phosphorus and nitrogen), and harmful bacteria. In recent years, however, more stress has been placed on improving the means of disposal of the solid residues from municipal treatment processes. The basic methods of treating municipal wastewater fall into three stages: primary treatment, including grit removal, screening, grinding, flocculation (aggregation of the solids), and sedimentation; secondary treatment, which entails oxidation of dissolved organic matter by means of biologically active sludge, which is then filtered off; and tertiary treatment, in which advanced biological methods of nitrogen removal and chemical and physical methods such as granular filtration and activated carbon adsorption are employed.

The characteristics of industrial wastewaters can differ markedly both within and among industries. The impact of industrial discharges depends not only on their collective characteristics, such as biochemical oxygen demand and the amount of suspended solids, but also on their content of specific inorganic and organic substances. Three options (which are not mutually exclusive) are available in controlling industrial wastewater. Control can take place at the point of generation within the plant; wastewater can be pretreated for discharge to municipal treatment systems; or wastewater can be treated completely at the plant and either reused or discharged directly into receiving waters.

Agriculture, including commercial livestock and poultry farming, is the source of many organic and inorganic pollutants in surface waters and groundwater. These contaminants include both sediment from the erosion of cropland and compounds of phosphorus and nitrogen that partly originate in animal wastes and commercial fertilizers. Animal wastes are high in oxygen-demanding material, nitrogen, and phosphorus, and they often harbour pathogenic organisms. Wastes from commercial feeders are contained and disposed of on land; their main threat to natural waters, therefore, is via run-off and leaching. Control may involve settling basins for liquids, limited biological treatment in aerobic or anaerobic lagoons, and a variety of other methods.

#### 2.1.1.3 Origin of Wastewater

When waste matter enters water, the resulting product is called sewage or wastewater. Wastewater originates mainly from domestic, industrial, groundwater, and meteorological sources; and these forms of wastewater are commonly referred to as domestic sewage, industrial waste, infiltration, and storm-water drainage, respectively.

Domestic sewage results from people's day-to-day activities, such as bathing, body excretion, food preparation, and recreation.
The quantity and character of industrial wastewater is highly varied, depending on the type of industry, the management of its water usage, and the degree of treatment the wastewater receives before it is discharged.
Infiltration occurs when sewer lines are placed below the water table or when rainfall percolates down to the depth of the pipe.
The amount of storm-water drainage to be carried away depends on the amount of rainfall as well as on the run-off or yield of the drainage basin. (Nigel Bell, 2003)

### 2.1.2 Air Pollution

Air pollution is the contamination of the atmosphere by gaseous, liquid, or solid wastes or by-products that can endanger human health and the health and welfare of plants and animals, or can attack materials, reduce visibility, or produce undesirable odours. Among air pollutants emitted by natural sources, only the radioactive gas radon is recognized as a widespread major health threat, although gases and particles from volcanic eruptions can cause serious more localized problems. A by-product of the radioactive decay of uranium minerals in certain kinds of rock, radon seeps into the basements of homes built on these rocks, posing a risk of lung cancer to residents.

Air pollution can result in adverse effects on health, crops, natural ecosystems, materials, and visibility. The major concerns over air pollution are acidification of soils and waters with its detrimental affects on animal and plant life, and the impact of traffic-derived pollutants on health in cities. On a global scale air pollution probably represents the greatest problem of all, with greenhouse gases (such as carbon dioxide) resulting in global warming and synthetic chlorine compounds (chlorofluorocarbons) depleting the stratospheric ozone layer.

The tall smokestacks used by industries and utilities do not remove pollutants but simply boost them higher into the atmosphere, thereby reducing their concentration at the site. These pollutants may then be transported over large distances and produce adverse effects in areas far from the site of the original emission. Sulphur dioxide and nitrogen oxide emissions from Britain and other industrialized countries of Western and Central Europe are causing acid rain in Norway and Sweden. The pH level, or relative acidity, of many freshwater lakes has been altered so dramatically by acid rain that entire fish populations have been destroyed.

### 2.1.3 Land Pollution

Land pollution is the contamination of land by solid wastes. Solid wastes include materials resulting from human and animal activities that are useless, unwanted, or hazardous. Solid wastes typically may be classified as follows:

1 Household Waste Production: Household waste is often a mix of potentially reusable or recyclable items (such as newspapers and cans)

and largely non-recyclable material (such as broken or worn out domestic appliances and plastic packaging)

2 Garbage: decomposable wastes from food

3 Rubbish: non-decomposable wastes, either combustible (such as paper, wood, and cloth) or noncombustible (such as metal, glass, and ceramics)

4 Ashes: residues of the combustion of solid fuels

5 Large wastes: demolition and construction debris and trees

6 Dead animals

7 Sewage-treatment solids: material retained on sewage-treatment screens, settled solids, and biomass sludge

8 Industrial wastes: such materials as chemicals, paints, and sand

9 Mining wastes: slag heaps and coal refuse piles

10 Agricultural wastes: farm animal manure and crop residues.

### 2.1.4 Noise Pollution

Noise pollution is the adverse effects of noise in our living and working environment. Noise is, by definition, unwanted sound. It may be annoying, it may interfere with speech communication, leisure, or relaxation, and, at very high levels which may occur at work or during certain noisy leisure activities, it may result in hearing loss by causing damage to the hair-cells in the cochlea in the inner ear. Rather than leading to significant adverse physiological responses, however, noise is more often a major problem in terms of quality of human life in specific localities.

Noise pollution sources include road traffic, aircraft, railways, industry, construction activities, social noise, military sources and low frequency sources. (John G. Walker, Bell)

## 2.2 MATHEMATICAL MODELING

Mathematical modeling is a comprehensive process of representing real-world phenomena in terms of mathematical equations and extracting from them useful information for understanding and prediction.

In recent years, mathematical modeling has become a powerful tool to solve complex, interconnected and interacting phenomena arising from the rapid development taking place in science and technology. (R. A. Meyers, 1984)

### 2.2.1 Mathematical Model

A mathematical model is a set of mathematical equations representing a process or a system. It is a mathematical idealization of a real world phenomenon. In the process of idealization, some simplifications will have been made in obtaining the model. Therefore, the mathematical model is less real than the system it is supposed to represent.

### 2.2.2 Importance of Models

1 Models permit abstraction based on logical formulations using a convenient language expressed in shorthand notation, thus enabling one to visualize better the main elements of a problem and at the same time, satisfying communication, decreasing ambiguity, and improving the chances of agreement on the results.

2 A model allows one to keep track of a line of thought, focusing attention on the important parts of the problem.

3 Models help one to generalize or to apply the results to problems in other areas.

4 Models are used to predict future course of observed phenomenon.

5 Models are used to explain known facts and lay a foundation for the theory behind the phenomenon.

### 2.2.3 The Modeling Process

The modeling process consists of the following stages (Fig. 2.1):

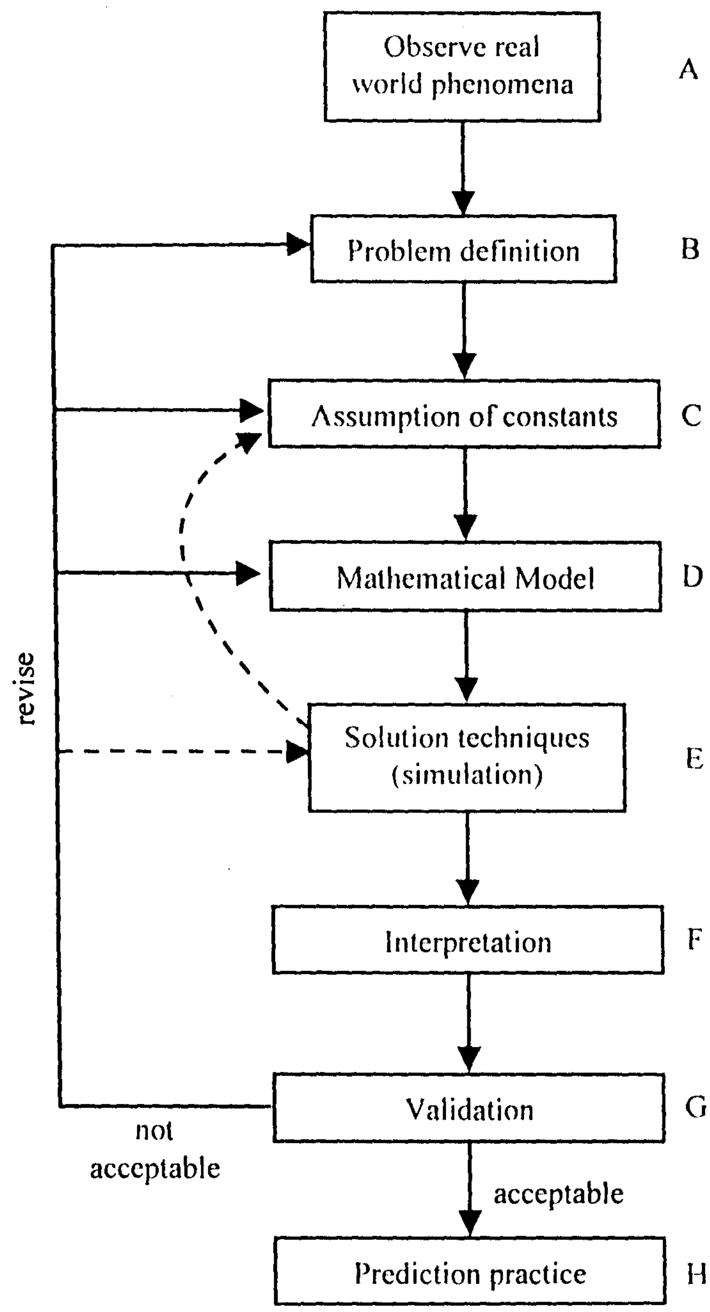


Figure 2.1: Schematic of a mathematical modeling procedure

Step A - B involves bringing out a well-defined problem from the maze of observations

Step C involves sorting out the essential and significant features that need to be incorporated in the model

Step D involves translating features into mathematical entities and relating them under certain simplifying but realistic assumptions and constraints.

Steps E and F involves using one or more solution techniques to obtain and interprete a solution from the viewpoint of accuracy and stability

Step G involves determining how closely the solution approaches the original, real-world phenomenon. If solution meets the imposed limit of acceptability, the model is considered valid and then put into practice

**2.3 WATER QUALITY**

Water quality is usually determined by the purpose for which it is to be used and/or its effect on the equipment involved in the processes and on the environment to which it is discharged. Effluent quality - the standard of quality of effluent to be aimed at in treatment works design depends upon the river or other body of water, which is to receive the discharge. In the case of a river which is still almost in its natural state, supporting fish life and possibly used as a source of water supply, the standards will need to be fixed to preserve its condition. For rivers which are already polluted, there will be a long term aim to restore them if at all feasible so that new works will have to be designed to produce a high-quality effluent ultimately, if not immediately (J. B. White, 1987)

## 2.4 SEWAGE / WASTEWATER

All industrial operations produce some wastewaters, which must be returned to the environment. Wastewater can be classified as

i. Domestic waste water
ii. Process waste water
iii. Cooling waste water

Domestic wastewaters are produced by plant workers, shower facilities and cafeterias. Process wastewaters result from spills, leaks and product washing. Cooling waste waters are the result of various cooling processes and can be once-pass systems or multiple recycle cooling towers to return excess heat to the environment and require periodic blow down to prevent excess build up to salts.

Domestic wastewaters are generally handled by the normal sanitary-sewerage system to prevent the spread of pathogenic microorganisms which might cause disease. Normally, process wastewaters do not pose the potential for pathogenic microorganisms, but they do pose potential damage to the environment through either direct or indirect chemical reactions. Some process wastes are readily biodegraded and create an immediate oxygen demand. Other process wastes are toxic and represent a direct health hazard to biological life in the environment. Cooling wastewaters are the least dangerous, but they can contain process wastewaters as a result of leaks in the cooling system. Recycle cooling systems tend to concentrate both inorganic and organic contaminants to a point at which damage can be created.

## 2.5 pH AND THE pH SCALE

pH is the potency of hydrogen. The intensity of acidity or alkalinity of a sample is measured on the pH scale, which actually measures the concentration of hydrogen ions present. Water is only weakly ionized

$$H_2O \rightleftharpoons H^+ + OH^-$$

Since only about $10^{-7}$ molar concentration of $[H^+]$ and $[OH^-]$ are present at equilibrium, $[H_2O]$ may be taken as unity.

Thus,

$[H^+] [OH^-] = k = 1.01 \times 10^{-14}$ mol/l at 25°C

pH is given by the expression

$pH = - \log [H^+]$

The pH scale goes from 0 to 14. A pH of 0 means a very high acid activity, a pH of 14 means a very low acid activity. In between these two extremes is a pH of 7. This is the pH of pure water. The pH scale is a quantitative way of expressing the active acid or alkali concentration of a solution.

Many chemical reactions are controlled by pH and biological activity is usually restricted to a fairly narrow pH range of 6 - 8. High acidic/alkaline waters are undesirable because of corrosion hazards and possible difficulties in treatment. (T. Tebbut)

### 2.5.1 The Importance of pH

The pH or acidity of a solution is important throughout all phases of chemistry and biochemistry. It is also of immense importance in some branches of engineering such as chemical, manufacturing engineering etc.

*In the chemical industry*, the efficient production of nylon, as well as other modern fibers depends on rigid pH control.

*In biochemistry*, the pH of our blood is normally controlled to within a few tenths of a pH unit by our body chemistry. If our blood pH changes as much as half a pH unit, serious illness will result. Proper skin pH is essential for a healthy complexion. The pH of one's stomach directly affects the digestive process.

*In agronomy,* the pH of the soil regulates the availability of nutrients for plant growth, as well as the activity of soil bacteria. In alkaline soils (pH 8 and above) the amount of nitrogen, phosphorus, iron and other nutrients in solution become so low that special treatment is necessary to insure property growth.

*In the pulp and paper industry*, pH control is essential to the proper operation of bleaching plants and wet-end processes. Also, in order to conform to environmental protection regulations, the pH of wastewater from these plants must be controlled.

*In chemical research and engineering*, accurate pH measurement is necessary to the study of many chemical processes. The researcher needs to know the pH at which a chemical reaction proceeds at its fastest in order to understand the reaction. The engineer uses the information to develop practical commercial processes.

*In environmental research and pollution control*, the pH of a river or lake is important in maintaining a proper ecological balance. The pH of the water directly affects the physiological functions and nutrient utilization by plant and animal life. Extremes in pH can reduce a lake of a lifeless, smelly bog. Protecting our waterways requires constant monitoring of industrial effluent. Plating and metal finishing plants tend to produce acidic wastewater, as do mining operations. Chemical plants often have very alkaline wastewater. pH measurements are sued as a guide to the proper neutralization of these plant wastes, as well as to monitor the final effluent quality. Occasionally, an acidic stream can be combined with an alkaline stream to produce a final stream, which is close to neutral. pH measurement assure the proper management of this cost saving technique.

### 2.5.2 pH Control

pH of water is controlled or varied by the addition of acid to increase acid or the addition of alkali to increase alkalinity. The pH of water and the ease with which it is changed by the addition of acid or alkalis depends on the relative and total concentration of the different substances already present in the water.

## 2.6 WASTEWATER/SEWAGE CHARACTERISTICS

1. Organics
2. Inorganic
3. pH & alkalinity
4. Temperature
5. Dissolved oxygen

**1. Organics**: Organic compounds in wastewaters have created most of the pollution problems as a result of their effect on oxygen resources in the environment. The low-molecular weight water soluble organics tend to be biodegraded by bacteria and fungi with the utilization of oxygen. As the complexity of organic molecules increases, their solubility and biodegradability decrease.

Organic compounds are normally composed of a combination of carbon, hydrogen and oxygen, together with nitrogen in some cases. Sulphur, phosphorus and iron may be present. These elements are present in protein, carbohydrates, fats and oils, urea, phenols, surfactants and pesticides and agricultural chemicals in sewage.

The Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) are used to determine organic content of sewage.

BOD is used as an approximate measure of the amount of biochemically degradable organic matter in a sample. COD is used to measure the content of organic matter of both wastewater and natural waters (Suess, 1982)

**2. Inorganics**: Inorganics include pH, chlorides, alkalinity, nitrogen, phosphorus, sulphur, toxic compounds and heavy metals.

pH is hydrogen-ion concentration of the water. Chlorides ($Cl^-$) are responsible for brackish taste in water and are indicators of sewage pollution because of the chloride content of urine.

Alkalinity is composed of carbonates, bicarbonates and hydroxides of elements such as calcium, magnesium, sodium, potassium of ammonia. Sewage is normally alkaline.

Nitrogen can be present as free ammonia, nitrates or nitrites and organic (e.g. in proteins).

Toxic compounds include copper, lead, silver, chromium, arsenic and boron, cyanides and chromates.

Heavy metals include nickel, cadmium, lead, manganese, zinc and copper, iron and mercury.

Soft water sources will have lower inorganics than hard water or salt-water sources.

**3. pH and Alkalinity**: Wastewaters should have pH values between 6 and 9 for minimum impact on the environment. Wastewaters with pH values less than 6 will tend to be corrosive as a result of excess hydrogen ions. On the other hand, raising the pH above 9 will cause some of the metal ions to precipitate as carbonates or as hydroxides at higher pH levels. Alkalinity is important in keeping pH values at the right levels. Bicarbonate alkalinity is the primary buffer in wastewaters. It is important to have adequate alkalinity to neutralize the acid waste component as well as those formed by partial metabolism of organizes.

**4. Temperature**: the temperature of wastewater is commonly higher than that of the water supply because of the addition of warm water from households and industrial activities.

Temperature is a very important parameter because of its effect on the aquatic life, the chemical reactions and reaction rates, and the suitability of the water for beneficial uses. Increased temperature can cause a change in the species of fish that can exist in the water.

In addition, oxygen is less soluble in warm water than in cold water. The increase in the rate of biochemical reactions that accompanies an increase in temperature, combined with the decrease in the quantity of oxygen present in surface waters, can often cause serious depletions in dissolved oxygen concentration during hot seasons.

**5. Dissolved Oxygen**: this is required for the respiration of aerobic microorganisms as well as all other aerobic life forms. Oxygen is only slightly soluble in water. Dissolved oxygen is a minimum when BOD rates are a maximum. (Ross E. McKinney, 1984)

### 2.6.1 Other Measurable Parameters

Total hardness (TH) - this is the property of water which prevents lather formation with soap and produces scale in hot water systems. It is due mainly to the metallic ions $Ca^{2+}$ and $Mg^{2+}$ although $Fe^{2+}$ and $Si^{2+}$ are also responsible. The metals are usually associated with $HCO_3^-$, $SO_4^{2-}$, $Cl^-$ and $NO_3^-$. Hardness is expressed in terms of $CaCO_3$ and is divided into two forms:

a) Carbonate hardness -metals associated with $HCO_3^-$

b) Non-carbonate hardness - metals associated $SO_4^{2-}$, $Cl^-$, $NO_3^-$.

If high concentrations of sodium and potassium salts are present, the non-carbonate hardness may be negative since such salts could form alkalinity without producing hardness. Total hardness is the sum of carbonate (due to the presence of calcium and magnesium carbonates and bicarbonates) and non-carbonates (caused by sulphuric, hydrochloric, silicic and nitric salts of calcium and magnesium) hardness.

# CHAPTER THREE

## 3.0 MATHEMATICAL MODELING OF INTERACTION BETWEEN THE OBSERVED PARAMETERS AND SEWAGE pH

## 3.1 INTERACTION OF THE PARAMETERS WITH ONE ANOTHER AND WITH pH

### 3.1.1 Alkalinity and pH

The alkalinity of water is usually determined by the presence of bicarbonate $HCO_3^-$, carbonate $CO_3^{2-}$ and hydroxide $OH^-$ ions. The alkalinity, A in equivalents per liter is

$A = [HCO_3^-] + 2[CO_3^{2-}] + [OH^-] - [H^+]$

$[H^+]$ is the hydrogen ion concentration, which is the pH. Therefore A decreases as $[H^+]$ increases.

This implies that: alkalinity $\alpha$ pH.

(Fair, Geyer, Okun, 1958)

### 3.1.2 Alkalinity and Hardness

The amount of alkalinity and hardness are both expressed in terms of $CaCO_3$: $Ca^{2+}$ - hardness, $CO_3^{2-}$ alkalinity. If high concentrations of sodium and potassium salts are present, the non-carbonate hardness may be negative since such salts could form alkalinity without producing hardness. Therefore, as hardness increases, alkalinity increases.

This implies that: Hardness $\alpha$ alkalinity (T. Tebbut)

### 3.1.3 Hardness and pH

The metallic ions responsible for hardness - $Ca^{2+}$, $Mg^{2+}$ and others - are usually associated with $HCO_3^-$ amongst other anions, which is a contributor to alkalinity. Since hardness is directly proportional to alkalinity;

This implies that: Hardness $\alpha$ pH

### 3.1.4 Hardness and Chloride

$Ca^{2+}$, $Mg^{2+}$ and the other metallic ions responsible for hardness are usually associated with $HCO_3^-$, $SO_4^{2-}$, $Cl^-$ and $NO_3^-$. This means that as hardness increases, chloride concentration increases. Since hardness $\alpha$ chloride

This implies that: pH $\alpha$ Chloride

### 3.1.5 Temperature and Dissolved Oxygen

Oxygen is only slightly soluble in water. It is less soluble in warm water than in cold water. As temperature increases, dissolved oxygen decreases.

This implies that: Temperature $\alpha$ (dissolved oxygen)$^{-1}$

### 3.1.6 Temperature and BOD, COD

As temperature increases, dissolved oxygen in water decreases and the demand for oxygen - COD or BOD increases.

This implies that: Temperature $\alpha$ BOD

Temperature $\alpha$ COD

D. O. $\alpha \frac{1}{BOD}$

### 3.1.7 Temperature and pH

The rate of corrosion is inversely proportional to the alkalinity hardness and pH value of water and is directly proportional to the content of dissolved oxygen, $CO_2$ and the temperature of water (Ihekoronye, Ngoddy, 1985)

This implies that: pH $\alpha$ Temperature$^{-1}$

pH $\alpha$ BOD$^{-1}$

## 3.2 LEAST SQUARES METHOD

When studying jointly several random variables, it is necessary to determine some characteristics of dependence between them.

The least squares method is generally used for searching approximate dependencies between variables studied experimentally. The sought-for function is of the form $y = kx + b$ but the values of k and b are yet unknown. The substitution of $x = x_i$ into the formula should have resulted in $kx_i + b$ but the experimental data gives the value $y_i$, and thus we have the difference $y_i - kx_i - b$ between the theoretical and experimental data which is due to errors of the experimental and of the calculations, the non-linearity of the relationship under consideration, etc. (V. S. Pugachev)

The difference is called a discrepancy. The values of k and b are then selected in such a way that the sum of the squares of these discrepancies takes on its minimal value among all the possible values i.e.

$$S = \sum_{i=1}^{N} (y_i - kx_i - b)^2$$

Applying necessary conditions,

$f'x\ (x_0, y_0) = 0,\ f'y\ (x_0, y_0) = 0$

We see that for the function to have a minimum, the equalities

$$S'_k = -\sum_{i=1}^{N} 2(y_i - kx_i - b)x_i = 0$$

$$S'_b = -\sum_{i=1}^{N} 2(y_i - kx_i - b) = 0$$

should be fulfilled.

$$K\sum_{i=1}^{N} x_i^2 + b\sum_{i=1}^{N} x_i = \sum_{i=1}^{N} x_i y_i$$

$$K\sum_{i=1}^{N} x_i + bN = \sum_{i=1}^{N} y_i$$

Hence we have obtained a simple system of first order algebraic equations with equal number of equations and unknowns from which k and b can be found. All $x_i$ and $y_i$ being known the system can easily be solved.

$pH \ \alpha \ A$

$pH \ \alpha \ H$

$pH \ \alpha \ \frac{1}{T}$

$pH \ \alpha \ C$

$pH \ \alpha \ A_2$

$$p = f(A_1, H, \frac{1}{T}, C, A_2)$$

$$p = k_1A_1 + k_2H + \frac{k_3}{T} + k_4C + k_5A_2 \text{ ..................................... } (3.1)$$

Let S be the sum of the squares of the discrepancies, having its minimal value among all the possible values of coefficients.

$$S = \sum_{i=1}^{N}\left(p - k_1A - k_2H - \frac{k_3}{T} - k_4C - k_5A_2\right)^2 = \min \text{ ........................... } (3.2)$$

Where p = potency of hydrogen (pH)

$A_1$ = Total Alkalinity (TA)

$A_2$ = Total Alkalinity Content (TAC)

H = Hardness (H)

T = Temperature

C = Chloride, $Cl^-$

Using the conventional method of equating to zero the first derivatives of S with respect to $k_1$, $k_2$, $k_3$, $k_4$ and $k_5$ to minimize S, and letting $\Sigma = \sum_{i=1}^{N}$

$$\frac{\delta S}{\delta k_1} = -2\sum A_1\left(p - k_1A_1 - k_2H - \frac{k_3}{T} - k_4C - k_5A_2\right) = 0 \text{ .......................... } (3.3)$$

$$\frac{\delta S}{\delta k_2} = -2\sum H\left(p - k_1A_1 - k_2H - \frac{k_3}{T} - k_4C - k_5A_2\right) = 0 \text{ .......................... } (3.4)$$

$$\frac{\delta S}{\delta k_3} = -2\sum \frac{1}{T}\left(p - k_1A_1 - k_2H - \frac{k_3}{T} - k_4C - k_5A_2\right) = 0 \text{ .......................... } (3.5)$$

$$\frac{\delta S}{\delta k_4} = -2\sum C\left(p - k_1A_1 - k_2H - \frac{k_3}{T} - k_4C - k_5A_2\right) = 0 \quad (3.6)$$

$$\frac{\delta S}{\delta k_5} = -2\sum A_2\left(p - k_1A_1 - k_2H - \frac{k_3}{T} - k_4C - k_5A_2\right) = 0 \quad (3.7)$$

Dividing through by 2

$$-\sum A_1\left(p - k_1A_1 - k_2H - \frac{k_3}{T} - k_4C - k_5A_2\right) = 0 \quad (3.8)$$

$$-\sum H\left(p - k_1A_1 - k_2H - \frac{k_3}{T} - k_4C - k_5A_2\right) = 0 \quad (3.9)$$

$$-\sum \frac{1}{T}\left(p - k_1A_1 - k_2H - \frac{k_3}{T} - k_4C - k_5A_2\right) = 0 \quad (3.10)$$

$$-\sum C\left(p - k_1A_1 - k_2H - \frac{k_3}{T} - k_4C - k_5A_2\right) = 0 \quad (3.11)$$

$$-\sum A_2\left(p - k_1A_1 - k_2H - \frac{k_3}{T} - k_4C - k_5A_2\right) = 0 \quad (3.12)$$

Expanding equations 3.8 – 3.12 gives:

$$-\sum A_1p + k_1\sum A_1^2 + k_2\sum A_1H + k_3\sum \frac{A_1}{T} + k_4\sum A_1C + k_5\sum A_1A_2 = 0 \quad (3.13)$$

$$-\sum Hp + k_1\sum HA_1 + k_2\sum H^2 + k_3\sum \frac{H}{T} + k_4\sum HC + k_5\sum HA_2 = 0 \quad (3.14)$$

$$-\sum \frac{p}{T} + k_1\sum \frac{A_1}{T} + k_2\sum \frac{H}{T} + k_3\sum\left(\frac{1}{T}\right)^2 + k_4\sum \frac{C}{T} + k_5\sum \frac{A_2}{T} = 0 \quad (3.15)$$

$$-\sum Cp + k_1\sum CA_1 + k_2\sum CH + k_3\sum \frac{C}{T} + k_4\sum C^2 + k_5\sum CA_2 = 0 \quad (3.16)$$

$$-\sum A_2p + k_1\sum A_2A_1 + k_2\sum A_2H + k_3\sum \frac{A_2}{T} + k_4\sum A_2C + k_5\sum A_2^2 = 0 \quad (3.17)$$

Rearranging equations 3.13 – 3.17 gives:

$$\sum A_1 p = k_1\sum A_1^2 + k_2\sum A_1 H + k_3\sum \frac{A_1}{T} + k_4\sum A_1 C + k_5\sum A_1 A_2 \quad \ldots\ldots\ldots\ldots\ldots (3.18)$$

$$\sum Hp = k_1\sum HA_1 + k_2\sum H^2 + k_3\sum \frac{H}{T} + k_4\sum HC + k_5\sum HA_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.19)$$

$$\sum \frac{p}{T} = k_1\sum \frac{A_1}{T} + k_2\sum \frac{H}{T} + k_3\sum \left(\frac{1}{T}\right)^2 + k_4\sum \frac{C}{T} + k_5\sum \frac{A_2}{T} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.20)$$

$$\sum Cp = k_1\sum CA_1 + k_2\sum CH + k_3\sum \frac{C}{T} + k_4\sum C^2 + k_5\sum CA_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.21)$$

$$\sum A_2 p = k_1\sum A_2 A_1 + k_2\sum A_2 H + k_3\sum \frac{A_2}{T} + k_4\sum A_2 C + k_5\sum A_2^2 \quad \ldots\ldots\ldots\ldots\ldots (3.22)$$

The experimental data obtained from the establishment are processed to give mean monthly values of all the parameters from January to December of 1998 and the values are shown in the table below.

Table 3.1: Experimental effluent characteristics for Jan. - Dec. 1998

| | **Parameter** | | | | | |
|---|---|---|---|---|---|---|
| **Month** | p | $A_1$ | $A_2$ | H | T | C |
| January | 7.5 | 0 | 108.7 | 32.7 | 30 | 20.7 |
| February | 7.5 | 0 | 108.3 | 33.0 | 30 | 16.0 |
| March | 7.3 | 0 | 124.8 | 29.5 | 30 | 18.3 |
| April | 7.4 | 0 | 99.3 | 31.5 | 30 | 21.0 |
| May | 7.1 | 0 | 98.3 | 34.0 | 30 | 23.8 |
| June | 7.1 | 0 | 107.0 | 33.2 | 30 | 23.8 |
| July | 7.2 | 0 | 111.0 | 26.7 | 30 | 26.0 |
| August | 7.3 | 0 | 96.0 | 24.8 | 30 | 24.3 |
| September | 7.0 | 0 | 117.8 | 26.0 | 30 | 24.8 |
| October | 7.2 | 0 | 151.0 | 36.7 | 30 | 23.3 |
| November | 7.0 | 0 | 91.8 | 28.0 | 30 | 21.8 |
| December | 6.9 | 0 | 103.3 | 43.3 | 30 | 16.7 |

Where p= pH

$A_1$ =Total Alkalinity (TA) in mg/l

$A_2$ = Total Alkalinity Content (TAC) in mg/l

H = Total hardness (TH) in mg/l

C = Chloride ($Cl^-$) in mg/l

The sum is obtained from the experimental data using Excel computer software and the values obtained for final effluent are shown in Table 3.2.

Table 3.2: summations and outputs of summations

| Summations | Output of summations |
|---|---|
| $\sum(A_1p)$ | 0.00 |
| $\sum(A_1^2)$ | 0.00 |
| $\sum(A_1H)$ | 0.00 |
| $\sum(A_1/T)$ | 0.00 |
| $\sum(A_1C)$ | 0.00 |
| $\sum(A_1A_2)$ | 0.00 |
| $\sum(Hp)$ | 2732.61 |
| $\sum(H^2)$ | 12288.74 |
| $\sum(H/T)$ | 12.65 |
| $\sum(HC)$ | 8135.86 |
| $\sum(H A_2)$ | 41824.83 |
| $\sum(p/T)$ | 2.88 |
| $\sum(1/T)^2$ | 0.01 |
| $\sum(C/T)$ | 8.68 |
| $\sum(A_2/T)$ | 43.91 |
| $\sum(Cp)$ | 1875.98 |
| $\sum C^2$ | 5771.81 |
| $\sum(C A_2)$ | 28623.06 |
| $\sum(A_2p)$ | 9498.16 |
| $\sum A_2^2$ | 147405.00 |

Substituting the values of the sums into equations 3.18-3.22, the following equations are obtained:

$$2732.61 = 12288.74\ K_2 + 12.65\ K_3 + 8135.86\ K_4 + 41824.83\ K_5 \quad ---- (3.23)$$

$$2.88 = 12.65\ K_2 + 0.01\ K_3 + 8.68\ K_4 + 43.91\ K_5 \quad ----------- (3.24)$$

$$1875.98 = 8135.86\ K_2 + 8.68\ K_3 + 5771.81\ K_4 + 28623.06\ K_5 \quad ------ (3.25)$$

$$9498.16 = 41824.83\ K_2 + 43.91\ K_3 + 28623.06\ K_4 + 147405\ K_5 \quad ------ (3.26)$$

A computer programme written in Java language is used to solve equations 3.23 –3.26. The programme uses the sums obtained in Table 3.2 and the values of the constant coefficients are obtained as follows:

$K_2 = -0.0206$

$K_3 = 249.3052$

$K_4 = -0.0336$

$K_5 = 0.0026$

Substituting these values into equation (1) give the model equation:

$p = -0.0206\ H + (249.3052/T) - 0.0336\ C + 0.0026\ A_2$

# CHAPTER FOUR

## 4.0 EXPERIMENTAL METHODOLOGY

Experimental methods carried out in this project research are aimed at analyzing and determining the quality of sewage effluent from the NICON Hilton Hotel, Abuja and the influence of certain parameters such as chloride, hardness, etc. (which constitute pollutants) on the pH of the water.

Authorized and qualified personnel of the Environmental Service Department of the hotel performed all the experiments.

## 4.1 SAMPLE TECHNIQUE

Water samples were collected from the source using sample bottles. The sample bottles were rinsed, first with distilled water, and then with the sample before sample collection to ensure no alteration of physical and/or chemical properties due to residual ions in the bottle. The bottles were kept tightly closed until time for analysis.

## 4.2 SAMPLE ANALYSIS

### 4.2.1 Determination of Temperature

**Apparatus:** Thermometer

**Procedure:** Temperature was measured with the aid of a thermometer at the time experiments were to be carried out. In this peculiar hotel situation, all analysis was carried out at a sample temperature of 30°C. The measurement was made after giving sufficient time for the thermometer dipped into the sewage effluent sample to produce a constant reading.

**Result:** Temperature values were recorded to the nearest whole number

### 4.2.2 Determination of pH

**Apparatus:** pH meter

**Procedure:** Before measuring the pH of the sample, the electrode was thoroughly washed with distilled water and then with the sample. The electrode was then dipped into the sample and the system allowed to stabilize before readings were taken.

**Result:** the pH values were recorded to one decimal place.

### 4.2.3 Determination to Total Hardness (TH) Drop Count Method

**Apparatus**

- 500ml measuring cylinder
- 100ml conical flash

**Reagents**

- Hardness solution 1 = TH buffer solution
- Hardness solution 2 = Eriochrome black T indicator
- Hardness solution 3 = 0.4n EDTA

**Procedure**

1. Fill the measuring cylinder to the 50ml mark with the water to be tested. Transfer the content to the conical flask
2. Add 20 drops of hardness solution 1 and swirl to mix

3. Add 4 drops of hardness solution 2 and swirl to mix
4. Add hardness solution 3, drop by drop to flask. Swirl the flask constantly as the drops are added. Count each drop as it is added, and continue until the solution changes from purple to blue

**Results**

Total hardness in mg/l or ppm = number of drops of solution 3 added to bring about the change x M. F.

*Note:* M. F. is the multiplying factor

### 4.2.4 Determination of Chloride, $Cl^-$ by drop-count titration

**Apparatus**

- 50ml measuring cylinder
- 100ml conical flask

**Reagents**

- Chloride solution 1 = phenolphthalein indicator
- Chloride solution 2 = 10% oxalic acid
- Chloride solution 3 = $K_2Cr_2O_4$ indicator
- Chloride solution 4 = 0.0141 N $AgNO_3$
- Chloride solution 5 = $H_2O_2$ solution

**Procedure**

1. Fill the measuring cylinder to the 50ml mark with water to be tested and transfer the content to the conical flask

2. Add 1 - 2 drops of chloride solution 1 and swirl to mix. If there is no colour change, proceed to procedure 3. If not go straight to procedure 4.
3. Add chloride solution 2, drop by drop to flask. Swirl flask constantly as the drops are added. Continue adding drops until the colour disappears.
4. Add 4 drops of chloride solution 3 and swirl to mix
5. Add chloride solution 4 drop by drop to flask. Swirl the flask constantly as the drops are added. Count each drop as it is added. Continue adding drops until the solution changes from yellow to red brick colour

**Result**

Chloride ($Cl^-$) mg/l or ppm

= Number of drops of chloride solution 4 added to bring about the colour change x MF

**4.2.5 Determination of TA & TAC (By drop count titration)**

**Apparatus**

- 50ml measuring cylinder
- 100ml conical flask

**Reagent**

- Alkalinity solution 1 = phenolphthalein indicator
- Alkalinity solution 2 = methyl orange indicator
- Alkalinity solution 3 = 0.04N $H_2SO_4$

#### 4.2.5.1 Procedure for TA

1. Fill the measuring cylinder to the 50ml mark with the water to be tested. Transfer the content to the conical flask
2. Add 6 drops of alkalinity solution 1 and swirl to mix
3. Add alkalinity solution 3, drop by drop to the flask. Swirl the flask constantly as the drops are added. Count each drop as it is added and continue adding drops until the solution changes from purple to colourless.

**Result**

TA (mg/l or ppm) = Number of drops of alkalinity solution 3 added to bring about the colour change x MF

#### 4.2.5.2 Procedure for TAC

1. Fill the measuring cylinder to the 50ml mark with the water to be tested. Transfer the content to the conical flask
2. Add 4 drops of alkalinity solution 2 and swirl to mix.
3. Add alkalinity solution 3, drop by drop to the flask. Swirl the flask constantly as the drops are added. Count each drop as it is added and continue adding drops until the solution changes from yellow to orange.

**Result**

TAC (mg/l or ppm) = Number of drops of alkalinity solution 3 added to bring about the colour change x MF

# CHAPTER FIVE

## 5.0 DISCUSSION OF RESULTS

A mathematical model for pH assessment of a sewage treatment plant effluent has been developed. Based on this model, simulated results were obtained and presented alongside experimental values in Table 5.1.

Table 5.1: Experimental and simulated pH values

| Month | Experimental pH | Simulated pH |
|---|---|---|
| January | 7.5 | 7.2 |
| February | 7.5 | 7.4 |
| March | 7.3 | 7.4 |
| April | 7.4 | 7.2 |
| May | 7.1 | 7.1 |
| June | 7.1 | 7.1 |
| July | 7.2 | 7.2 |
| August | 7.3 | 7.2 |
| September | 7.0 | 7.2 |
| October | 7.2 | 7.2 |
| November | 7.0 | 7.2 |
| December | 6.9 | 7.1 |

The comparison of the experimental and the simulated results as shown in Table 5.1 is needful in order to ascertain the validity of the developed model and subsequently effectively discuss the simulated results.

The accuracy of the results obtained determined by calculating the absolute deviation, D if the simulated pH, S from the experimental pH, E and subsequently calculating the percentage, ε of the simulated pH to the experimental according to the following equation:

$$\varepsilon = D/E \times 100$$

The accuracy results are shown in the table below.

Table 5.2: Accuracy table for 1998

| Month | Experimental pH, (E) | Simulated pH, (S) | Absolute Deviation $D = \lvert E - S \rvert$ | % Error ε |
|---|---|---|---|---|
| January | 7.5 | 7.2 | 0.3 | 4.0 |
| February | 7.5 | 7.4 | 0.1 | 1.3 |
| March | 7.3 | 7.4 | 0.1 | 1,4 |
| April | 7.4 | 7.2 | 0.2 | 2.7 |
| May | 7.1 | 7.1 | 0.0 | 0.0 |
| June | 7.1 | 7.1 | 0.0 | 0.0 |
| July | 7.2 | 7.2 | 0.0 | 0.0 |
| August | 7.3 | 7.2 | 0.1 | 1.4 |
| September | 7.0 | 7.2 | 0.2 | 2.9 |
| October | 7.2 | 7.2 | 0.0 | 0.0 |
| November | 7.0 | 7.2 | 0.2 | 2.9 |
| December | 6.9 | 7.1 | 0.2 | 2.9 |
| | | | $\sum D = 1.4$ | $\sum \varepsilon = 19.5$ |

Average deviation = 1.4/12 = 0.12

Average % error = 19.5/12 = 1.6%

The simulated results compare well with the experimental results as some of them are exactly the same as, while others differ slightly from their corresponding experimental results. From table 5.2, an average deviation of 0.12 is obtained and an average percentage error of 1.6%. These small and almost negligible values go a long way to prove the validity of the model.

A mathematical model is a mathematical idealization of a real-world phenomenon. In the process of idealization, some simplifications will have been made in obtaining the model. Therefore the model is less real than the system it represents. (R. Meyers, 1992)

As regards this research project, some of the simplifications, which are contributory to the discrepancy between the simulated and experimental results, include:

1. Not considering other parameters that affect pH such as BOD, COD, sulphite, etc. as a result of the fact that there were no records for them in the establishment.
2. Approximations in numerical values, which may have resulted in some propagated errors.

The ultimate test of a model is validation, in other words comparison of the model with the real world system it is supposed to portray. In principle, validation requires the use of a completely different set of data from that used to construct the model in the first place. Irrespective of how carefully validation is carried out, there will always be some degree of uncertainty in model output. (Hardisty, Taylor, Metcalfe, 1993)

In this case, data obtained from the same system but for the year 2000 (not 1998 which was used to construct the model) is used to validate the model.

The experimental effluent characteristics are shown in the table below:

Table 5.3: Experimental effluent characteristics for Jan. - Dec. 2000

| | **Parameter** | | | | | |
|---|---|---|---|---|---|---|
| **Month** | p | $A_1$ | $A_2$ | H | T | C |
| January | 7.25 | 0 | 144.0 | 39.5 | 30.0 | 19.75 |
| February | 7.18 | 0 | 128.0 | 42.75 | 31.0 | 19.5 |
| March | 7.18 | 0 | 132.2 | 48.6 | 31.4 | 17.6 |
| April | 7.25 | 0 | 112.5 | 45.5 | 32.5 | 19.25 |
| May | 7.18 | 0 | 162.2 | 61.8 | 32.6 | 22.0 |
| June | 7.03 | 0 | 101.25 | 33.75 | 30.5 | 21.75 |
| July | 7.26 | 0 | 95.4 | 29.0 | 29.0 | 24.0 |
| August | 7.18 | 0 | 106.75 | 38.25 | 27.75 | 23.0 |
| September | 7.35 | 0 | 115.5 | 35.0 | 27.25 | 24.75 |
| October | 6.95 | 0 | 121.5 | 39.25 | 27.25 | 24.25 |
| November | 7.18 | 0 | 110.75 | 36.0 | 26.5 | 24.5 |
| December | 6.88 | 0 | 117.0 | 35.75 | 25.5 | 23.75 |

The following accuracy table was obtained for the 2000 data:

Table 5.4: Accuracy table for 2000

| Month | Experimental pH | Simulated pH | Absolute deviation | % Error |
|---|---|---|---|---|
| January | 7.25 | 7.21 | 0.04 | 0.55 |
| February | 7.18 | 6.84 | 0.34 | 4.74 |
| March | 7.18 | 6.69 | 0.49 | 6.83 |
| April | 7.25 | 6.38 | 0.87 | 12.00 |
| May | 7.18 | 6.06 | 1.12 | 15.60 |
| June | 7.03 | 7.01 | 0.02 | 0.29 |
| July | 7.26 | 7.44 | 0.18 | 2.48 |
| August | 7.18 | 7.70 | 0.52 | 7.24 |
| September | 7.35 | 7.90 | 0.55 | 7.48 |
| October | 6.95 | 7.84 | 0.89 | 12.81 |
| November | 7.18 | 8.13 | 0.95 | 13.23 |
| December | 6.88 | 8.55 | 1.67 | 24.27 |
| | | | $\sum D = 7.64$ | $\sum \varepsilon = 107.52$ |

Average deviation = 7.64 / 12 = 0.64

Average % error = 107.52 / 12 = 8.96

**5.1 CONCLUSION**

A mathematical model for pH assessment of a sewage treatment plant effluent has been successfully developed. The model was used to simulate pH results both from the data used to construct it and from an entirely different set of data, and the simulated results compared well with the experimental results with average percentage errors of 1.6 and 8.96 respectively, thereby proving the validity of the model.

Consequently, the model can be used in prediction practice i.e. to predict the behaviour of the sewage treatment plant it was developed to represent.

## 5.2 RECOMMENDATIONS

The experimental records of the effluent of the NICON-Hilton Hotel sewage treatment plant effluent should be improved to include other parameters such as Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), sulphite, etc. which influence pH to aid in further research work.

Furthermore, researchers should investigate the individual influence of each of the water quality parameters on pH and make effort to develop a model equation that will aid, not only in the prediction of the behaviour of the system, but also in its precise and accurate control.

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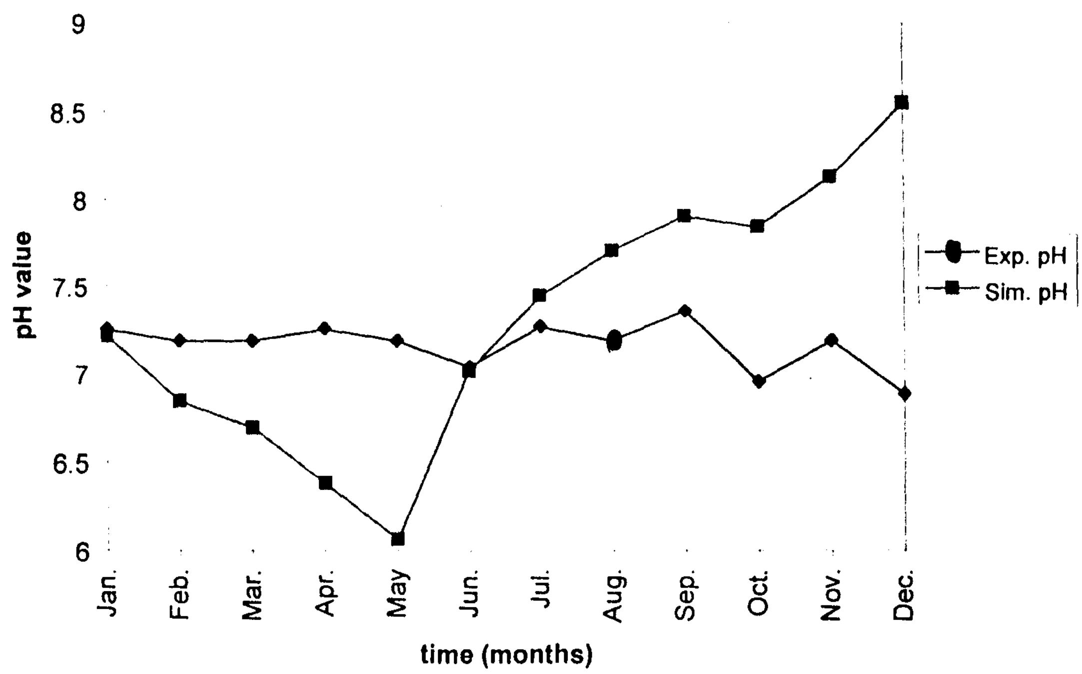
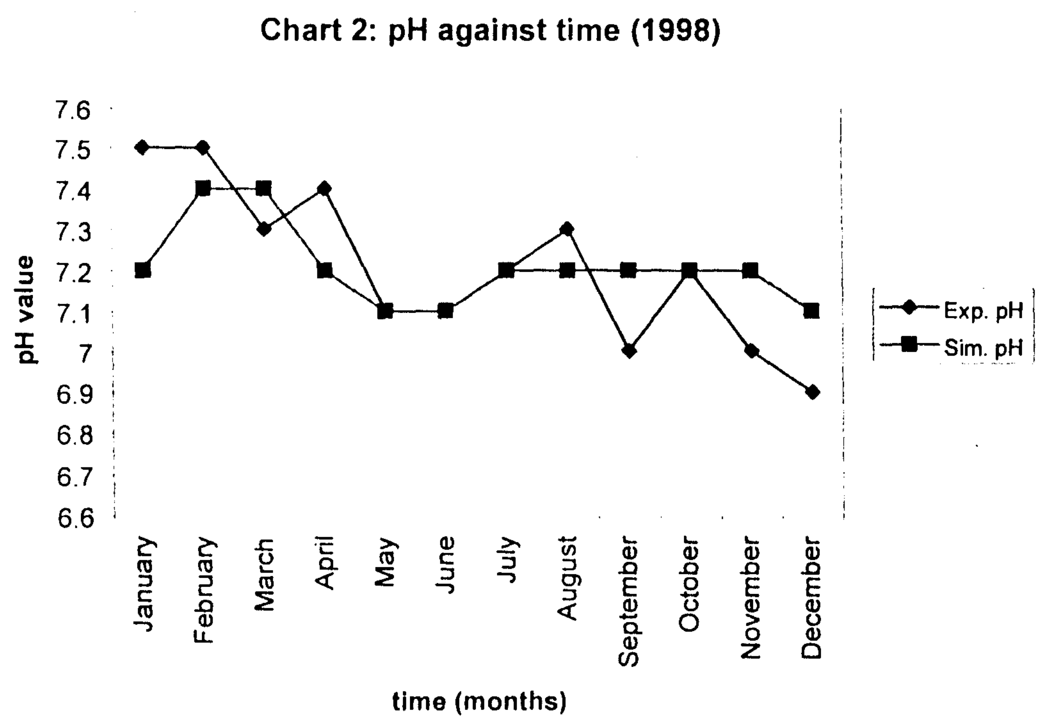
# APPENDIX A

Chart 1: pH against time (2000)




| Month | Jan. | Feb. | Mar | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Exp. pH | 7.25 | 7.18 | 7.18 | 7.25 | 7.18 | 7.03 | 7.26 | 7.18 | 7.35 | 6.95 | 7.18 | 6.88 |
| Sim. pH | 7.21 | 6.84 | 6.69 | 6.38 | 6.06 | 7.01 | 7.44 | 7.70 | 7.90 | 7.84 | 8.13 | 8.55 |

# APPENDIX B




| Month | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Exp. pH | 7.5 | 7.5 | 7.3 | 7.4 | 7.1 | 7.1 | 7.2 | 7.3 | 7.0 | 7.2 | 7.0 | 6.9 |
| Sim. pH | 7.2 | 7.4 | 7.4 | 7.2 | 7.1 | 7.1 | 7.2 | 7.2 | 7.2 | 7.2 | 7.2 | 7.1 |

## APPENDIX C: Computer Program

```
import javax.swing.*;
import java.awt.*;
import java.awt.event.*;
import javax.swing.table.*;
import javax.swing.event.*;



public class Futiles implements ActionListener {
        MyTableModel bisi = new MyTableModel();
        private boolean DEBUG = true;
        private JTextArea txt = new JTextArea(4, 20);

        static float EA1Sq;
        static float EA2Sq;
        static float EA1H;
        static float EA2H;
        static float EA1_T;
        static float EA2_T;
        static float EA1C;
        static float EA2C;
        static float EA1A2;
        static float EHSq;
        static float ECSq;
        static float E_TSq;
        static float EH_T;
        static float ECH;
        static float EC_T;
        static float EA1P, EHP, EP_T, ECP, EA2P;


        static float K1, K2, K3, K4, K5;

    JFrame frame;
    JPanel panel, bpanel, mainpanel, buttons;
    JButton exit;
    JButton getEq, solEq, blankDB, rawSew, finEff;
    static JLabel equation1, equation2, equation3, equation4, equation5;
    static JLabel k1, k2, k3, k4, k5;
    JPanel  dispanel, solpanel, bpanel2;
```

```
public Futiles() {
        //create the frame and containers
        frame = new JFrame("Annie Umoffia");
        panel = new JPanel();
        buttons = new JPanel();
        bpanel = new JPanel();
        bpanel2 = new JPanel();
        dispanel = new JPanel();
        solpanel = new JPanel();
        mainpanel = new JPanel();
        panel.setLayout(new GridLayout(0, 2));
        buttons.setLayout(new GridLayout(0, 1));
        dispanel.setLayout(new GridLayout(0,1));
        solpanel.setLayout(new GridLayout(0,1));


        JTable table = new JTable(bisi);
        table.setPreferredScrollableViewportSize(new Dimension(500,

200) );

        //Create scroll pane and add table to it.
        JScrollPane scrollPane = new JScrollPane(table);


// Add the widgets.
addWidgets();



//Add subpanels to main panel
buttons.add(bpanel);
buttons.add(bpanel2);


mainpanel.setLayout(new GridLayout(0,2));
mainpanel.add(scrollPane);
```

```
mainpanel.add(buttons);
mainpanel.add(dispanel);
mainpanel.add(solpanel);


// Add the panel to the frame.
frame.getContentPane().add(mainpanel, BorderLayout.CENTER);


// Exit when the window is closed.
frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

// Show the Frame

frame.pack();
frame.setVisible(true);




}

private void addWidgets() {


exit = new JButton("Exit");

getEq = new JButton("Get Equations");
solEq = new JButton("Solve Equations");
blankDB = new JButton("Four Equations");
rawSew = new JButton("Raw Sewage");
finEff = new JButton("Final Effluent");


equation1 = new JLabel( EA1Sq + " K1 + " + EA1H + " K2 + " +  EA1_T  +
" K3 + "
+  EA1C +" K4 + " + EA1A2 + " K5  = " + EA1P);
equation1.setFont(new Font ("Arial", 0, 9) );
```

```
equation2 = new JLabel(EA1H  + " K1 + " + EHSq + " K2 + " +  EH_T + "
K3 + "
+  ECH +" K4 + " + EA2H + " K5  = " + EHP);
equation2.setFont(new Font ("Arial", 0, 9) );
equation3 = new JLabel( EA1_T  + " K1 + " + EH_T + " K2 + " +  E_TSq +
" K3
+ " +  EC_T  +" K4 + " + EA2_T + " K5  = " + EP_T);
equation3.setFont(new Font ("Arial", 0, 9) );
equation4 = new JLabel( EA1C + " K1 + " + ECH + " K2 + " +  EC_T  + "
K3 + "
+  ECSq +" K4 + "+EA2C+" K5  = " + ECP);
equation4.setFont(new Font ("Arial", 0, 9) );
equation5 = new JLabel( EA1A2 + " K1 + " + EA2H + " K2 + " +  EA2_T +
" K3 +
" +  EA2C +" K4 + "+EA2Sq+" K5  = " + EA2P);
equation5.setFont(new Font ("Arial", 0, 9) );

        k1 = new JLabel("K1 = " + K1, SwingConstants.CENTER);
        k2 = new JLabel("K2 = " + K2, SwingConstants.CENTER);
        k3 = new JLabel("K3 = " + K3, SwingConstants.CENTER);
        k4 = new JLabel("K4 = " + K4, SwingConstants.CENTER);
        k5 = new JLabel("K5 = " + K5, SwingConstants.CENTER);


        dispanel.add(equation1);
        dispanel.add(equation2);
        dispanel.add(equation3);
        dispanel.add(equation4);
        dispanel.add(equation5);

        solpanel.add(k1);
        solpanel.add(k2);
        solpanel.add(k3);
        solpanel.add(k4);
        solpanel.add(k5);

        //bpanel2.add(rawSew);
        //bpanel2.add(finEff);
        bpanel2.add(getEq);
        bpanel2.add(solEq);
```

```
        bpanel2.add(exit);
        bpanel2.add(blankDB);


        exit.addActionListener(this);
        getEq.addActionListener(this);
        solEq.addActionListener(this);
        blankDB.addActionListener(this);
        //rawSew.addActionListener(this);
        //finEff.addActionListener(this);

    }


        class MyTableModel extends AbstractTableModel {
                final String[] columnNames = {"Month", "P",
                                "A1", "A2","H", "T", "C"};

                final Object[][] data = {
                {"January", new Float(8.1), new Float(53.5), new Float(149.7),
                        new Float(28.7), new Float(30), new Float(13.3) },
                {"February", new Float(10.7), new Float(42.5), new
Float(174.5),
                        new Float(27.5), new Float(30), new Float(25.5) },
                {"March", new Float(8.0), new Float(13.8), new Float(126.0),
                        new Float(31.5), new Float(30), new Float(20.8) },
                {"April", new Float(8.3), new Float(25.8), new Float(157.3),
                        new Float(35.3), new Float(30), new Float(20.3) },
                {"May", new Float(7.0), new Float(0), new Float(81.0),
                        new Float(33), new Float(30), new Float(14.8) },
                {"June", new Float(7.9), new Float(18.2), new Float(124.4),
                        new Float(30.4), new Float(30), new Float(19) },
                {"July", new Float(8.1), new Float(8.8), new Float(89),
                        new Float(25), new Float(30), new Float(21.8) },
                {"August", new Float(8.8), new Float(32.5), new Float(132),
                        new Float(24.3), new Float(30), new Float(18.8) },
                {"September", new Float(7.8), new Float(13.0), new
Float(119),
                        new Float(26), new Float(30), new Float(23.3) },
                {"October", new Float(7.7), new Float(3.0), new Float(120.5),
```

```
                new Float(48.0), new Float(30), new Float(21.2) },
          {"November", new Float(7.6), new Float(7.8), new Float(97.8),
                new Float(26.8), new Float(30), new Float(21.3) },
          {"December", new Float(7.4), new Float(0), new Float(102.5),
                new Float(44.3), new Float(30), new Float(13.8) }

};

          public int getColumnCount() {
                return columnNames.length;
          }

          public int getRowCount() {
                return data.length;
          }

          public String getColumnName(int col) {
                return columnNames[col];
          }

          public Object getValueAt(int row, int col) {
                return   data[row][col] ;
          }

          public boolean isCellEditable(int row, int col) {
                return true;
          }

          public void setValueAt(Object value, int row, int col) {
             data[row][col] = value;
      fireTableCellUpdated(row, col);
          }

          public Class getColumnClass(int c) {
               return getValueAt(0, c).getClass();
          }

    }
    public void actionPerformed(ActionEvent e) {
```

```
        if(e.getSource() == exit) {
                System.exit(0);
        }
        if(e.getSource() == getEq) {
                calc();
                getEquations();
        }
        if(e.getSource() == solEq) {
                getSolutions();
        }
        if(e.getSource() == blankDB) {
                calc2();
                getEquations();
                getSolutions();

        }

}

public void calc() {

        float _A1, _A2, _H, _T, _C;
        float _P;

        EA1Sq = 0;
        EA2Sq = 0;
        EA1H = 0;
        EA2H = 0;
        EA1_T = 0;
        EA2_T = 0;
        EA1C = 0;
        EA2C = 0;
        EA1A2 = 0;
        EHSq = 0;
        ECSq = 0;
        E_TSq = 0;
        EH_T = 0;
        ECH = 0;
        EC_T = 0;
        EA1P = 0;
```

```
EHP = 0;
EP_T = 0;
ECP = 0;
EA2P = 0;

for(int i = 0; i < 12; i++) {
        /*_P = ( (Float)bisi.getValueAt(i, 1)
).floatValue();
        _A1 = ( (Float)bisi.getValueAt(i, 2) ).floatValue();
        _A2 = ( (Float)bisi.getValueAt(i, 3) ).floatValue();
        _H = ( (Float)bisi.getValueAt(i, 4) ).floatValue();
        _T = ( (Float)bisi.getValueAt(i, 5) ).floatValue();
        _C = ( (Float)bisi.getValueAt(i, 6) ).floatValue();
*/

        _P = ( (Float)bisi.data[i][1] ).floatValue();
        _A1 = ( (Float)bisi.data[i][2] ).floatValue();
        _A2 = ( (Float)bisi.data[i][3] ).floatValue();
        _H = ( (Float)bisi.data[i][4] ).floatValue();
        _T = ( (Float)bisi.data[i][5] ).floatValue();
        _C = ( (Float)bisi.data[i][6] ).floatValue();

        EA1Sq += (_A1*_A1) ;
        EA2Sq += (_A2*_A2) ;
        EA1H  += (_A1*_H);
        EA2H  += (_H * _A2);
        EA1_T  += (_A1 / _T);
        EA2_T  += (_A2 / _T);
        EA1C  += (_A1 * _C);
        EA2C  += (_A2 * _C);
        EA1A2 += (_A1 * _A2);
        EHSq  += (_H * _H);
        ECSq += (_C * _C);
        E_TSq +=  ( (1/_T ) * (1/_T) );
        EH_T  += (_H / _T);
        ECH += (_H * _C);
        EC_T  += (_C/_T);
        EA1P += (_A1*_P);
```

```
                EHP += (_H*_P);
                EP_T += (_P / _T);
                ECP += (_C*_P);
                EA2P += (_A2*_P);

          K1 = 0;
          K2 = 0;
          K3 = 0;
          K4 = 0;
          K5 = 0;

          for(int j = 0; j < 10001; j++) {
           K1 = ( EA1P - ( EA1H*K2 +  EA1_T*K3 +  EA1C* K4 +
EA1A2*K5

) ) / EA1Sq ;
           K2 = ( EHP - ( EA1H*K1 + EH_T*K3 + ECH*K4 +
EA2H*K5 ) ) /

EHSq;
           K3 =  (EP_T - ( EA1_T*K1 + EH_T*K2 + EC_T*K4 +
EA2_T*K5 )

) / E_TSq;
           K4 = ( ECP - ( EA1C*K1 + ECH*K2 + EC_T*K3 +
EA2C*K5 ) ) /

ECSq;
           K5 = ( EA2P - ( EA1A2*K1 + EA2H*K2 + EA2_T*K3 +
EA2C*K4 )

) / EA2Sq;
          }


          }

      }

public void calc2() {
```

```
float _A1, _A2, _H, _T, _C;
float _P;

EA1Sq = 0;
EA2Sq = 0;
EA1H = 0;
EA2H = 0;
EA1_T = 0;
EA2_T = 0;
EA1C = 0;
EA2C = 0;
EA1A2 = 0;
EHSq = 0;
ECSq = 0;
E_TSq = 0;
EH_T = 0;
ECH = 0;
EC_T = 0;
EA1P = 0;
EHP = 0;
EP_T = 0;
ECP = 0;
EA2P = 0;


for(int i = 0; i < 12; i++) {
        /*_P = ( (Float)bisi.getValueAt(i, 1)
).floatValue();
                _A1 = ( (Float)bisi.getValueAt(i, 2) ).floatValue();
                _A2 = ( (Float)bisi.getValueAt(i, 3) ).floatValue();
                _H = ( (Float)bisi.getValueAt(i, 4) ).floatValue();
                _T = ( (Float)bisi.getValueAt(i, 5) ).floatValue();
                _C = ( (Float)bisi.getValueAt(i, 6) ).floatValue();
*/

                _P = ( (Float)bisi.data[i][1] ).floatValue();
                _A1 = ( (Float)bisi.data[i][2] ).floatValue();
```

```
_A2 = ( (Float)bisi.data[i][3] ).floatValue();
_H = ( (Float)bisi.data[i][4] ).floatValue();
_T = ( (Float)bisi.data[i][5] ).floatValue();
_C = ( (Float)bisi.data[i][6] ).floatValue();

EA1Sq += (_A1*_A1) ;
EA2Sq += (_A2*_A2) ;
EA1H += (_A1*_H);
EA2H += (_H * _A2);
EA1_T += (_A1 / _T);
EA2_T += (_A2 / _T);
EA1C += (_A1 * _C);
EA2C += (_A2 * _C);
EA1A2 += (_A1 * _A2);
EHSq += (_H * _H);
ECSq += (_C * _C);
E_TSq += ( (1/_T ) * (1/_T) );
EH_T += (_H / _T);
ECH += (_H * _C);
EC_T += (_C/_T);
EA1P += (_A1*_P);
EHP += (_H*_P);
EP_T += (_P / _T);
ECP += (_C*_P);
EA2P += (_A2*_P);

K1 = 0;
K2 = 0;
K3 = 0;
K4 = 0;
K5 = 0;

for(int j = 0; j < 10001; j++) {
 //K1 = ( EA1P - ( EA1H*K2 + EA1_T*K3 + EA1C* K4 +
EA1A2*K5 ) ) / EA1Sq ;
 K2 = ( EHP - ( EH_T*K3 + ECH*K4 + EA2H*K5 ) ) /
EHSq;
 K3 = (EP_T - ( EH_T*K2 + EC_T*K4 + EA2_T*K5 ) ) /
```

```
E_TSq;
                K4 = ( ECP - (  ECH*K2 + EC_T*K3 + EA2C*K5 ) ) / ECSq;
                K5 = ( EA2P - (  EA2H*K2 + EA2_T*K3 + EA2C*K4 ) ) /
EA2Sq;
            }

            }

    }

    public void getEquations() {

equation1.setText( EA1Sq + " K1 + " + EA1H + " K2 + " +  EA1_T  + " K3
+ " +

 EA1C +" K4 + " + EA1A2 + " K5  = " + EA1P);
equation1.setFont(new Font ("Arial", 0, 9) );
equation2.setText(EA1H  + " K1 + " + EHSq + " K2 + " +  EH_T + " K3 + "
+

ECH +" K4 + " + EA2H + " K5  = " + EHP);
equation2.setFont(new Font ("Arial", 0, 9) );
equation3.setText( EA1_T  + " K1 + " + EH_T + " K2 + " +  E_TSq + " K3
+ " +

 EC_T  +" K4 + " + EA2_T + " K5  = " + EP_T);
equation3.setFont(new Font ("Arial", 0, 9) );
equation4.setText( EA1C + " K1 + " + ECH + " K2 + " +  EC_T  + " K3 + "
+

ECSq +" K4 + "+EA2C+" K5  = " + ECP);
equation4.setFont(new Font ("Arial", 0, 9) );
equation5.setText( EA1A2 + " K1 + " + EA2H + " K2 + " +  EA2_T + " K3
+ " +

 EA2C +" K4 + "+EA2Sq+" K5  = " + EA2P);
equation5.setFont(new Font ("Arial", 0, 9) );

    }
```

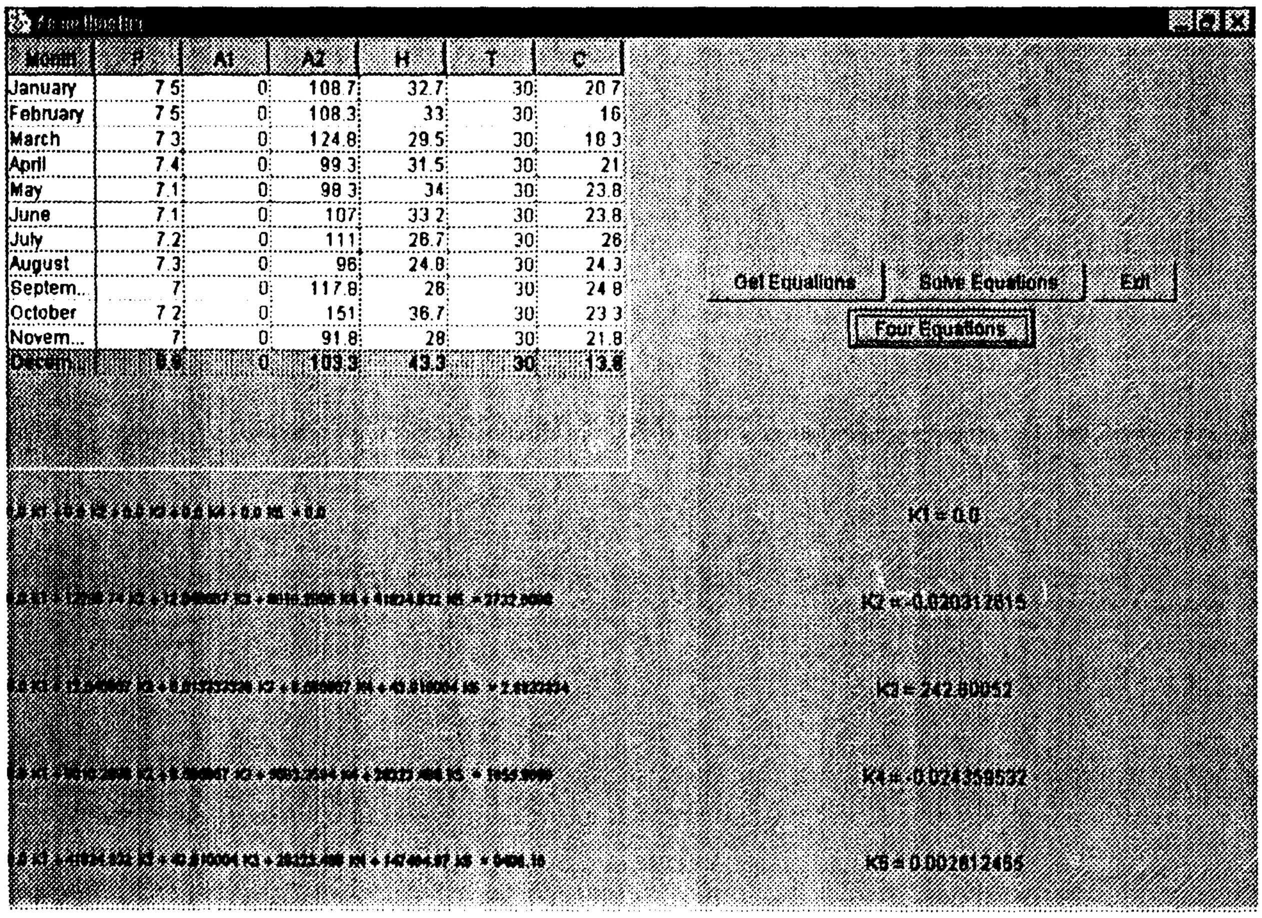
```
	public void getSolutions() {

	k1.setText("K1 = " + K1); //, SwingConstants.CENTER);
	k2.setText("K2 = " + K2); //, SwingConstants.CENTER);
	k3.setText("K3 = " + K3); //, SwingConstants.CENTER);
	k4.setText("K4 = " + K4); //, SwingConstants.CENTER);
	k5.setText("K5 = " + K5); //, SwingConstants.CENTER);

	}

}
```

# APPENDIX D: PROGRAMME PROCESSING




| Month | P | A1 | A2 | H | T | C |
|---|---|---|---|---|---|---|
| January | 7.5 | 0 | 108.7 | 32.7 | 30 | 20.7 |
| February | 7.5 | 0 | 108.3 | 33 | 30 | 16 |
| March | 7.3 | 0 | 124.8 | 29.5 | 30 | 18.3 |
| April | 7.4 | 0 | 99.3 | 31.5 | 30 | 21 |
| May | 7.1 | 0 | 98.3 | 34 | 30 | 23.8 |
| June | 7.1 | 0 | 107 | 33.2 | 30 | 23.8 |
| July | 7.2 | 0 | 111 | 28.7 | 30 | 26 |
| August | 7.3 | 0 | 96 | 24.8 | 30 | 24.3 |
| Septem... | 7 | 0 | 117.8 | 26 | 30 | 24.8 |
| October | 7.2 | 0 | 151 | 36.7 | 30 | 23.3 |
| Novem... | 7 | 0 | 91.8 | 28 | 30 | 21.8 |
| Decem... | 6.9 | 0 | 103.3 | 43.3 | 30 | 13.8 |